RADIO

REFERENCE

Compiled by
BERNARD B. BABANI

HANDBOOK

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RADIO REFERENCE HANDBOOK

COMPILED BY

BERNARD B. BABANI.

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LONDON, W.6

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Claude Lyons Ltd., Tottenham Court Road, London, and Liverpool. (Britain's premier Importers of American Electronic Equipment).

General Radio Company, Cambridge, Mass., U.S.A.

Sylvania Electric Products Incorporated, Emporium, Penna., U.S.A.

Allen B. Du Mont, Labs., Incorporated, 2, Main Avenue, Passiac, N.J., U.S.A.

Radio Corporation of America, Harrison, N.J., U.S.A.

Radio Craft Magazine, N.Y., U.S.A.

Telegraph Condenser Company, London, England.

Vactite Co. Ltd., London, England.

London Electric Wire Co., and Smiths Ltd., London.

Dubillier Condenser (1925) Ltd., London.

Bureau of Standards, Department of Commerce, United States Government.

Mullard Radio Valve Co., Ltd., London, England.

Etc., etc., etc.

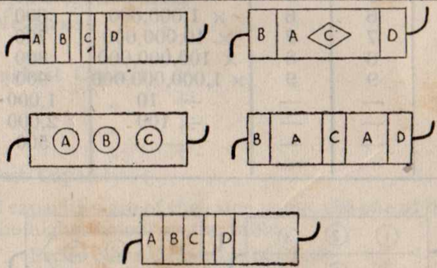
B. B. BABANI.

London, 1945.

BRITISH AND U.S.A. RESISTANCE COLOUR CODE.

Colour code shall consist of four bands of colour which may be adjacent to each other or be slightly separated from each other as desired. They shall be placed on the resistor towards one end of it and the significance of the colour bands shall be read from the band nearest to one end and in the order of the bands as follows :—

Band	*Indicates*
1st	First significant figure of the resistance value.
2nd	Second significant figure of the resistance value.
3rd	Decimal multiplier applicable to the first two significant figures.
4th	% Tolerance.



The meaning assigned to the various colours are set out in the Table below :—

Colour	*Shade*	*Significant Figures*	*Decimal Multiplier*	*Tolerance*
Black	—	0	1	—
Brown	No. 13	1	10	—
Red	No. 38	2	100	—
Orange	No. 57	3	1,000	—
Yellow	No. 55	4	10,000	—
Green	No. 26	5	100,000	—
Blue	No. 5	6	1,000,000	—
Violet	*	7	10,000,000	—
Grey	No. 31	8	100,000,000	—
White	—	9	1,000,000 000	—
Gold (metallic) ...	*	—	0.1	5%
Silver (metallic) ...	*	—	0.01	10%
No additional colour	—	—	—	20%

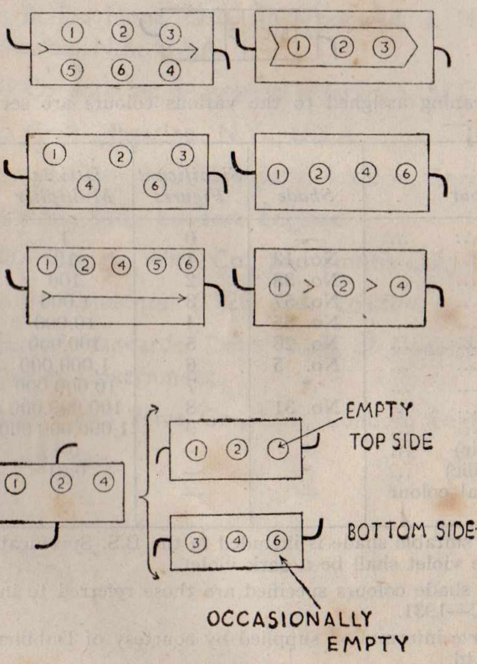
*No suitable shade is included in the B.S. Specification. The violet shall be a **dark** violet.

NOTE.—The shade colours specified are those referred to in B.S.S. No. 381C—1931.

The above information supplied by courtesy of Dubilier Condenser Co. (1925) Ltd.

BRITISH AND U.S.A. COLOUR CODES FOR FIXED MICA CONDENSERS.

Colour Mark	1 *First Figure*	2 *Second Figure*	3 *Third Figure*	4 *Multiplier Value*	5 *Direct Current Voltage Test Rating*	6 *Percentage Tolerance Plus or Minus*
Black ...	0	0	0	Nil	—	—
Brown ...	1	1	1	× 10	100	1%
Red ...	2	2	2	× 100	200	2%
Orange ...	3	3	3	× 1,000	300	3%
Yellow ...	4	4	4	× 10,000	400	4%
Green ...	5	5	5	× 100,000	500	5%
Blue ...	6	6	6	× 1,000,000	600	6%
Violet ...	7	7	7	× 10,000,000	700	7%
Grey ...	8	8	8	× 100,000,000	800	8%
White ...	9	9	9	× 1,000,000,000	900	9%
Gold ...	—	—	—	÷ 10	1,000	5%
Silver ...	—	—	—	÷ 100	2,000	10%
No Colour	—	—	—	—	500	20%



BRITISH AND U.S.A. COLOUR CODES FOR RADIO COMPONENTS.

FUSES.

Colour :	*Value* :	*Colour* :	*Value* :
Black ...	.060 Amp.	Dark Blue ...	1 Amp.
Grey ...	.100 Amp.	Light Blue ...	1.5 Amp.
Red... ...	.150 Amp.	Purple	2 Amp.
Brown ...	.250 Amp.	White	3 Amp.
Yellow ...	.500 Amp.	Black and White	5 Amp.
Green ...	.750 Amp.		

FIXED CONDENSER LEADS.

Value :	*Colour* :
Centre lead of Voltage doubler Condensers	White
Principal Negative Lead	Black
2nd Negative "	Brown
3rd " "	Grey
5th highest Capacity +	Violet
4th " " +	Blue
3rd " " +	Green
2nd " " +	Yellow
Highest Capacity +	Red

When 2 capacities are of the same value, the one of the higher voltage rating has the higher colour in the table.

Series connections are marked ±
Common Positive junctions are marked +
Unconnected sections are marked &
Common Negative junctions are marked —

Examples :—

6 ± 6 = A series voltage doubler connection.
2 + 2 = Two 2uF condensers with common positive lead.
4 & 4 = Two isolated 4uF condensers.
8 — 8 = Two 8uF condensers with common negative lead.

WANDER PLUGS.

Value :	*Colour* :
Highest + H.T.	Red
2nd highest + H.T.	Yellow
3rd highest + H.T.	Green
4th highest + H.T.	Blue
L.T. Positive	Pink
L.T. —	Black
H.T. —	Black
G.B. +	Black
Highest G.B. —	Brown
2nd highest G.B. —	Grey
3rd highest G.B. —	White

Any additional battery lead is Violet, and any centre tap is White.

BRITISH AND U.S.A. COLOUR CODES.

U.S.A. COLOUR CODES FOR LOUDSPEAKER LEADS AND PLUG CONNECTORS.

A = Blue lead. B = Brown lead. C = Red lead. D = Black and Red striped lead. E = Slate and Red striped lead. F = Yellow and Red striped lead. G = Black lead. H = Green lead. J = Black and Green striped lead. K = Yellow and Green striped lead. P = Primary. S = Secondary.

Sketch A.
Plugs shown with Pins facing the reader.

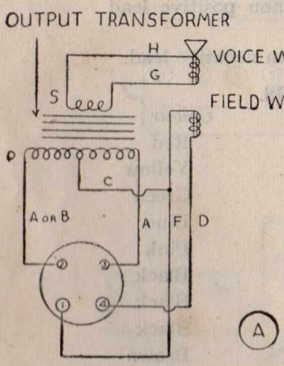
Sketch B.
Plugs shown with Pins facing the reader.

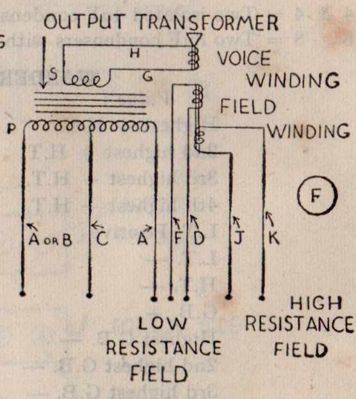
Sketch C.
Plugs shown with Pins facing the reader.

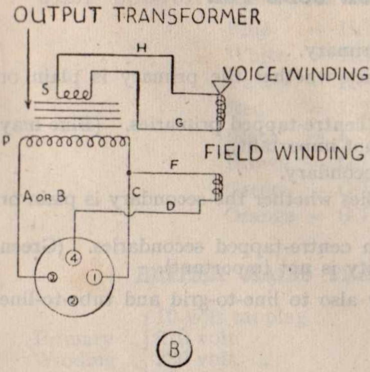
Sketch D.
Plugs shown with Pins facing the reader.

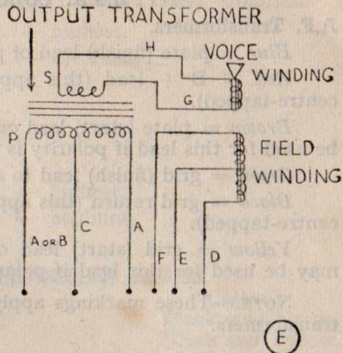
Sketch E.
Plugs shown with Pins facing the reader.

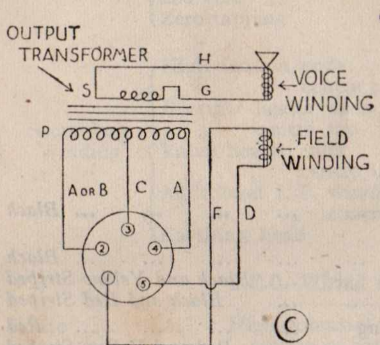
Sketch F.
Plugs shown with Pins facing the reader.

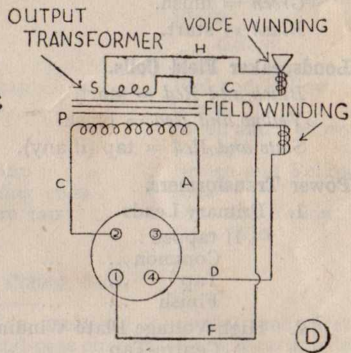












BRITISH AND U.S.A. COLOUR CODES.

BRITISH COLOUR CODE FOR BATTERY CORDS.

Colour.	*Purpose.*
Maroon	3rd Positive Voltage.
Maroon and Red	2nd Positive Voltage.
Red	Highest Positive Voltage.
Black and Green	2nd Negative Bias.
Black with Green Tracer	Maximum Negative Bias.
Green	Positive Bias Voltage.
Black with Yellow Tracer	Negative L.T. Voltage.
Yellow	Positive L.T. Voltage.
Black with Red Tracer	Negative H.T.
Black with Brown Tracer	Loud-speaker Connections.
High Potential, Brown	Loud-speaker Connections.

U.S.A. COLOUR CODE FOR

A.F. Transformers.

Blue = plate (finish) lead of primary.

Red = B + lead (this applies whether the primary is plain or centre-tapped).

Brown = plate (start) lead on centre-tapped primaries. (Blue may be used for this lead if polarity is not important).

Green = grid (finish) lead to secondary.

Black = grid return (this applies whether the secondary is plain or centre-tapped).

Yellow = grid (start) lead on centre-tapped secondaries. (Green may be used for this lead if polarity is not important).

NOTE.—These markings apply also to line-to-grid and tube-to-line transformers.

Loudspeaker Voice Coils.

Green = finish.

Black = start.

Loudspeaker Field Coils.

Black and Red = start.

Yellow and Red = finish.

Slate and Red = tap (if any).

Power Transformers.

1.	Primary Leads	*Black*
	If tapped :	
	Common	*Black*
	Tap	*Black and Yellow Striped*
	Finish	*Black and Red Striped*
2.	High-Voltage Plate Winding	*Red*
	Centre-Tap	*Red and Yellow Striped*
3.	Rectifier Fil. Winding	*Yellow*
	Centre-Tap	*Yellow and Blue Striped*
4.	Fil. Winding No. 1	*Green*
	Centre-Tap	*Green and Yellow Striped*
5.	Fil. Winding No. 2	*Brown*
	Centre-Tap	*Brown and Yellow Striped*
6.	Fil. Winding No. 3	*Slate*
	Centre-Tap	*Slate and Yellow Striped*

RADIO GRAMOPHONE ELECTRIC MOTORS. COLOUR CODE FOR FREQUENCY.

White dot = 25 cycles.
Green dot = 50 „
No mark = 60 „

U.S.A. COLOUR CODE FOR MULTIPLE BATTERY CABLES.

Blue	=	H.T. + highest.
White	=	H.T. + medium.
Yellow	=	H.T. —
Red	=	L.T. +
Black	=	L.T. —
Brown	=	G.B. +
Green	=	G.B. — highest.
Orange	=	G.B. — medium.

BRITISH MAINS TRANSFORMER LEADS.

		Colour.
Primary Winding	10 volt tapping	Black and Green.
	210 volt „	Black and Yellow.
	230 volt „	Black and Red.
	250 volt „	Black and Brown.
	Zero tapping	Black.

		Colour.
Secondary Winding	High tension ends	Red.
	„ „ centre tap	Red and Yellow.
	Rectifier heater ends	Green.
	„ centre tap	Green and Yellow.
	Valve heater ends	Brown.
	„ „ centre tap	Brown and Yellow.
	Additional L.T. winding ends	Blue
	„ „ centre tap	Blue and Yellow.
	Earthing Lead	Bare Wire

G.E.C. Wiring Colour Code.

White	High-potential connections to aerial and first section of band-pass circuits, also non-earth side of special coil.
Green	Other high potential signal circuits, including grid circuits.
Blue	Screening grid circuits.
Pink	Cathode connections.
Orange	Anode connections.
Black	Earth connections.
Slate	H.T. negative, when not earthed.
Red	Smoothed H.T. positive.
Red/White ...	Unsmoothed H.T. positive.
Green/White ...	A.V.C. and grid de-coupling.
Black/Red ...	Heaters.
Black/White ...	Heaters.
Black/Red ...	L.T. positive (in battery sets).

BRITISH MOVING COIL SPEAKER—COLOUR CODE.

Colour.	*Purpose.*
Green (outer end)	Output Transformer—Primary ends of winding.
Brown (inner end)	„ „ Primary ends of winding.
Red	„ „ Primary centre tap.
Maroon	„ „ Secondary end—inside.
White	„ „ „ „ outside.
Yellow	Field Winding—Outside end.
Black	„ „ Inside end.

I.F. Transformers.

Blue = plate lead.
Red = B + lead.
Green = grid (or diode) lead.
Black = grid (or diode) return.

NOTE.—If the secondary of the i.f.t. is centre-tapped, the second diode plate lead is green-and-black striped, and black is used for the centre-tap lead.

REACTANCE FORMULAS.

Reactance is measured in ohms and is defined as the resistance against the flow of an A.C. in any component due to its capacity or inductance. Amongst other factors it is variable due to the frequency of the A.C.

Reactance in ohms of a condenser is equal to 1 divided by (6.283 × frequency of A.C. in cycles per second × capacity of condenser in farads).

Reactance of a coil is equal to (6.283 × frequency of A.C. in cycles per second × inductance of coil in henries).

Reactance of a condenser and a coil in series is equal to the reactance of the coil on its own minus the reactance of the condenser.

RESONANT FREQUENCY.

This is the condition when a condenser and coil in a tuning circuit are so adjusted as to produce resonance. The formula for this condition is as follows :—

Frequency of resonance = 1 ÷ [6.283 (square root of the coil inductance in henries multiplied by the condenser capacity in farads)]

Capacity in farads of a condenser in a resonant circuit =

1 ÷ [39.478 × (resonant frequency)^2 × inductance of the coil in circuit in henries]

Inductance in henries of a coil in a resonant circuit =

1 ÷ [39.478 × (resonant frequency)^2 × capacity of the condenser in circuit in farads].

WORLD-WIDE MILEAGE CHART.

43	83	76	90	11	78	71	46	50	41	57	59	55	72	16	15	10	70	10	34	21	46	59	39	66	22	13	103	10	51	25	22	15	63	62	52	46	60	38	MOSCOW
29	113	58	57	49	99	108	57	42	14	83	69	10	85	51	52	47	40	48	31	53	9	41	67	66	63	50	66	44	25	60	57	52	91	82	58	60	51	KHABAROVSK	
23	61	93	74	62	48	63	22	11	65	35	23	56	35	55	57	58	25	62	81	63	54	89	97	16	59	56	66	54	73	56	58	59	99	36	16	25	LOS ANGELES.		
33	53	118	99	42	40	48	4	25	73	25	13	38	29	34	36	40	50	43	79	42	67	101	74	22	36	36	89	37	85	33	36	39	77	22	9	NEW YORK. (U.S.A.)			
29	55	108	90	49	41	52	7	17	72	26	13	45	28	42	44	47	41	51	82	51	63	99	83	14	45	44	80	43	82	42	44	47	86	25	ST. LOUIS, (U.S.A.)				
54	31	108	96	54	19	28	25	42	95	6	14	52	11	46	47	52	60	55	96	52	88	121	71	23	41	49	81	52	106	40	43	49	63	CARACAS, VENEZUELA.					
104	42	54	68	56	53	38	81	101	79	65	77	61	66	59	57	59	115	56	59	52	91	59	25	85	49	60	70	65	74	53	53	51	CAPE TOWN, S. AFRICA.						
49	68	87	105	5	63	56	39	51	57	55	50	7	60	4	3	5	77	6	47	4	61	72	38	60	11	4	118	9	66	9	6	GENEVA, SWITZERLAND.							
51	62	91	110	11	57	50	37	52	62	49	46	13	54	8	6	11	78	12	53	8	67	77	39	56	5	9	124	15	73	3	MADRID, SPAIN.								
51	59	94	113	14	54	47	35	51	66	46	43	15	51	9	9	14	78	15	56	12	70	81	40	54	4	12	120	17	75	LISBON, PORTUGAL.									
53	110	32	39	61	117	111	81	65	12	107	94	60	107	67	67	62	53	61	22	61	18	17	58	88	76	64	52	60	MANILA, P.I.										
40	76	87	99	8	68	64	36	45	50	57	49	3	62	7	8	5	78	9	45	12	53	69	44	57	20	5	110	OSLO, NORWAY.											
73	61	32	14	113	67	72	87	72	62	75	78	112	69	118	118	113	47	112	71	115	58	45	84	68	118	116	WELLINGTON, NEW ZEALAND.												
44	71	88	103	5	65	59	37	48	54	55	49	3	60	3	3	4	72	7	47	8	58	72	41	58	14	HUIZEN, HOLLAND.													
55	58	92	112	15	52	46	38	54	67	47	45	17	52	12	11	16	81	16	56	12	72	79	38	56	RABAT, MOROCCO.														
38	46	100	80	63	33	58	21	25	70	20	11	59	19	56	57	61	38	64	96	62	70	103	92	MEXICO CITY.															
82	64	55	75	37	71	55	75	89	58	76	81	42	79	42	40	39	50	36	38	38	70	49	NAIROBI, KENYA COL.																
36	93	18	32	67	107	95	98	82	36	121	110	69	118	74	73	68	66	66	25	69	36	BANDOENG, JAVA.																	
33	114	50	48	57	103	117	64	47	12	88	74	55	89	60	60	56	38	56	32	61	TOKIO, JAPAN.																		
52	69	83	101	5	65	57	44	55	56	58	54	9	63	9	7	7	80	5	45	ROME, ITALY.																			
58	102	42	57	43	108	92	77	70	20	102	92	43	106	49	49	44	70	41	CALCUTTA, INDIA.																				
49	73	81	99	2	69	61	44	52	51	61	55	6	66	9	7	4	76	BUDAPEST, HUNGARY.																					
28	75	68	51	76	66	82	46	27	50	57	48	71	55	72	74	72	HONOLULU, HAWAII.																						
45	73	85	101	3	68	61	40	49	51	58	52	2	63	6	5	BERLIN, GERMANY.																							
47	68	89	105	6	62	56	37	49	56	54	48	6	58	2	PARIS, FRANCE.																								
45	69	91	106	9	61	58	35	47	55	53	46	6	57	LONDON, ENGLAND.																									
56	22	99	83	63	14	29	31	43	99	5	16	63	QUITO, ECUADOR.																										
43	74	85	99	5	68	62	39	47	50	58	51	COPENHAGEN, DENMARK.																											
40	43	110	90	54	29	42	15	28	83	14	HAVANA, CUBA.																												
55	29	98	88	59	15	28	28	42	98	BOGOTA, COLOMBIA.																													
43	122	44	50	51	112	112	76	56	NANKING, CHINA.																														
13	70	92	78	52	70	69	21	VANCOUVER, CANADA.																															
29	56	113	96	43	52	52	TORONTO, CANADA.																																
81	12	83	72	61	16	RIO DE JANEIRO, BRAZIL.																																	
69	13	90	80	68	LA PAZ. BOLIVIA.																																		
48	73	83	99	VIENNA, AUSTRIA.																																			
73	72	20	SYDNEY, AUSTRALIA.																																				
83	76	PERTH, AUSTRALIA.																																					
83	BUENOS AIRES, ARGENTINA.																																						
ANCHORAGE, ALASKA.																																							

To determine Mileage between any two of the listed Cities in the World, first find these two Cities on the World Chart above. Follow the horizontal column across chart from the upper city, and the vertical column up from the lower city. The box at which these two columns intersect shows the required mileage in HUNDREDS OF MILES.

All Mileages show the shortest (Great Circle) paths between points.

ELECTRICAL DEFINITIONS.

Capacity is calculated by the charge which must be transmitted to a body to lift its potential one unit. A capacity of one farad needs one coulomb of electricity to increase its potential by one volt.

Charged with a quantity A to a potential E a conductor has a capacity K equal to :—

$$A \div E$$

Amperage of alternating current in circuits which include resistance and inductance is equal to :—

$$\frac{V}{\sqrt{S^2 + (6.28\ FL)^2}}$$

where F is the frequency in cycles per second, L the inductance in henries. Current will be expressed in virtual amperes where S is in ohms and V in virtual volts. The denominator gives the impedance of the circuit in question.

For circuits also involving a capacity K in farads, the impedance is then equal to :—

$$\sqrt{B^2 + (6.28FL - \frac{1}{6.28FK})^2}$$

Current in a simple circuit.—The current in a circuit including a cell of electromotive force V, an external resistance U and internal resistance P is equal to :—

$$\frac{V}{Y + P} \text{ amperes}$$

For two cells in parallel the amperage is equal to :—

$$\frac{V}{Y + \frac{P}{2}}$$

For two cells in series the amperage is equal to :—

$$\frac{V}{Y + 2P}$$

Conductivity is measured by the amount of electricity moved across a unit area per unit potential rise in unit time. S is the reciprocal of resistivity. **Specific conductance** or **volume conductivity** is equal to :—

$$\frac{I}{V}$$

where V is the volume resistivity. **Equivalent conductivity** E is equal to :—

$$S \div W$$

where W is the number of equivalents per unit volume of solution. **Mass conductivity** is equal to :—

$$\frac{S}{D}$$

where D is density.

The dielectric constant of a medium is shown by E in the equation :—

$$\frac{A + BD}{EU^2}$$

where A is the force of attraction between two charges B and D parted by a distance U in a uniform medium.

Hysteresis.—The magnetization of mass of iron or steel due to a magnetic field which is made to alter through a cycle of value, lags behind the field. This effect is known as hysteresis.

Steinmetz' equation for hysteresis states that the loss of energy in ergs per cycle per cubic centimetre is equal to :—

$$CM^{1\cdot6}$$

where M is the maximum induction in maxwells per cm.^{2} and C the co-efficient of hysteresis.

Force between two magnetic poles.—If two poles of strength V and W are separated by a distance D in a medium whose permeability is P, the force between them is equal to :—

$$\frac{VW}{PD^2} \text{ dynes}$$

when the permeability of a vacuum is unity. Here D is in cm. and V and W are in cgs. units of pole strength.

The strength of a magnetic field at a point distant D from an isolated pole of strength K is equal to :—

$$\frac{K}{PD^2} \text{ gauss}$$

Here K and D are in cgs. units.

Faraday's Law.—The mass of substance decomposed by the passing of the same amount of electricity through different electrolytic cells are, for the same electrolyte, equal, and for different electrolytes are in ratio to the combining weight of the elements which are deposited.

Induced electromotive force in a circuit is in ratio to the amount of alteration of magnetic flux through the circuit and is equal to :—

$$-\frac{A}{B} \text{ volts}$$

where A is the change of magnetic flux in a time B. The current induced is equal to :—

$$\frac{A}{CB}$$

where C is the resistance of the circuit.

Heat Effect.—The heat caused in a circuit by an electric current of A amperes flowing through a resistance of R ohms, with a difference of potential of V volts for a time T seconds is equal to :—

$$\frac{VAT}{4.18} \text{ or } \frac{TRA^2}{4.18} \text{ calories}$$

Kirchoff's Laws.—(*a*) The algebraic sum of the currents which meet at any point is equal to zero. (*b*) The algebraic sum of the products of the current and the resistance in each conductor in a closed circuit is equal to the electromotive force in the stated circuit.

Magnetic Field due a Magnet.—At a point on the magnetic axis extended at a distance S cm. from the magnet centre, the length of magnet being R cms. whose poles are +P and —P and magnetic moment T, the field strength is equal to :—

$$2\ SRP \div \left[S^2 - \left(\frac{R}{2} \right)^2 \right]^2 \text{ gauss}$$

If S is large compared with $\frac{R}{2}$ then the field is eaual to :—

$$2T \div S^2$$

Magnetic Field due to a Current.—The strength of the magnetic field at the midpoint of a round conductor of radius R and in which a current C in absolute electromagnetic units is passing is equal to :—

$$\frac{6.28C \text{ gauss}}{R}$$

If the circular coil has M turns the magnetic intensity at the centre is equal to :—

$$\frac{6.28MC \text{ gauss}}{R}$$

The magnetic field in a long single layer coil of M turns per centimetre length passing a current C in absolute electromagnetic units is equal to :—

$$12.56MC \text{ gauss}$$

If C is given in amperes the above formulae then become equal to :—

$$\frac{6.28C}{10R},\quad \frac{6.28MC}{10R},\quad 1.256MC.$$

Lenz's Law.—When an electromotive force is caused in a conductor by an alteration in the relation between the magnetic field and conductor, the electromotive force direction is such as to produce a current whose magnetic field will oppose the change.

The Magnetic Field.—At a point on a line cutting the magnet into two right angles, is equal to :—

$$RP \div \left[\left(\frac{R}{2} \right)^2 + S^2 \right]^{1.5} \text{ gauss}$$

The magnetic field for large values of r is equal to :—

$$T \div S^3 \text{ gauss}$$

The electrostatic unit of charge is the quantity which, if concentrated at a point and set at unit distance from an equivalent and similarly concentrated amount, is repelled with unit force. If the distance is one cm. and the force of repulsion one dyne and the surrounding medium is a vacuum, this is equivalent to one electrostatic unit of quantity. The electromagnetic unit of quantity is known as the amount transferred by unit current in unit time. The quantity passed by one ampere in one second is called the coulomb. The faraday is the electrical charge carried by one gram equivalent. The coulomb is equal to :—

$$3 \times 10^9 \text{ electrostatic units}$$

The time of frequency of vibration of a magnet of magnetic moment A and moment of inertia B oscillating in a field of strength G is equal to :—

$$6.28 \sqrt{B \div GA} \text{ seconds}$$

The power developed by an electric current in watts passing in a conductor where V is the difference of potential at its ends in volts, R is its resistance in ohms, and A the current in amperes is equal to :—

$$RA^2 \text{ or } AV \text{ watts.}$$

The work done in joules in a time S secs. is equal to :—

$$SRA^2 \text{ or } ASV \text{ jourles.}$$

The power for alternating current in a circuit is equal to :—

$$AV \cos P \text{ watts}$$

where V and A are the effective values of the electromotive force and current in volts and amperes and P the phase angle between the current and the impressed electromotive force and the ratio watts ÷ AVW cos P is known as the power factor.

The tangent galvanometer has A turns, or radius R in the earth's field F and has a deflection K^6 then the current flowing is equal to :—

$$\tan_{K^6} \frac{RF}{6.28A}$$

Torque produced by the effect of one magnet on another.—The turning moment felt by a magnet of pole strength M and length R put at a distance K from another magnet of length S and pole strength N where the axis of the first is perpendicular to the axis of the second, and the centre of the first magnet is on the extended axis of the second one, then the torque is equal to :—

$$\frac{NMRS}{4(K^3)} B.$$

If the first magnet is turned through angle A, the formula for the torque is equal to :—

$$8 \frac{NMRS \cos A}{4(K^3)}$$

The pulling effect of a magnet with induction K has a pole face of area B the force then being equal to :—

$$K^2 B \div 25.132$$

DATA ON ALTERNATING CURRENTS

Ohms Law for A.C. is modified as follows :—

$$A = \frac{E}{\sqrt{\left[R^2 + \left(LM - \frac{1}{CM}\right)^2\right]}}$$

Where E = voltage, A = amperes, R = ohms resistance, C = capacitance in farads, L = inductance in henries, F = frequency, and $M = 2\pi F$.

Note for 50 cycles supply M = 314.16

„ „ 60 „ „ M = 376.99

Special formula for Resistance only $A = E \div R$
" " " Capacitance only $A = ECM$
" " " Inductance only $A = E \div LM$

R.M.S. (Root mean Square) values, is the value of A.C. that has the same heating effect as D.C.

In the case of Sine Waves which generally apply

Maximum value $= \pi \div 2$ average value $= \sqrt{2}$ R.M.S. value.

Form Factor $= \dfrac{\text{R.M.S. value}}{\text{Average value}} = \dfrac{\pi}{2\sqrt{2}}$

Average Value $= 2 \div \pi \times$ maximum value.

Power Factor $=$ P.F. or equivalent $\cos \varnothing$.

$= \dfrac{\text{Watts}}{\text{Volts} \times \text{Amps.}}$

P.F. is equal to the cosine of the angle of lag between voltage and current in the case of Sine Waves.

Power in A.C. circuits.—Single Phase Watts = Volts $\times$ amps. $\times \cos \varnothing$.

2 phase Watts $= 2 \times$ volts $\times$ amps. $\times \cos \varnothing$.

3 phase Watts $= \sqrt{3} \times$ volts $\times$ amps. $\times \cos \varnothing$.

Where in each case the amps is the line current and volts the voltage between lines, (This is incorrect for common wires in 2 and 3 phase circuits).

Delta connection 3 phase motors. Voltage across phase windings = Line Volts. Current in phase windings = Line current $\div \sqrt{3}$.

Star connections, 3 phase motors. Voltage across phase windings = Line Volts $\div \sqrt{3}$. Current in phase windings = Line current.

Three-phase Supply.—The black wire is neutral and the red, green, and white wires are the 3-phase leads. If single phase connection is desired use neutral and any one of the three coloured wires. Three-phase voltage between phase-wires is equal to $\sqrt{3} \times$ single phase voltage.

USEFUL FORMULAE.

Theoretical power of single phase circuit in K.V.A. = (Volts $\times$ Amps.) $\div$ 1,000.

Real power of single phase circuit in kilowatts = (Volts $\times$ Amps. $\times$ P.F.) $\div$ 1,000.

Apparent power of 2-phase circuit in K.V.A. = (2 $\times$ Volts $\times$ Amps.) $\div$ 1,000.

Real power of 2-phase circuit in Kilowatts = (2 $\times$ Volts $\times$ Amps. $\times$ P.F.) $\div$ 1,000.

Theoretical power of 3-phase circuit in K.V.A. = (1.73 $\times$ Volts $\times$ Amps.) $\div$ 1,000.

Real power of 3-phase circuit in Kilowatts = (1.73 $\times$ Volts $\times$ Amps. $\times$ P.F.) $\div$ 1,000.

Input of 1, 2, or 3-phase Motor in K.V.A. = (H.P. $\times$ .746) $\div$ (Efficiency $\times$ P.F.).

Output of 1, 2 or 3-phase Motors in H.P. = (Input in K.V.A. $\times$ Efficiency $\times$ P.F.) $\div$ .746.

RADIO FORMULAS AND LAWS.

Wavelength of a Tuned Circuit.

$W = 1{,}885 \sqrt{AB}$ where A = inductance in microhenries, and B = capacity in microfarads.

Frequency of a Tuned Circuit.

$F = \dfrac{1{,}000{,}000}{6.283 \sqrt{AB}}$ where F = frequency in cycles per second and A and B have values as shown in the previous formula.

Low Frequency Amplification.

The voltage stage gain of an L.F. transformer coupled-amplifier is approximately as follows :—

$$A = \mu \frac{N_2}{N_1} \times \frac{P}{\sqrt{p^2 \times R^2}}$$

Where μ = voltage gain of valve, N_2 = number of secondary turns of transformer, N_1 = number of primary turns of transformer, R = A.C. resistance of valve, and P = reactance of primary coil in ohms.

Resistance Coupled L.F. Amplification.

Voltage stage gain of a resistance coupled L.F. amplifier is as follows :

$$A = \mu \times \frac{R}{R + T}$$

where μ = amplification factor of valve, R = external coupling resistance on ohms. and T = A.C. resistance (impedance) of valve.

USEFUL CONSTANTS.

π	= 3.14159	g	= 32.16
$3 \div \pi$	= .95492	$1 \div 2g$	= .01555
π^2	= 9.8696	$\pi \div \sqrt{g}$	= .55399
$\sqrt{\pi}$	= 1.77245	$\sqrt[3]{6 \div \pi}$	= 1.2407
$1 \div \sqrt[3]{\pi}$	= .68278	$\pi \div 3$	= 1.0472
$\pi \div 4$	= .7854	$1 \div \pi$	= .31831
$2g$	= 64.32	$1 \div \pi^2$	= .10132
$1 \div \sqrt{g}$	= .17634	$\sqrt[3]{\pi}$	= 1.46459
$\pi \div 180$	= .01745	$\sqrt[3]{3 \div 4\pi}$	= .62035
2π	= 6.28318	g^2	= 1034.226
$4\pi \div 3$	= 4.18879	$\sqrt{2g}$	= 8.01998
π^3	= 31.00628	e	= 2.71828
$1 \div \sqrt{\pi}$	= .56419	$180° \div \pi$	= 57.2958°
$\sqrt[3]{\pi^2}$	= 2.14503		

DECIBEL CONVERSION TABLES

It is convenient in measurements and calculations on communications systems to express the ratio between any two amounts of electric or acoustic power in units on a logarithmic scale. The *decibel* (1/10th of the *bel*) on the briggsian or base-10 scale and the *neper* on the napierian or base-*e* scale are in almost universal use for this purpose.

Since voltage and current are related to power by impedance, both the *decibel* and the *neper* can be used to express voltage and current ratios, if care is taken to account for the impedances associated with them. In a similar manner the corresponding acoustical quantities can be compared.

Table I and Table II on the following pages have been prepared to facilitate making conversions in either direction between the number of *decibels* and the corresponding power, voltage, and current ratios. Both tables can also be used for *nepers* and the *mile of standard cable* by applying the conversion factors from the table on the opposite page.

Decibel — The number of decibels N_{db} corresponding to the ratio between two amounts of power P_1 and P_2 is

$$N_{db} = 10 \log_{10} \frac{P_1}{P_2} \qquad (1)$$

When two voltages E_1 and E_2 or two currents I_1 and I_2 operate in the same or equal impedances,

$$N_{db} = 20 \log_{10} \frac{E_1}{E_2} \qquad (2)$$

and

$$N_{db} = 20 \log_{10} \frac{I_1}{I_2} \qquad (3)$$

If E_1 and E_2 or I_1 and I_2 operate in unequal impedances,

$$N_{db} = 20 \log_{10} \frac{E_1}{E_2} + 10 \log_{10} \frac{Z_2}{Z_1} + 10 \log_{10} \frac{k_1}{k_2} \qquad (4)$$

and

$$N_{db} = 20 \log_{10} \frac{I_1}{I_2} + 10 \log_{10} \frac{Z_1}{Z_2} + 10 \log_{10} \frac{k_1}{k_2} \qquad (5)$$

where Z_1 and Z_2 are the absolute magnitudes of the corresponding impedances and k_1 and k_2 are the values of power factor for the impedances. Note that Table I and Table II can be used to evaluate the impedance and power factor terms, since both are similar to the expression for power ratio, equation (1).

Neper — The number of nepers N_{nep} corresponding to a power ratio $\frac{P_1}{P_2}$ is

$$N_{nep} = \frac{1}{2} \log_e \frac{P_1}{P_2} \qquad (6)$$

For voltage ratios $\frac{E_1}{E_2}$ or current ratios $\frac{I_1}{I_2}$ working in the same or equal impedances,

$$N_{nep} = \log_e \frac{E_1}{E_2} \qquad (7)$$

and

$$N_{nep} = \log_e \frac{I_1}{I_2}$$

When E_1 and E_2 or I_1 and I_2 operate in unequal impedances,

$$N_{nep} = \log_e \frac{E_1}{E_2} + \frac{1}{2} \log_e \frac{Z_2}{Z_1} + \frac{1}{2} \log_e \frac{k_1}{k_2} \qquad (8)$$

and

$$N_{nep} = \log_e \frac{I_1}{I_2} + \frac{1}{2} \log_e \frac{Z_1}{Z_2} + \frac{1}{2} \log_e \frac{k_1}{k_2} \qquad (9)$$

where Z_1 and Z_2 and k_1 and k_2 are as in equations (4) and (5).

RELATIONS BETWEEN DECIBELS, NEPERS, AND MILES OF STANDARD CABLE

Multiply	*By*	*To Find*
decibels	1151	nepers
decibels	1.056	miles of standard cable
miles of standard cable	947	decibels
miles of standard cable	109	nepers
nepers	8.686	decibels
nepers	9 175	miles of standard cable

TO FIND VALUES OUTSIDE THE RANGE OF CONVERSION TABLES

Values outside the range of either Table I or Table II on the following pages can be readily found with the help of the following simple rules

TABLE I: DECIBELS TO VOLTAGE AND POWER RATIOS

Number of decibels positive (+): Subtract +20 decibels successively from the given number of decibels until the remainder falls within range of Table I. *To find the voltage ratio,* multiply the corresponding value from the right-hand voltage-ratio column by 10 for each time you subtracted 20 db. *To find the power ratio,* multiply the corresponding value from the right-hand power-ratio column by 100 for each time you subtracted 20 db.

Example—*Given:* 49.2 db

49.2 db − 20 db − 20 db = 9.2 db

Voltage ratio: 9.2 db →

2.884 × 10 × 10 = 288.4

Power ratio: 9.2 db →

8.318 × 100 × 100 = 83180

Number of decibels negative (—): Add +20 decibels successively to the given number of decibels until the sum falls within the range of Table I. *For the voltage ratio,* divide the value from the left-hand voltage-ratio column by 10 for each time you added 20 db. *For the power ratio,* divide the value from the left-hand power-ratio column by 100 for each time you added 20 db.

Example—*Given:* −49.2 db

−49.2 db + 20 db + 20 db = −9.2 db

Voltage ratio: −9.2 db →

.3467 × 1/10 × 1/10 = .003467

Power ratio: −9.2 db →

.1202 × 1/100 × 1/100 = .00001202

TABLE II: VOLTAGE RATIOS TO DECIBELS

For ratios smaller than those in table—Multiply the given ratio by 10 successively until the product can be found in the table. From the number of decibels thus found, subtract +20 decibels for each time you multiplied by 10.

Example—*Given* Voltage ratio = .0131

.0131 × 10 = 131 × 10 = 1.31

From Table II, 1.31 →

2.345 db − 20 db − 20 db = −37.655 db

For ratios greater than those in table—Divide the given ratio by 10 successively until the remainder can be found in the table. To the number of decibels thus found, add + 20 db for each time you divided by 10.

Example—*Given:* Voltage ratio = 712

712 × 1/10 = 71.2 × 1/10 = 7.12

From Table II, 7.12 →

17.050 db + 20 db + 20 db = 57.050 db

TABLE I

GIVEN: Decibels — TO FIND: Power and Pressure Ratios

TO ACCOUNT FOR THE SIGN OF THE DECIBEL

For positive (+) values of the decibel — Both pressure and power ratios are greater than unity. Use the two right-hand columns.

For negative (—) values of the decibel — Both pressure and power ratios are less than unity. Use the two left-hand columns.

Example—*Given:* ± 9.1 db. *Find:*

	Power Ratio	*Pressure Ratio*
+9.1 db	8.128	2.851
−9.1 db	0.1230	0.3508

← −db+ →					← −db+ →				
Pressure Ratio	*Power Ratio*	*db*	*Pressure Ratio*	*Power Ratio*	*Pressure Ratio*	*Power Ratio*	*db*	*Pressure Ratio*	*Power Ratio*
1.0000	**1.0000**	**0**	**1.000**	**1.000**	**.5623**	**.3162**	**5.0**	**1.778**	**3.162**
.9886	.9772	.1	1.012	1.023	.5559	.3090	5.1	1.799	3.236
.9772	.9550	.2	1.023	1.047	.5495	.3020	5.2	1.820	3.311
.9661	.9333	.3	1.035	1.072	.5433	.2951	5.3	1.841	3.388
.9550	.9120	.4	1.047	1.096	.5370	.2884	5.4	1.862	3.467
.9441	.8913	.5	1.059	1.122	.5309	.2818	5.5	1.884	3.548
.9333	.8710	.6	1.072	1.148	.5248	.2754	5.6	1.905	3.631
.9226	.8511	.7	1.084	1.175	.5188	.2692	5.7	1.928	3.715
.9120	.8318	.8	1.096	1.202	.5129	.2630	5.8	1.950	3.802
.9016	.8128	.9	1.109	1.230	.5070	.2570	5.9	1.972	3.890
.8913	**.7943**	**1.0**	**1.122**	**1.259**	**.5012**	**.2512**	**6.0**	**1.995**	**3.981**
.8810	.7762	1.1	1.135	1.288	.4955	.2455	6.1	2.018	4.074
.8710	.7586	1.2	1.148	1.318	.4898	.2399	6.2	2.042	4.169
.8610	.7413	1.3	1.161	1.349	.4842	.2344	6.3	2.065	4.266
.8511	.7244	1.4	1.175	1.380	.4786	.2291	6.4	2.089	4.365
.8414	.7079	1.5	1.189	1.413	.4732	.2239	6.5	2.113	4.467
.8318	.6918	1.6	1.202	1.445	.4677	.2188	6.6	2.138	4.571
.8222	.6761	1.7	1.216	1.479	.4624	.2138	6.7	2.163	4.677
.8128	.6607	1.8	1.230	1.514	.4571	.2089	6.8	2.188	4.786
.8035	.6457	1.9	1.245	1.549	.4519	.2042	6.9	2.213	4.898
.7943	**.6310**	**2.0**	**1.259**	**1.585**	**.4467**	**.1995**	**7.0**	**2.239**	**5.012**
.7852	.6166	2.1	1.274	1.622	.4416	.1950	7.1	2.265	5.129
.7762	.6026	2.2	1.288	1.660	.4365	.1905	7.2	2.291	5.248
.7674	.5888	2.3	1.303	1.698	.4315	.1862	7.3	2.317	5.370
.7586	.5754	2.4	1.318	1.738	.4266	.1820	7.4	2.344	5.495
.7499	.5623	2.5	1.334	1.778	.4217	.1778	7.5	2.371	5.623
.7413	.5495	2.6	1.349	1.820	.4169	.1738	7.6	2.399	5.754
.7328	.5370	2.7	1.365	1.862	.4121	.1698	7.7	2.427	5.888
.7244	.5248	2.8	1.380	1.905	.4074	.1660	7.8	2.455	6.026
.7161	.5129	2.9	1.396	1.950	.4027	.1622	7.9	2.483	6.166
.7079	**.5012**	**3.0**	**1.413**	**1.995**	**.3981**	**.1585**	**8.0**	**2.512**	**6.310**
.6998	.4898	3.1	1.429	2.042	.3936	.1549	8.1	2.541	6.457
.6918	.4786	3.2	1.445	2.089	.3890	.1514	8.2	2.570	6.607
.6839	.4677	3.3	1.462	2.138	.3846	.1479	8.3	2.600	6.761
.6761	.4571	3.4	1.479	2.188	.3802	.1445	8.4	2.630	6.918
.6683	.4467	3.5	1.496	2.239	.3758	.1413	8.5	2.661	7.079
.6607	.4365	3.6	1.514	2.291	.3715	.1380	8.6	2.692	7.244
.6531	.4266	3.7	1.531	2.344	.3673	.1349	8.7	2.723	7.413
.6457	.4169	3.8	1.549	2.399	.3631	.1318	8.8	2.754	7.586
.6383	.4074	3.9	1.567	2.455	.3589	.1288	8.9	2.786	7.762
.6310	**.3981**	**4.0**	**1.585**	**2.512**	**.3548**	**.1259**	**9.0**	**2.818**	**7.943**
.6237	.3890	4.1	1.603	2.570	.3508	.1230	9.1	2.851	8.128
.6166	.3802	4.2	1.622	2.630	.3467	.1202	9.2	2.884	8.318
.6095	.3715	4.3	1.641	2.692	.3428	.1175	9.3	2.917	8.511
.6026	.3631	4.4	1.660	2.754	.3388	.1148	9.4	2.951	8.710
.5957	.3548	4.5	1.679	2.818	.3350	.1122	9.5	2.985	8.913
.5888	.3467	4.6	1.698	2.884	.3311	.1096	9.6	3.020	9.120
.5821	.3388	4.7	1.718	2.951	.3273	.1072	9.7	3.055	9.333
.5754	.3311	4.8	1.738	3.020	.3236	.1047	9.8	3.090	9.550
.5689	.3236	4.9	1.758	3.090	.3199	.1023	9.9	3.126	9.772

TABLE I (continued)

Pressure Ratio (−db)	Power Ratio (−db)	db	Pressure Ratio (+db)	Power Ratio (+db)
.3162	.1000	10.0	3.162	10.000
.3126	.09772	10.1	3.199	10.23
.3090	.09550	10.2	3.236	10.47
.3055	.09333	10.3	3.273	10.72
.3020	.09120	10.4	3.311	10.96
.2985	.08913	10.5	3.350	11.22
.2951	.08710	10.6	3.388	11.48
.2917	.08511	10.7	3.428	11.75
.2884	.08318	10.8	3.467	12.02
.2851	.08128	10.9	3.508	12.30
.2818	.07943	11.0	3.548	12.59
.2786	.07762	11.1	3.589	12.88
.2754	.07586	11.2	3.631	13.18
.2723	.07413	11.3	3.673	13.49
.2692	.07244	11.4	3.715	13.80
.2661	.07079	11.5	3.758	14.13
.2630	.06918	11.6	3.802	14.45
.2600	.06761	11.7	3.846	14.79
.2570	.06607	11.8	3.890	15.14
.2541	.06457	11.9	3.936	15.49
.2512	.06310	12.0	3.981	15.85
.2483	.06166	12.1	4.027	16.22
.2455	.06026	12.2	4.074	16.60
.2427	.05888	12.3	4.121	16.98
.2399	.05754	12.4	4.169	17.38
.2371	.05623	12.5	4.217	17.78
.2344	.05495	12.6	4.266	18.20
.2317	.05370	12.7	4.315	18.62
.2291	.05248	12.8	4.365	19.05
.2265	.05129	12.9	4.416	19.50
.2239	.05012	13.0	4.467	19.95
.2213	.04898	13.1	4.519	20.42
.2188	.04786	13.2	4.571	20.89
.2163	.04677	13.3	4.624	21.38
.2138	.04571	13.4	4.677	21.88
.2113	.04467	13.5	4.732	22.39
.2089	.04365	13.6	4.786	22.91
.2065	.04266	13.7	4.842	23.44
.2042	.04169	13.8	4.898	23.99
.2018	.04074	13.9	4.955	24.55
.1995	.03981	14.0	5.012	25.12
.1972	.03890	14.1	5.070	25.70
.1950	.03802	14.2	5.129	26.30
.1928	.03715	14.3	5.188	26.92
.1905	.03631	14.4	5.248	27.54
.1884	.03548	14.5	5.309	28.18
.1862	.03467	14.6	5.370	28.84
.1841	.03388	14.7	5.433	29.51
.1820	.03311	14.8	5.495	30.20
.1799	.03236	14.9	5.559	30.90
.1778	.03162	15.0	5.623	31.62
.1758	.03090	15.1	5.689	32.36
.1738	.03020	15.2	5.754	33.11
.1718	.02951	15.3	5.821	33.88
.1698	.02884	15.4	5.888	34.67
.1679	.02818	15.5	5.957	35.48
.1660	.02754	15.6	6.026	36.31
.1641	.02692	15.7	6.095	37.15
.1622	.02630	15.8	6.166	38.02
.1603	.02570	15.9	6.237	38.90

Pressure Ratio (−db)	Power Ratio (−db)	db	Pressure Ratio (+db)	Power Ratio (+db)
.1585	.02512	16.0	6.310	39.81
.1567	.02455	16.1	6.383	40.74
.1549	.02399	16.2	6.457	41.69
.1531	.02344	16.3	6.531	42.66
.1514	.02291	16.4	6.607	43.65
.1496	.02239	16.5	6.683	44.67
.1479	.02188	16.6	6.761	45.71
.1462	.02138	16.7	6.839	46.77
.1445	.02089	16.8	6.918	47.86
.1429	.02042	16.9	6.998	48.98
.1413	.01995	17.0	7.079	50.12
.1396	.01950	17.1	7.161	51.29
.1380	.01905	17.2	7.244	52.48
.1365	.01862	17.3	7.328	53.70
.1349	.01820	17.4	7.413	54.95
.1334	.01778	17.5	7.499	56.23
.1318	.01738	17.6	7.586	57.54
.1303	.01698	17.7	7.674	58.88
.1288	.01660	17.8	7.762	60.26
.1274	.01622	17.9	7.852	61.66
.1259	.01585	18.0	7.943	63.10
.1245	.01549	18.1	8.035	64.57
.1230	.01514	18.2	8.128	66.07
.1216	.01479	18.3	8.222	67.61
.1202	.01445	18.4	8.318	69.18
.1189	.01413	18.5	8.414	70.79
.1175	.01380	18.6	8.511	72.44
.1161	.01349	18.7	8.610	74.13
.1148	.01318	18.8	8.710	75.86
.1135	.01288	18.9	8.811	77.62
.1122	.01259	19.0	8.913	79.43
.1109	.01230	19.1	9.016	81.28
.1096	.01202	19.2	9.120	83.18
.1084	.01175	19.3	9.226	85.11
.1072	.01148	19.4	9.333	87.10
.1059	.01122	19.5	9.441	89.13
.1047	.01096	19.6	9.550	91.20
.1035	.01072	19.7	9.661	93.33
.1023	.01047	19.8	9.772	95.50
.1012	.01023	19.9	9.886	97.72
.1000	.01000	20.0	10.000	100.00

Pressure Ratio (−db)	Power Ratio (−db)	db	Pressure Ratio (+db)	Power Ratio (+db)
3.162×10^{-1}	10^{-1}	10	3.162	10
10^{-1}	10^{-2}	20	10	10^{2}
3.162×10^{-2}	10^{-3}	30	3.162×10	10^{3}
10^{-2}	10^{-4}	40	10^{2}	10^{4}
3.162×10^{-3}	10^{-5}	50	3.162×10^{2}	10^{5}
10^{-3}	10^{-6}	60	10^{3}	10^{6}
3.162×10^{-4}	10^{-7}	70	3.162×10^{3}	10^{7}
10^{-4}	10^{-8}	80	10^{4}	10^{8}
3.162×10^{-5}	10^{-9}	90	3.162×10^{4}	10^{9}
10^{-5}	10^{-10}	100	10^{5}	10^{10}

To find decibel values outside the range of this table, see page 17

TABLE II

GIVEN: {Pressure} Ratio TO FIND: Decibels

POWER RATIOS

To find the number of decibels corresponding to a given power ratio—Assume the given power ratio to be a voltage ratio and find the corresponding number of decibels from the table. The desired result is exactly one-half of the number of decibels thus found.

Example—*Given:* a power ratio of 3.41. *Find:* 3.41 in the table:

3.41→10.655 db × ½ = 5.328 db

Pressure Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
1.0	.000	.086	.172	.257	.341	.424	.506	.588	.668	.749
1.1	.828	.906	.984	1.062	1.138	1.214	1.289	1.364	1.438	1.511
1.2	1.584	1.656	1.727	1.798	1.868	1.938	2.007	2.076	2.144	2.212
1.3	2.279	2.345	2.411	2.477	2.542	2.607	2.671	2.734	2.798	2.860
1.4	2.923	2.984	3.046	3.107	3.167	3.227	3.287	3.346	3.405	3.464
1.5	3.522	3.580	3.637	3.694	3.750	3.807	3.862	3.918	3.973	4.028
1.6	4.082	4.137	4.190	4.244	4.297	4.350	4.402	4.454	4.506	4.558
1.7	4.609	4.660	4.711	4.761	4.811	4.861	4.910	4.959	5.008	5.057
1.8	5.105	5.154	5.201	5.249	5.296	5.343	5.390	5.437	5.483	5.529
1.9	5.575	5.621	5.666	5.711	5.756	5.801	5.845	5.889	5.933	5.977
2.0	6.021	6.064	6.107	6.150	6.193	6.235	6.277	6.319	6.361	6.403
2.1	6.444	6.486	6.527	6.568	6.608	6.649	6.689	6.729	6.769	6.809
2.2	6.848	6.888	6.927	6.966	7.008	7.044	7.082	7.121	7.159	7.197
2.3	7.235	7.272	7.310	7.347	7.384	7.421	7.458	7.495	7.532	7.568
2.4	7.604	7.640	7.676	7.712	7.748	7.783	7.819	7.854	7.889	7.924
2.5	7.959	7.993	8.028	8.062	8.097	8.131	8.165	8.199	8.232	8.266
2.6	8.299	8.333	8.366	8.399	8.432	8.465	8.498	8.530	8.563	8.595
2.7	8.627	8.659	8.691	8.723	8.755	8.787	8.818	8.850	8.881	8.912
2.8	8.943	8.974	9.005	9.036	9.066	9.097	9.127	9.158	9.188	9.218
2.9	9.248	9.278	9.308	9.337	9.367	9.396	9.426	9.455	9.484	9.513
3.0	9.542	9.571	9.600	9.629	9.657	9.686	9.714	9.743	9.771	9.799
3.1	9.827	9.855	9.883	9.911	9.939	9.966	9.994	10.021	10.049	10.076
3.2	10.103	10.130	10.157	10.184	10.211	10.238	10.264	10.291	10.317	10.344
3.3	10.370	10.397	10.423	10.449	10.475	10.501	10.527	10.553	10.578	10.604
3.4	10.630	10.655	10.681	10.706	10.731	10.756	10.782	10.807	10.832	10.857
3.5	10.881	10.906	10.931	10.955	10.980	11.005	11.029	11.053	11.078	11.102
3.6	11.126	11.150	11.174	11.198	11.222	11.246	11.270	11.293	11.317	11.341
3.7	11.364	11.387	11.411	11.434	11.457	11.481	11.504	11.527	11.550	11.573
3.8	11.596	11.618	11.641	11.664	11.687	11.709	11.732	11.754	11.777	11.799
3.9	11.821	11.844	11.866	11.888	11.910	11.932	11.954	11.976	11.998	12.019
4.0	12.041	12.063	12.085	12.106	12.128	12.149	12.171	12.192	12.213	12.234
4.1	12.256	12.277	12.298	12.319	12.340	12.361	12.382	12.403	12.424	12.444
4.2	12.465	12.486	12.506	12.527	12.547	12.568	12.588	12.609	12.629	12.649
4.3	12.669	12.690	12.710	12.730	12.750	12.770	12.790	12.810	12.829	12.849
4.4	12.869	12.889	12.908	12.928	12.948	12.967	12.987	13.006	13.026	13.045
4.5	13.064	13.084	13.103	13.122	13.141	13.160	13.179	13.198	13.217	13.236
4.6	13.255	13.274	13.293	13.312	13.330	13.349	13.368	13.386	13.405	13.423
4.7	13.442	13.460	13.479	13.497	13.516	13.534	13.552	13.570	13.589	13.607
4.8	13.625	13.643	13.661	13.679	13.697	13.715	13.733	13.751	13.768	13.786
4.9	13.804	13.822	13.839	13.857	13.875	13.892	13.910	13.927	13.945	13.962
5.0	13.979	13.997	14.014	14.031	14.049	14.066	14.083	14.100	14.117	14.134
5.1	14.151	14.168	14.185	14.202	14.219	14.236	14.253	14.270	14.287	14.303
5.2	14.320	14.337	14.353	14.370	14.387	14.403	14.420	14.436	14.453	14.469
5.3	14.486	14.502	14.518	14.535	14.551	14.567	14.583	14.599	14.616	14.632
5.4	14.648	14.664	14.680	14.696	14.712	14.728	14.744	14.760	14.776	14.791
5.5	14.807	14.823	14.839	14.855	14.870	14.886	14.902	14.917	14.933	14.948
5.6	14.964	14.979	14.995	15.010	15.026	15.041	15.056	15.072	15.087	15.102
5.7	15.117	15.133	15.148	15.163	15.178	15.193	15.208	15.224	15.239	15.254
5.8	15.269	15.284	15.298	15.313	15.328	15.343	15.358	15.373	15.388	15.402
5.9	15.417	15.432	15.446	15.461	15.476	15.490	15.505	15.519	15.534	15.549

TABLE II (continued)

Pressure Ratio	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
6.0	15.563	15.577	15.592	15.606	15.621	15.635	15.649	15.664	15.678	15.692
6.1	15.707	15.721	15.735	15.749	15.763	15.778	15.792	15.806	15.820	15.834
6.2	15.848	15.862	15.876	15.890	15.904	15.918	15.931	15.945	15.959	15.973
6.3	15.987	16.001	16.014	16.028	16.042	16.055	16.069	16.083	16.096	16.110
6.4	16.124	16.137	16.151	16.164	16.178	16.191	16.205	16.218	16.232	16.245
6.5	16.258	16.272	16.285	16.298	16.312	16.325	16.338	16.351	16.365	16.378
6.6	16.391	16.404	16.417	16.430	16.443	16.456	16.469	16.483	16.496	16.509
6.7	16.521	16.534	16.547	16.560	16.573	16.586	16.599	16.612	16.625	16.637
6.8	16.650	16.663	16.676	16.688	16.701	16.714	16.726	16.739	16.752	16.764
6.9	16.777	16.790	16.802	16.815	16.827	16.840	16.852	16.865	16.877	16.890
7.0	16.902	16.914	16.927	16.939	16.951	16.964	16.976	16.988	17.001	17.013
7.1	17.025	17.037	17.050	17.062	17.074	17.086	17.098	17.110	17.122	17.135
7.2	17.147	17.159	17.171	17.183	17.195	17.207	17.219	17.231	17.243	17.255
7.3	17.266	17.278	17.290	17.302	17.314	17.326	17.338	17.349	17.361	17.373
7.4	17.385	17.396	17.408	17.420	17.431	17.443	17.455	17.466	17.478	17.490
7.5	17.501	17.513	17.524	17.536	17.547	17.559	17.570	17.582	17.593	17.605
7.6	17.616	17.628	17.639	17.650	17.662	17.673	17.685	17.696	17.707	17.719
7.7	17.730	17.741	17.752	17.764	17.775	17.786	17.797	17.808	17.820	17.831
7.8	17.842	17.853	17.864	17.875	17.886	17.897	17.908	17.919	17.931	17.942
7.9	17.953	17.964	17.975	17.985	17.996	18.007	18.018	18.029	18.040	18.051
8.0	18.062	18.073	18.083	18.094	18.105	18.116	18.127	18.137	18.148	18.159
8.1	18.170	18.180	18.191	18.202	18.212	18.223	18.234	18.244	18.255	18.266
8.2	18.276	18.287	18.297	18.308	18.319	18.329	18.340	18.350	18.361	18.371
8.3	18.382	18.392	18.402	18.413	18.423	18.434	18.444	18.455	18.465	18.475
8.4	18.486	18.496	18.506	18.517	18.527	18.537	18.547	18.558	18.568	18.578
8.5	18.588	18.599	18.609	18.619	18.629	18.639	18.649	18.660	18.670	18.680
8.6	18.690	18.700	18.710	18.720	18.730	18.740	18.750	18.760	18.770	18.780
8.7	18.790	18.800	18.810	18.820	18.830	18.840	18.850	18.860	18.870	18.880
8.8	18.890	18.900	18.909	18.919	18.929	18.939	18.949	18.958	18.968	18.978
8.9	18.988	18.998	19.007	19.017	19.027	19.036	19.046	19.056	19.066	19.075
9.0	19.085	19.094	19.104	19.114	19.123	19.133	19.143	19.152	19.162	19.171
9.1	19.181	19.190	19.200	19.209	19.219	19.228	19.238	19.247	19.257	19.266
9.2	19.276	19.285	19.295	19.304	19.313	19.323	19.332	19.342	19.351	19.360
9.3	19.370	19.379	19.388	19.398	19.407	19.416	19.426	19.435	19.444	19.453
9.4	19.463	19.472	19.481	19.490	19.499	19.509	19.518	19.527	19.536	19.545
9.5	19.554	19.564	19.573	19.582	19.591	19.600	19.609	19.618	19.627	19.636
9.6	19.645	19.654	19.664	19.673	19.682	19.691	19.700	19.709	19.718	19.726
9.7	19.735	19.744	19.753	19.762	19.771	19.780	19.789	19.798	19.807	19.816
9.8	19.825	19.833	19.842	19.851	19.860	19.869	19.878	19.886	19.895	19.904
9.9	19.913	19.921	19.930	19.939	19.948	19.956	19.965	19.974	19.983	19.991

Pressure Ratio	0	1	2	3	4	5	6	7	8	9
10	20.000	20.828	21.584	22.279	22.923	23.522	24.082	24.609	25.105	25.575
20	26.021	26.444	26.848	27.235	27.604	27.959	28.299	28.627	28.943	29.248
30	29.542	29.827	30.103	30.370	30.630	30.881	31.126	31.364	31.596	31.821
40	32.041	32.256	32.465	32.669	32.869	33.064	33.255	33.442	33.625	33.804
50	33.979	34.151	34.320	34.486	34.648	34.807	34.964	35.117	35.269	35.417
60	35.563	35.707	35.848	35.987	36.124	36.258	36.391	36.521	36.650	36.777
70	36.902	37.025	37.147	37.266	37.385	37.501	37.616	37.730	37.842	37.953
80	38.062	38.170	38.276	38.382	38.486	38.588	38.690	38.790	38.890	38.988
90	39.085	39.181	39.276	39.370	39.463	39.554	39.645	39.735	39.825	39.913
100	40.000	—	—	—	—	—	—	—	—	—

PROPERTIES OF SOLID

	Specific Gravity	Tensile Strength Lbs. per square inch (Multiply by 10^3)	Compressive Strength Lbs. per square inch (Multiply by 10^3)	Softens at °C.	Stable at °C.	Specific Heat	Coefficient of Linear Expansion Parts in 10^6 per °C.	Heat Conductivity c.g.s.
Amber	1.1			250	180		44	
Casein — Moulded	1.33	7		177	165		80	
Cellulose Acetate	1.3	3	4	70	65	.5	150	.0005
Cellulose Nitrate	1.5	3-6		85	85	.36	140	.0003
Fibre	1.3	10	25	130	95		25	.0011
Glass — Crown	2.48	2-5	10-30	1100		.161	8.9	.0025
Glass — Flint	3.7	3-6	6-10			.117	7.9	.002
Glass — Pyrex	2.25		40	600	520	.2	3.2	.0027
Methacrylic Resin	1.19	8-9	12	135	90	.45	70	.00055
Mica — Clear India	2.8			1200	600	2.06	3-7	.0018
Mycalex	3.5	6-8	25-40		350	.22	8-9	.0014
Marble — White	2.7	2	8-15			.21	8-12	.0015
Phenol — Pure	1.3	5-11	15-30		120	.3	28	.0004
Phenol — Yellow	1.9	5.5			130			
Phenol — Black Moulded	1.35	7.5	30		140	.35	40	.0005
Phenol — Paper Base	1.35	10-15	30		125	.3	30	.00065
Phenol — Cloth Base	1.38	11	35		115	.35	20	.0005
Porcelain — Wet-Process	2.4	3-6	30-50	1610	1050	.25	4-5	.0025
Porcelain — Dry-Process	2.3	2-3	30-50		1050	.26	3-4	.0025
Quartz — Fused	2.21	7-10	200	1430	1150	.18	45	.0024
Rubber — Hard	1.15	4-7	7	70	65	.33	70-80	.0004
Slate	2.8	5	15			.22	10	.005
Steatite	2.5	8-10	50-100	1500	1000		6-8	
Styrene (Polymerized)	1.05	6-9	14	90	75	.324	70	.0004
Sulphur	2.05			113	95	.17	64	.0006
Shellac	1.1	.9	7	85	75			.0006
Titanium Dioxide	4-5	4	60	1600			7-8	
Urea — Formaldehyde Compounds	1.48	6-9	25-30	200	80			.00017
Vinyl Resins — Unfilled	1.35	8-10			50	.244	70	.0005

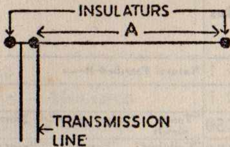
INSULATING MATERIALS

Dielectric Constant	Power Factor in per cent			Machinability	Water Absorption % in 24 hours	Cost per pound Dollars	REMARKS
	60 Cycles	1 Kc	1 Mc				
2.9			.2	Very Good	0	12	Natural Petrified Resin
6.4			6	Very Good	4–9		
6–8	7		3–6	Very Good	4	.50	"Tenite" "Safety Film" — Burns very slowly.
4–7	5–9	5	5	Very Good	2–3	.50	"Celluloid" "Pyralin" "Pyroxylin" — Burns rapidly
4–5	6–9	5	5	Very Good	30	.35	
6.2		1		No	0		Window Glass
7		.45	.4	No	0		
4.5		.5	.2	Very Poor	0		
2.8	3	2	2	Very Good	.3		"Lucite" "Plexiglass" — Slow burning
7–7.3	.03	.02	.02			5	
6–8		.6	.3	Poor	.035	.80	Mica and Lead Borate
7–9			4	Fair	Very high		
5	2		1	Very Good	.15	1	"Catalin" "Bakelite" — Burns very slowly
5.3	2.5	1.4	.7	Poor	.2	.65	"Low-Loss Bakelite" — Nearly non-burning
5.5	8	6	3.5	Fair	.3	.40	Nearly non-burning
5.5	6	5	3.5	Good	.2–1	.55	Nearly non-burning
5.6	5	5	5	Good	.7	.65	Nearly non-burning
6.5–7	2	1	.6	No	Low		
6.2–7.5	2	1	.7	No	.1–1		
4.2	.03	.03	.03	Very Poor	0		SiO_2 conducts at 800° C.
2–3	1	1	.5–.9	Fair	.02	.60	Burns slowly
6–8		.9		Fair	High		
6.1	1	.4	.3	No	.02		Magnesium Silicate — "Isolantite" "Lava"
2.4–2.9	.02	.02	.03	Good	.01	1.20	"Victron" "Trolitul" — Very slow burning
3–3.8						.03	Burns rapidly
2.5–4	2.5		.9		.1	.25	Burns readily
90–170		1	.06	No	0	.20	Rutile
6–7	5	3.8	3	Fair	.4		"Beetle" "Plaskon"
4		1.4	1.7	Very Good	.15		"Vinylite" — Non-burning

FORMULAS FOR AERIALS CUT TO RESONATE AT ANY DESIRED FREQUENCY

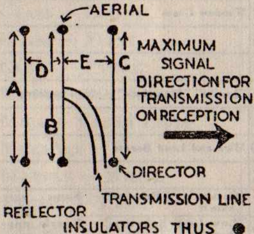
LONG WIRE MULTIBAND ZEPPELIN AERIAL

CUT FOR MOST FREQUENT BAND USED



A=[{164(NUMBER OF HALF WAVES ON THE AERIAL REQUIRED, MINUS ·05)}÷{FREQUENCY IN MEGACYCLES OF MOST USED BRAND}] YDS.

DIRECTOR AND REFLECTOR HALF WAVE AERIAL



A={164÷(FREQUENCY IN MEGACYCLES)} YDS.

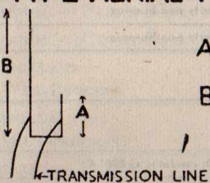
B={156÷(FREQUENCY IN MEGACYCLES)} YDS.

C={150÷(FREQUENCY IN MEGACYCLES)} YDS.

D={(WAVELENGTH IN METRES X ·125) X 1·094} YDS.

E={(WAVELENGTH IN METRES X ·1) X 1·094} YDS.

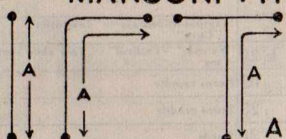
J TYPE AERIAL FOR VERY HIGH FREQUENCIES



A={(WAVELENGTH IN METRES ÷ 4) X 1·094} YDS.

B={(WAVELENGTH IN METRES X ·75) X 1·094} YDS.

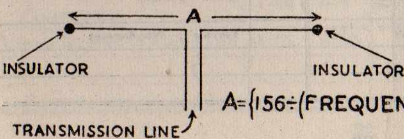
MARCONI TYPE ¼ WAVE AERIAL



A={(WAVELENGTH IN METRES ÷ 4) X 1·094} YARDS

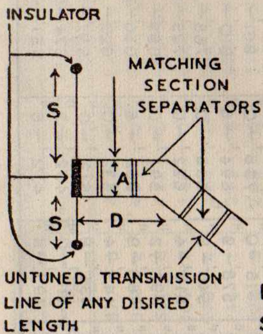
A HERE INCLUDES LENGTH OF LEADIN

HALF WAVE AERIAL



A={156÷(FREQUENCY IN MEGACYCLES)} YDS.

HALF WAVE Q MATCHED AERIAL



THE DIMENSION A DEPENDS UPON THE AERIAL IMPEDANCE AND THE IMPEDANCE OF THE TRANSMISSION LINE AND THE IMPEDANCE IN OHMS OF THE MATCHING SECTION IS EQUAL TO

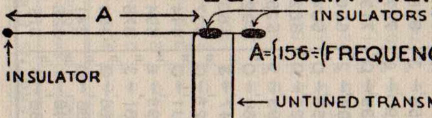
$$\sqrt{\text{AERIAL IMPEDANCE IN OHMS} \times \text{TRANSMISSION LINE IMPEDANCE IN OHMS}}$$

THEREFORE DIMENSION A IS OBTAINED BY REFERENCE TO THE SECTION DEALING WITH TRANSMISSION LINE FORMULAS ONCE THE IMPEDANCE OF THE MATCHING SECTION IS OBTAINED

D={78÷FREQUENCY IN MEGACYCLES)} YDS.

S={78÷FREQUENCY IN MEGACYCLES)} YDS.

ZEPPELIN AERIAL



A={156÷(FREQUENCY IN MEGACYCLES)} YDS

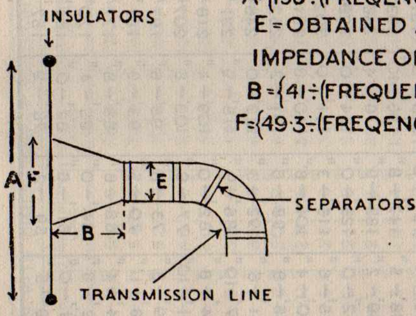
HALF WAVE DELTA MATCHED AERIAL

A={156÷(FREQENCY IN MEGACYCLES)} YDS.

E=OBTAINED ACCORDING TO THE IMPEDANCE OF THE TRANSMISSION LINE

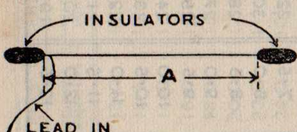
B={41÷(FREQUENCY IN MEGACYOLES)} YDS.

F={49·3÷(FREQENCY IN MEGACYCLES)} YDS.



LONG WAVE AERIAL

ANY NUMBER OF HALF WAVES IN LENGTH



A=[{164(NUMBER OF HALF WAVES ON THE AERIAL MINUS ·05)} ÷{FREQUENCY IN MEGACYCLES}] YDS.

TABLE OF FREQUENCIES WITH DIMENSIONS OF RESONANT WIRE LENGTHS FOR AERIAL CONSTRUCTION

FREQUENCY. in Megacycles.	1/4 WAVELENGTH LONG	1/2 WAVELENGTH LONG	3/4 WAVELENGTH LONG	1 WAVELENGTH LONG	2 WAVELENGTHS LONG	3 WAVELENGTHS LONG	4 WAVELENGTHS LONG	5 WAVELENGTHS LONG	6 WAVELENGTHS LONG	7 WAVELENGTHS LONG
0·5	492′–2″	984′–3″	1476′–5″	1968′–6″	3937′–0″	5905′–6″	7874′–0″	9842′–6″	11811′–0″	12779′–6″
1·0	246′–1″	492′–2″	738′–2″	984′–3″	1968′–6″	2952′–9″	3937′–0″	4921′–3″	5905′–6″	6389′–9″
1·5	164′–1″	328′–1″	492′–2″	656′–2″	1312′–4″	1968′–6″	2624′–8″	3280′–10″	3937′–0″	4259′–10″
2·0	123′–0″	246′–1″	369′–1″	492′–2″	984′–3″	1476′–5″	1968′–6″	2460′–8″	2952′–9″	3194′–10″
2·5	98′–5″	196′–10″	295′–5″	393′–8″	787′–4″	1181′–0″	1574′–8″	1968′–6″	2362′–0″	2755′–8″
3·0	82′–0″	164′–0″	246′–0″	328′–1″	656′–2″	984′–3″	1312′–4″	1640′–5″	1968′–6″	2296′–7″
3·5	70′–6″	140′–11″	211′–5″	281′–10″	562′–5″	844′–3″	1124′–10″	1406′–8″	1688′–6″	1968′–6″
4·0	61′–6″	123′–0″	184′–6″	246′–1″	492′–2″	738′–3″	984′–3″	1230′–5″	1476′–6″	1722′–6″
4·5	54′–8″	109′–4″	164′–0″	218′–9″	437′–6″	656′–3″	875′–0″	1093′–9″	1312′–6″	1531′–3″
5·0	49′–3″	98′–5″	147′–8″	196′–10″	393′–8″	590′–6″	787′–4″	984′–3″	1181′–0″	1377′–10″
5·5	44′–7″	89′–2″	133′–9″	178′–4″	356′–8″	535′–0″	713′–4″	891′–8″	1070′–0″	1248′–4″
6·0	41′–0″	82′–0″	123′–0″	164′–0″	328′–0″	492′–2″	656′–0″	820′–2″	984′–3″	1148′–2″
6·5	37′–9″	75′–6″	113′–3″	151′–0″	302′–0″	453′–0″	604′–0″	755′–0″	906′–0″	1057′–0″
7·0	35′–2″	70′–4″	105′–6″	140′–8″	281′–3″	422′–0″	562′–6″	703′–3″	844′–0″	984′–3″
7·5	32′–10″	65′–8″	98′–6″	131′–3″	262′–6″	393′–9″	525′–0″	656′–3″	787′–6″	918′–9″
8·0	30′–9″	61′–6″	92′–3″	123′–0″	246′–0″	369′–0″	492′–2″	615′–0″	738′–0″	861′–2″
8·5	28′–11″	57′–10″	86′–9″	115′–9″	231′–6″	347′–3″	463′–0″	578′–9″	694′–6″	810′–3″
9·0	27′–4″	54′–8″	82′–0″	109′–4″	218′–8″	328′–0″	437′–6″	546′–8″	656′–0″	765′–6″
9·5	25′–11″	51′–10″	77′–9″	103′–8″	207′–4″	311′–0″	414′–8″	518′–4″	622′–0″	725′–8″
10·0	24′–8″	49′–3″	73′–11″	98′–6″	197′–0″	295′–6″	394′–0″	492′–2″	591′–0″	689′–6″
10·5	23′–6″	46′–11″	70′–5″	93′–9″	187′–6″	281′–3″	375′–0″	468′–9″	562′–6″	656′–3″
11·0	22′–2″	44′–4″	66′–6″	88′–8″	177′–4″	266′–0″	354′–8″	443′–4″	532′–0″	620′–8″
11·5	21′–4″	42′–8″	64′–0″	85′–4″	170′–8″	256′–0″	341′–4″	436′–8″	512′–0″	597′–4″
12·0	20′–6″	41′–0″	61′–6″	82′–0″	164′–0″	246′–1″	328′–0″	410′–0″	492′–2″	574′–0″
12·5	19′–9″	39′–5″	59′–2″	78′–9″	157′–6″	236′–3″	315′–0″	393′–9″	472′–6″	551′–3″

TABLE OF FREQUENCIES WITH DIMENSIONS OF RESONANT WIRE LENGTHS FOR AERIAL CONSTRUCTION (CONTINUED)

FREQUENCY in Megacycles	¼ WAVELENGTH LONG	½ WAVELENGTH LONG	¾ WAVELENGTH LONG	1 WAVELENGTH LONG	2 WAVELENGTHS LONG	3 WAVELENGTHS LONG	4 WAVELENGTHS LONG	5 WAVELENGTHS LONG	6 WAVELENGTHS LONG	7 WAVELENGTHS LONG
13·0	18'—11"	37'—9"	56'—8"	75'—6"	151'—0"	226'—6"	302'—0"	377'—6"	453'—0"	528'—6"
13·5	18'—3"	36'—5"	54'—8"	72'—10"	145'—8"	218'—6"	291'—4"	364'—2"	437'—0"	509'—10"
14·0	17'—7"	35'—2"	52'—9"	70'—4"	140'—8"	211'—0"	281'—3"	351'—8"	422'—0"	492'—2"
16·0	15'—5"	30'—9"	46'—1"	61'—6"	123'—0"	184'—6"	246'—1"	307'—6"	368'—0"	430'—6"
18·0	13'—8"	27'—4"	41'—0"	54'—8"	109'—4"	164'—0"	218'—8"	273'—4"	328'—0"	382'—8"
20·0	12'—4"	24'—8"	36'—0"	49'—3"	98'—6"	147'—9"	197'—0"	246'—1"	295'—6"	344'—9"
22·0	11'—3"	22'—5"	33'—8"	44'—9"	89'—6"	134'—3"	179'—0"	223'—9"	268'—6"	313'—3"
24·0	10'—3"	20'—6"	30'—9"	41'—0"	82'—0"	123'—0"	164'—0"	205'—0"	246'—1"	287'—0"
26·0	9'—6"	18'—11"	28'—5"	37'—10"	75'—8"	113'—6"	151'—4"	189'—2"	227'—0"	264'—10"
28·0	8'—9"	17'—6"	26'—3"	35'—1"	70'—2"	105'—3"	140'—4"	175'—5"	210'—6"	246'—1"
30·0	8'—3"	16'—5"	24'—8"	32'—10"	65'—8"	98'—6"	131'—4"	164'—2"	197'—0"	229'—10"
35·0	7'—0"	14'—1"	21'—1"	28'—2"	56'—4"	84'—6"	112'—8"	140'—10"	169'—0"	197'—2"
40·0	6'—1"	12'—3"	18'—4"	24'—7"	49'—2"	73'—9"	98'—4"	122'—11"	147'—6"	172'—1"
50·0	4'—11"	9'—10"	14'—9"	19'—8"	37'—4"	59'—6"	74'—8"	96'—4"	118'—0"	133'—8"
60·0	4'—1¼"	8'—2½"	12'—3¾"	16'—5"	32'—10"	49'—3"	65'—8"	82'—1"	98'—6"	114'—11"
70·0	3'—9"	7'—6¼"	11'—3¼"	15'—0½"	30'—1"	45'—1½"	60'—2"	75'—2½"	90'—3"	105'—3½"
80·0	3'—2"	6'—1¾"	9'—3¾"	12'—3½"	24'—7"	36'—10½"	49'—2"	61'—5½"	73'—9½"	86'—0½"
90·0	2'—8¾"	5'—5½"	8'—2¼"	10'—11"	21'—10"	32'—9"	43'—8"	54'—7"	65'—6"	76'—5"
100·0	2'—5½"	4'—10½"	7'—4½"	9'—10"	19'—8"	29'—6"	39'—4"	49'—2"	59'—0"	68'—10"
120·0	2'—0½"	4'—1¼"	6'—1¾"	8'—2½"	16'—5"	24'—7½"	32'—10"	41'—0½"	49'—3"	57'—5½"
140·0	1'—9"	3'—6"	5'—3"	7'—0¼"	14'—0½"	21'—0¾"	28'—1"	35'—1¼"	42'—1½"	49'—1¾"
160·0	1'—7"	3'—1¾"	4'—8¾"	6'—3½"	12'—7"	18'—10½"	25'—2"	31'—5½"	37'—9"	44'—0½"
180·0	1'—4¾"	2'—9½"	4'—2¼"	5'—7"	11'—2"	16'—9"	22'—4"	27'—11"	33'—6"	39'—1"
200·0	1'—2¾"	2'—5½"	3'—8¼"	4'—11"	9'—10"	14'—9"	19'—8"	24'—7"	29'—6"	34'—5"
250·0	1'—0"	1'—11¾"	2'—11¾"	3'—11¼"	7'—10½"	11'—9¾"	15'—9"	19'—8¼"	23'—7½"	27'—6¾"
300·0	0'—9⅞"	1'—7½"	2'—5½"	3'—3½"	6'—7"	9'—10½"	13'—2"	16'—5½"	19'—9"	23'—0½"

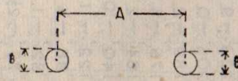
TRANSMISSION AND FEEDER LINE FORMULAS.

Two Wire Line.

Let A = Wire centre spacing in inches.
B = Wire diameters in inches.
C = Line impedance in ohms.
D = Capacity of twin line feeder in mmf. per foot.
E = Inductance of twin line feeder in millihenries per foot.

$$C = 276.36 \left\{ \log (2A \div B) \right\}. \quad D = 3.679 \div \left\{ \log (2A \div B) \right\}.$$

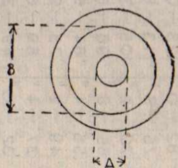
$$E = .2812 \left\{ \log (2A \div B) \right\}.$$



Concentric Line.

A and B are given in inches.

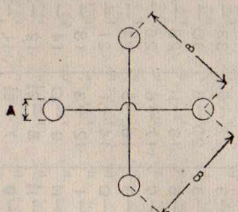
$$C = 138.18 \left\{ \log (B \div A) \right\} \text{ ohms.}$$



Double Twin Line.

A and B are given in inches.

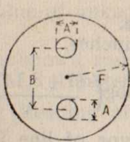
$$C = 138.18 \left\{ \log (1.41421\, B \div A) \right\} \text{ ohms.}$$



Shielded Twin Line.

A, B and F are given in inches.

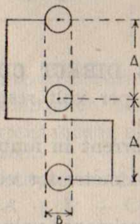
$$C = 276.36 \log \frac{2B}{A} \left\{ \left\{ 1 - (B \div 2F)^2 \right\} \div \left\{ 1 + (B \div 2F)^2 \right\} \right\} \text{ ohms.}$$



Twin Single Line.

A and B are given in inches.

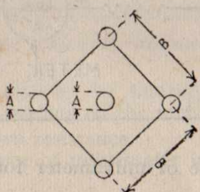
$$C = 207.3 \left\{ \log (1.587401A \div B) \right\} \text{ ohms.}$$



Square Concentric Line.

A and B are given in inches.

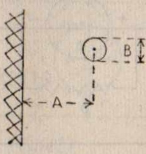
$$C = 171.71 \left\{ \log (1.148\ B \div A) \right\} \text{ ohms.}$$



Single Wire Line.

A and B are given in inches.

$$C = 138.18 \left\{ \log (4\ A \div B) \right\} \text{ ohms.}$$

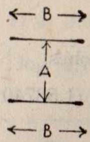


Parallel Thin Strip Foil Line.

A and B are given in inches.

$$C = 1188 \div \left[1 + 2.3 \log \left\{ 2.3 \log\left(\frac{(1+3.142B)}{A} \right) + \frac{3.142B}{A} + 1 \right\} + \frac{3.142B}{A} \right]$$

The formula for this type of line is only true when B is much greater than A.



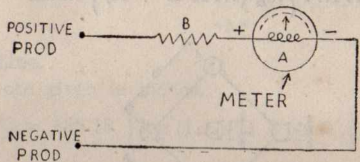
METER FORMULAS FOR DIRECT CURRENT MEASUREMENTS.

(*a*) To find the ohms. per volt resistance of a voltmeter. This value is equal to :—

1 ÷ full scale current in amperes.

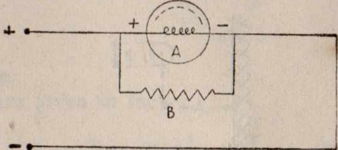
(*b*) To increase range of meter for voltage reading by any desired multiplier.

Let B = multiplier resistance value in ohms.
A = Total meter resistance in ohms.
Then B = (Required full scale reading in volts ÷ by the full scale meter current in amperes).



(*c*) To increase range of milliameter for current reading by any desired multiplier.

Let C = Required multiplying factor.
B = Shunt resistance value in ohms.
A = Total meter resistance in ohms.
Then B = A ÷ (C — 1).

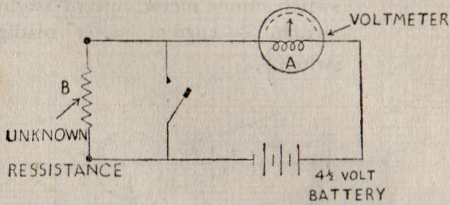


(*d*) To find ohmage value of unknown resistance by using a voltmeter and battery.

Let B = value of unknown resistance.

A = resistance of voltmeter in ohms.

Then B = A $\left\{ \text{(Reading of voltmeter with closed switch} \div \text{Reading of voltmeter with open switch)} - 1 \right\}$



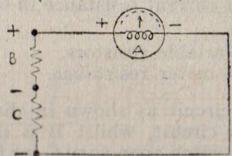
(*e*) To find value of universal current shunts.

Let D = required multiplier factor.

C + B = total resistance in ohms. for lowest shunted current range required.

A = meter resistance in ohms.

$$B = (A + B + C) \div D.$$



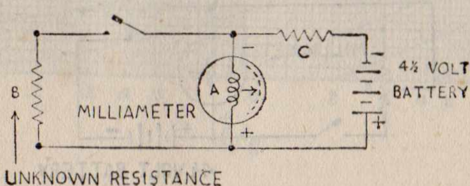
(*f*) To find ohmage value of unknown resistance by means of milliameter and battery.

Let C = series resistor for limiting battery current so as to give a reading on the meter scale when switch is open.

B = unknown resistance.

A = resistance of milliameter in ohms.

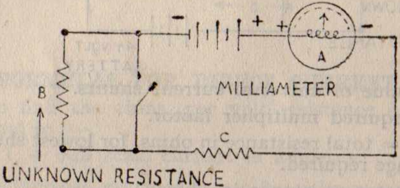
Then B = $\left\{ \text{Switch closed meter current reading} \div \text{(switch open meter current reading minus switch closed meter current reading)} \right\}$.



(*g*) To find ohmage value of unknown resistance by means of milliameter, battery and any known resistor.

Let C = known resistance value in ohms.
B = unknown resistance value in ohms.
A = Meter resistance in ohms.

Then B = {C + A} {(Meter current reading with closed switch minus meter current reading with open switch) ÷ current meter reading with open switch}.

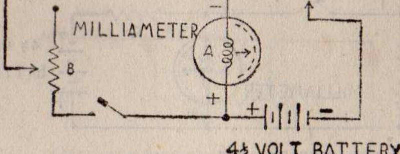


(*h*) To find the direct current resistance in ohms. of an unidentified voltmeter or milliameter.

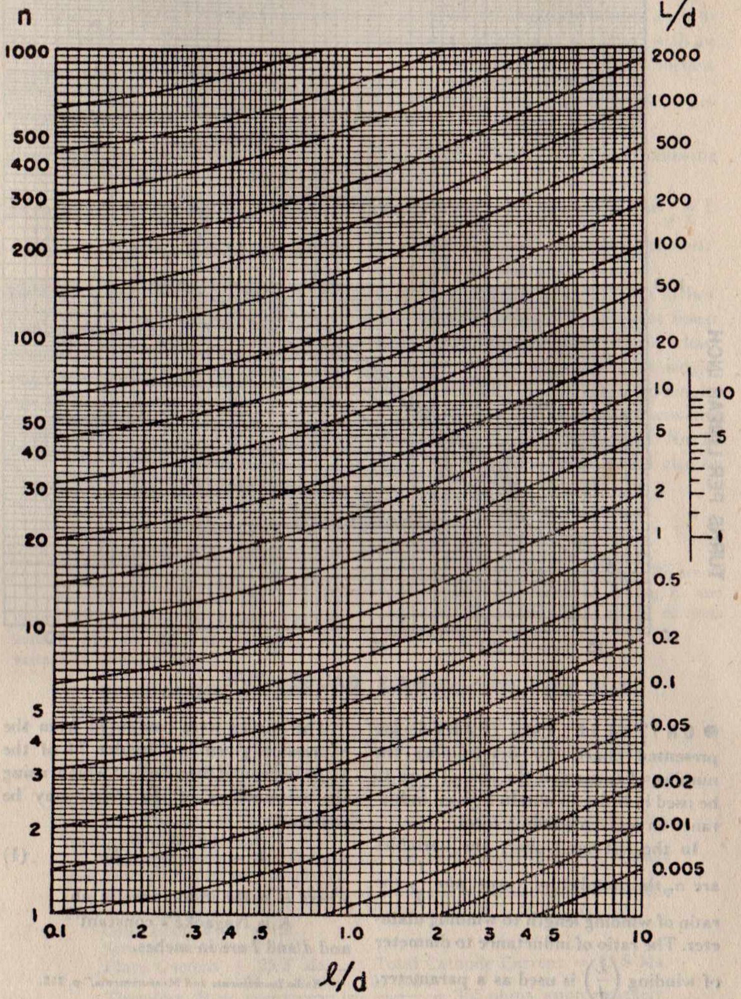
Let C and B = Variable resistors.
A = unknown meter resistance.

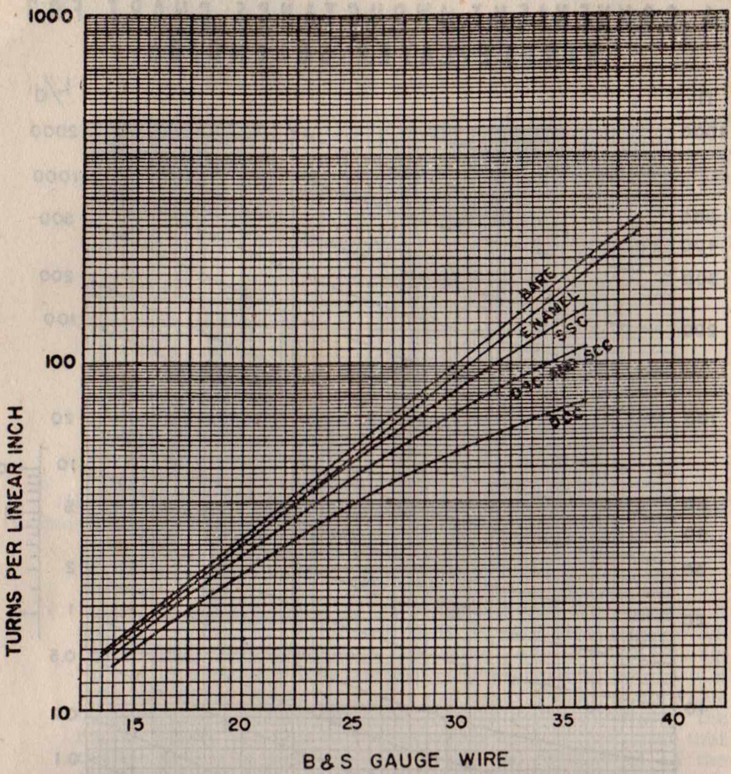
Then connect circuit as shown in diagram with resistor C only being used in circuit, whilst B is disconnected by switch being open. With switch open vary C for full scale meter reading, then bring resister B into circuit by closing switch, and vary B until the meter reading returns to half scale. Then, if the value of resistance B at this setting is checked by an ohmmeter, the reading shown is equal to the resistance of A. It is vital that resistance C is of sufficiently high value to prevent an off the scale meter reading. If the full scale current of the meter is known, it is easy to calculate value of C by the following formula :—

C = (1,000 times testing battery voltage used) ÷ (meter full scale current in milliamperes).



A CONVENIENT INDUCTANCE CHART FOR SINGLE-LAYER SOLENOIDS





● **ON THESE TWO PAGES** are presented charts for determining the number of turns and the size of wire to be used in order to obtain a given inductance on a given winding form.

In the left-hand chart the variables are n, the number of turns, and $\frac{l}{d}$, the ratio of winding length to winding diameter. The ratio of inductance to diameter of winding $\left(\frac{L}{d}\right)$ is used as a parameter.

The curves were computed from the expression given in Circular 74 of the U. S. Bureau of Standards,* which, using the terminology of the chart, may be written,

$$L = \frac{.02508\ n^2 d^2}{l} K \qquad (1)$$

where L is the inductance in μh

K is Nagaoka's constant

and d and l are in inches.

* "Radio Instruments and Measurements," p. 252.

For a given inductance the number of turns is then,

$$n = \sqrt{\left(\frac{L}{d}\right)\left(\frac{l}{d}\right)(39.88)\left(\frac{l}{K}\right)} \quad (2)$$

This form of the expression is particularly convenient because, in designing coils, the engineer usually starts with a given coil form ($\frac{l}{d}$ known) and needs a given inductance L ($\frac{L}{d}$ easily calculated).

Since Nagaoka's constant depends on the ratio $\frac{l}{d}$, the use of this ratio for the horizontal scale makes all the curves parallel, so that, in plotting them, only one curve need be calculated. The other can be drawn from a template.

For interpolating between curves, a logarithmic scale covering one decade of $\frac{L}{d}$ is shown at the right of the chart.

The second chart is plotted from standard winding data published by wire manufacturers.

As an example of the use of these charts, consider the problem of designing a coil of 100 μh inductance on a winding form two inches in diameter, with an available winding space of two inches. The quantity $\frac{l}{d}$ is unity and $\frac{L}{d}$ is 50. Entering the chart at $\frac{L}{d} = 50$ and following down the curve to the vertical line $\frac{l}{d} = 1$ we find that n, as indicated by the left hand vertical scale, is 54 turns.

With a winding space of two inches this is equivalent to 27 turns per linear inch, close wound. The second chart shows that No. 18 enamel or single silk-, No. 20 double-silk-, or single cotton- or No. 22 double-cotton-covered wire would be used close wound. No. 25 bare wire, double spaced, could also be used.

BIAS RESISTANCE.

Grid Leak Bias.

$Vg = Ig \times Rg \qquad Rg = \frac{Vg}{Ig} \qquad Rg = \frac{Vg - E}{Ig}$

Where Rg = grid leak resistance, Vg = bias voltage, Ig = d.c. grid current, and E = voltage of series battery.

Cathode Bias.

$Rg = \frac{Vg}{Ag + As + Aa}$ where Vg & Rg are as above, and Ag, As, and Aa are grid, screen, and anode currents respectively.

CALCULATION OF CORRECT RESISTOR FOR SELF BIAS.

From Ohms. law :—

$$R = \frac{\text{Grid Bias Voltage} \times 1{,}000.}{\text{Total Cathode Current in Ma} \times \text{number of Valves involved.}}$$

For Triodes total cathode current = plate current.

For Pentodes and Tetrodes, total cathode current = plate plus screen currents.

For Pentagrids, total cathode current = plate plus screen plus oscillator plate currents.

Example.—Find Bias Resistor for two 6K6 Valves operating in push pull with 315 volts on the plates.

The following data is obtained from valve characteristics for the 6K6 from Bernards "Radio Valve Manual, No. 30," price 3/6.

Grid Bias = 21 volts.

Screen Current = 4 Ma.

Plate Current = 25.5 Ma. $\therefore$ Total Cathode Current = 29.5 Ma.

Therefore, $R = \frac{21 \times 1{,}000}{29.5 \times 2} = \frac{21{,}000}{59} = 355$ ohms. approximately.

When over biased operation is used the advised bias resistor value will be shewn under Ratings and current applications for the type of Valve involved in Bernard's "Radio Valve Manual."

TIME CONVERSION LOG. (TIMES IN G.M.T.)

ALEUTIAN ISLANDS	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12m	11p	10p	9p	8p	7p
ALASKA (Hawaii Is. Less ½ hr.)	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12m	11p	10p	9p	8p
YUKON.	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12m	11p	10p	9p
PACIFIC TIME. Canada & U.S.A.	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12m	11p	10p
MOUNTAIN TIME. " " "	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12m	11p
CENTRAL TIME. " " "	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12m
EASTERN STAN. TIME, " " " Cuba.	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a
ATLANTIC TIME. Canada, Argentine (Venez. less ½ hr.)	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a
BRAZIL	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a
AZORES Is.	3a	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a
ICELAND, W. AFRICA, CANARY Is.	4a	3a	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a
ENGLAND, FRANCE, SPAIN, (HOLLAND add 20 mins.)	5a	4a	3a	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a
NORWAY, SWEDEN, GERMANY, ITALY.	6a	5a	4a	3a	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a
RUSSIA (Moscow) EGYPT, S. AFRICA.	7a	6a	5a	4a	3a	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a
MADAGASCAR, ARABIA, ABYSSINIA, PERSIA.	8a	7a	6a	5a	4a	3a	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a	9a
CENTRAL RUSSIA, TURKESTAN.	9a	8a	7a	6a	5a	4a	3a	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a	10a
INDIA, (Add 30 mins.)	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n	11a
BURMA, TIBET, E. INDIA, (Calcutta).	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12n	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p	12n
SUMATRA, (Java, add 20 mins.)	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p	1p
CHINA, WEST AUSTRALIA.	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12n	11p	10p	9p	8p	7p	6p	5p	4p	3p	2p
JAPAN, (CENTRAL AUSTRALIA, Add 30 mins.)	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12n	11p	10p	9p	8p	7p	6p	5p	4p	3p
EAST AUSTRALIA, NEW GUINEA.	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p	4p
SOLOMAN Is., NEW HEBRIDES.	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12m	11p	10p	9p	8p	7p	6p	5p
NEW ZEALAND, (Less 30 mins.)	5p	4p	3p	2p	1p	12n	11a	10a	9a	8a	7a	6a	5a	4a	3a	2a	1a	12n	11p	10p	9p	8p	7p	6p

TO FIND TIME AND DAY IN ANY COUNTRY OF THE WORLD (G.M.T.).

Select horizontal line opposite the country in which you live (using particular time band mentioned for your locality), and move along this line to the nearest hour as shown by your watch, then move up or down the vertical column to the line opposite the country in which you desire the time. The figure at the intersection is the time required ("a" denotes a.m.; "p" denotes p.m.).

To find the day, the rule is—if when moving up or down the vertical column you pass the zig-zag line in an upward movement, the time indicated will be "yesterday," or one day behind. If in moving downward on the vertical column you cross the zig-zag line, the time indicated is "to-morrow," or one day ahead.

Example.

If it is 5 p.m. on Wednesday in London (G.M.T.), what time and day is it in New Zealand? Follow horizontally along the line marked "ENGLAND" to 5 p.m. and drop down from this point to the New Zealand horizontal line. The intersection gives the time as 5 a.m. Having crossed the heavy zig-zag line in a downward direction *the time is one day ahead. HENCE IT IS 5 A.M. THURSDAY MORNING IN NEW ZEALAND.*

THE CIRCULAR MIL.

The circular mil. is a modern and facile method of calculating area of wire cross sections and is equal to the square of the wire diameter given in mils., which are the one thousandth part of an inch. Example : 26 S.W.G. wire is equal to .018″ diameter ; the circular mil. area of this size wire is calculated thus, $18 \times 18 = 324$. Therefore, the circular mil. area is equal to 324 mils.

The circular mil. foot is a piece of wire one foot in length by one circular mil. in area.

Symbols of Time and Relation to G.M.T.

VARIOUS PARTS OF THE WORLD:

L.S.T.	Local Standard Time.	
G.M.T.	Greenwich Mean Time.	
B.S.T.	British Summer Time (August 9th—April)	1 hour ahead of G.M.T. DURING WINTER.
D.B.S.T.	Double British Summer Time. (April—August 8th).	2 hours ahead of G.M.T. DURING SUMMER.
C.E.T.	Central European Time.	1 hour ahead of G.M.T.
S.A.T.	South African Time.	2 hours " " "
I.S.T.	Indian Standard Time.	5½ " " " "
E.A.S.T.	Eastern Australian Standard Time.	10 " " " "
J.S.T.	Japanese Standard Time.	9 " " " "
H.S.T.	Haiwaiian Standard Time.	10½ " earlier than G.M.T.
B.G.T.	British Guiana Time.	

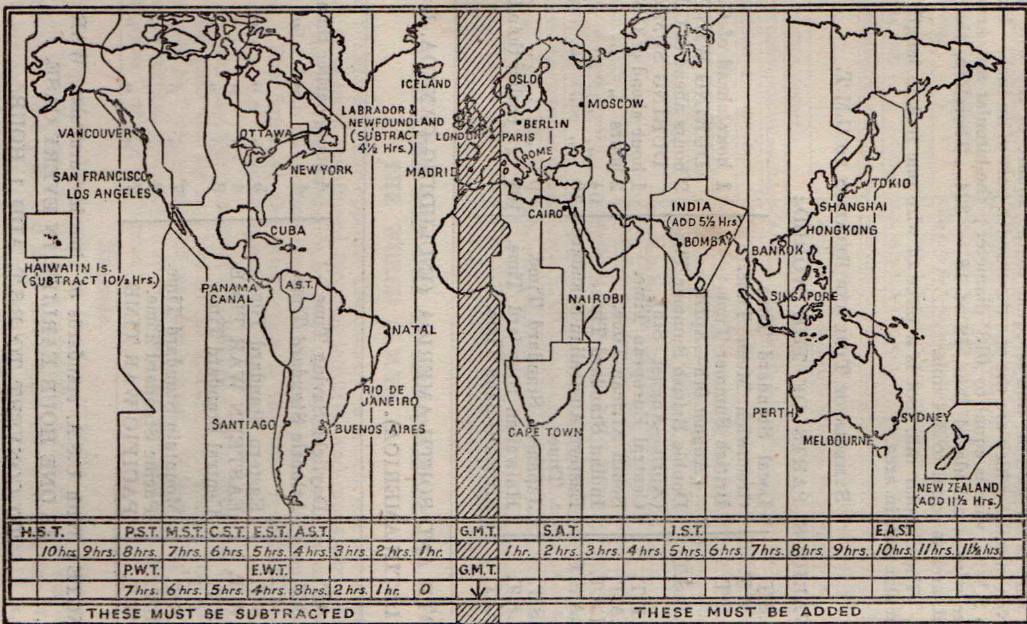
NORTH AND SOUTH AMERICA (INCLUDING CANADA, U.S.A., LATIN-AMERICA).

D.S.T.	Daylight Saving Time.	4 hours earlier than G.M.T.
A.S.T. or A.T.	Atlantic Standard Time.	4 " " " "
E.S.T.	Eastern Standard Time.	5 " " " "
E.W.T.	EASTERN WAR TIME.	4 " " " "
C.S.T. or C.T.	Central Standard Time.	6 " " " "
M.S.T.	Mountain Standard Time.	7 " " " "
P.S.T.	Pacific Standard Time.	8 " " " "
P.W.T.	PACIFIC WAR TIME.	7 " " " "

NOTE : With U.S.A. standards of time in particular, WAR TIME IS ONE HOUR EARLIER IN EVERY CASE.

TO CONVERT TO B.S.T. ADD 1 HOUR.
TO CONVERT TO D.B.S.T. ADD 2 HOURS.

TIME ZONE AND CONVERSION CHART



TO CONVERT G.M.T. TO B.S.T.—— ADD 1 HOUR
TO CONVERT G.M.T. TO D.B.S.T.— ADD 2 HOURS

Time and Relation of G.M.T. with Other Parts of the World.

Most Short-wave schedules make use of the 24-hour system for indicating times. Thus, 00.00 is midnight or zero hour, and 12.00 corresponds to noon. The time 7 a.m. is denoted thus : 07.00, 10 a.m. thus, 10.00; 4 p.m. by 16.00, 7 p.m. by 19.00, 9 p.m. by 21.00, and 11 p.m. by 23.00. Then follows 00.00 or zero hour

The conversion of Greenwich Mean Time to that of other places throughout the world and vice versa usually gives the beginner trouble and for this purpose reference should be made to the page detailing the SYMBOLS OF TIME and their equivalents, and the TIME ZONE AND CONVERSION CHART.

The earth rotates through 360 degrees in 24 hours, that is, through 15 degrees in one hour. Thus, one hour difference of mean time at two places denotes that they differ 15 degrees in LONGITUDE. As the earth rotates from West to East, places—

(1) East of Greenwich are AHEAD OF G.M.T.

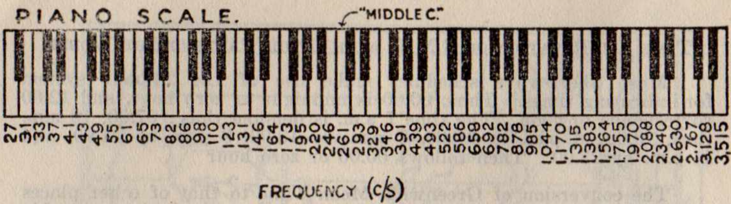
(2) and those West of Greenwich, EARLIER THAN G.M.T.

Many stations announce times locally, and these should be noted, and comparison and reckoning made when converting to G.M.T. (or B.S.T. and D.B.S.T.). Thus, if the listener happened to be listening to Sydney, Australia, on 31.28 metres at 19.00 or 7 p.m. D.B.S.T., Sunday, August 17th, the time by Eastern Australian Standard Time would be 03.00 MONDAY, AUGUST 18th. Similarly, E.S.T., or Eastern Standard Time in New York, is 5 hours earlier that G.M.T., and Eastern War Time, 4 hours earlier, and not only the time but the date should be considered when reckoning.

As will be seen from the Time Symbol Table and the Time Zone Chart, Hawaii, British Guiana, Labrador, Newfoundland, India, and New Zealand have their own standard times. Venezuela is included in the A.S.T. Zone, and South Africa is a zone by itself.

In China, Afghanistan, Iran, Arabia, Abyssinia, Borneo, Sumatra, Greenland, parts of New Guinea, and certain other parts, either the legal time is not known or no legal time is kept.

In particular, it should be noted that with her entry into the war, the United States has adopted "WAR TIME." Eastern War Time is 4 hours earlier than G.M.T., and Pacific War Time is 7 hours earlier. Again, Time in Britain is as follows : During the Winter B.S.T. is 1 hour ahead of G.M.T., and during the Summer D.B.S.T. is 2 hours ahead of G.M.T. Thus : 15.00 B.S.T. corresponds to 14.00 G.M.T., and 15.00 D.B.S.T. corresponds to 13.00 G.M.T.



Piano scale showing the frequencies to which the keys are usually tuned, which is to a slightly different pitch from that used by physicists, based on Middle C = 256 c/s., and such scales are apt to be misleading. Frequencies of black keys can be obtained by multiplying the frequency of the white key below it by 1.05946. This scale is useful for the approximate calibration of oscillators and rough determination of resonant frequencies, etc.

VIBRATIONS AND THE MUSICAL SCALE.

Ratio of vibrations of 1 octave in any part of the Musical Scale :—

Note	C.	D.	E.	F.	G.	A.	B.	C.
Ratio	1	9/8	5/4	4/3	3/2	5/3	15/8	2
Decimal Ratio ...	1	1.125	1.25	1.33	1.5	1.66	1.875	2
Tonic Sol Fa Scale	Doh	Ray	Me	Fah	Soh	Lah	Te	Doh

* STROBOSCOPE TABLE.

FREQUENCY of Supply (c/s.)		15	25	33	40	50	60	80	90	100
RECORD SPEED	78 r.p.m.	23	38	51	62	77	92	123	139	154

To find the number of black spokes required for any speed and a.c. mains-frequency, the formula is :—

$$N \; \ldots = \frac{120.f}{r}$$

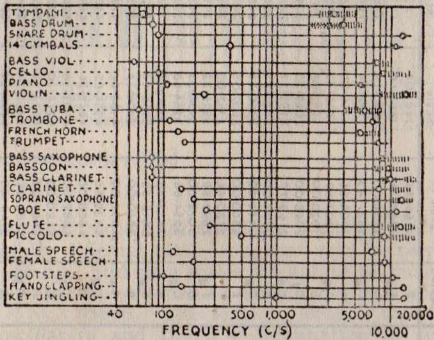
where N = number of black spokes.
f = mains supply frequency.
r = speed of record required.

N.B.—180 black spokes are required at 33⅓ r.p.m. for 50 c/s. mains.

·VIBRATIONS AND THE MUSICAL SCALES·

1 Note on Scale.	2 Musical Scale.	3 International Chromatic Scale.	4 American Chromatic Scale.	1 Note on Scale.	2 Musical Scale.	3 International Chromatic Scale.	4 American Chromatic Scale.	1 Note on Scale.	2 Musical Scale.	3 International Chromatic Scale.	4 American Chromatic Scale.
C_0	16·00	16·17	16·35	D	144·00	145·16	146·83	F	1365·33	1381·04	1396·91
C#	16·95	17·13	17·32	D#	152·56	153·80	155·56	F#	1446·29	1463·16	1479·98
D	18·00	18·15	18·35	E	160·00	162·94	164·81	G	1536·00	1550·16	1567·98
D#	19·07	19·22	19·45	F	170·66	172·63	174·61	G#	1627·33	1642·34	1661·22
E	20·00	20·37	20·60	F#	180·79	182·89	185·00	A	1706·66	1740·00	1760·00
F	21·33	21·58	21·83	G	192·00	193·77	196·00	A#	1807·69	1843·47	1864·66
F#	22·60	22·86	23·12	G#	203·42	205·29	207·65	B	1920·00	1953·08	1975·53
G	24·00	24·22	24·50	A	213·33	217·50	220·00	C_7	2048·00	2069·22	2093·00
G#	25·43	25·66	25·96	A#	225·96	230·43	233·08	C#	2169·77	2192·26	2217·46
A	26·66	27·19	27·50	B	240·00	244·14	246·94	D	2304·00	2322·62	2349·32
A#	28·25	28·80	29·14	Middle C_4	256·00	258·65	261·63	D#	2441·00	2460·73	2489·02
B	30·00	30·52	30·87	C#	271·22	274·03	277·18	E	2560·00	2607·05	2637·02
C_1	32·00	32·33	32·70	D	288·00	290·33	293·66	F	2730·66	2762·08	2793·83
C#	33·90	34·25	34·65	D#	305·12	307·59	311·13	F#	2892·58	2926·32	2959·96
D	36·00	36·29	36·71	E	320·00	325·88	329·63	G	3072·00	3100·33	3135·96
D#	38·14	38·45	38·89	F	341·33	345·26	349·23	G#	3254·66	3284·68	3322·44
E	40·00	40·74	41·20	F#	361·57	365·79	369·99	A	3413·33	3480·00	3520·00
F	42·66	43·16	43·65	G	384·00	387·54	392·00	A#	3615·38	3686·93	3729·31
F#	45·20	45·72	46·25	G#	406·83	410·59	415·30	B	3840·00	3906·17	3951·07
G	48·00	48·44	49·00	A	426·66	435·00	440·00	C_8	4096·00	4138·44	4186·01
G#	50·85	51·32	51·91	A#	451·92	460·87	466·16	C#	4339·55	4384·52	4434·92
A	53·33	54·38	55·00	B	480·00	488·27	493·88	D	4608·00	4645·24	4698·64
A#	56·49	57·61	58·27	C_5	512·00	517·31	523·25	D#	4882·00	4921·46	4978·04
B	60·00	61·03	61·74	C#	542·44	548·07	554·37	E	5120·00	5214·10	5274·04
C_2	64·00	64·66	65·41	D	576·00	580·66	587·33	F	5461·33	5524·16	5587·66
C#	67·81	68·51	69·30	D#	610·25	615·18	622·25	F#	5785·16	5852·64	5919·92
D	72·00	72·58	73·42	E	640·00	651·76	659·26	G	6144·00	6200·66	6271·92
D#	76·28	76·90	77·78	F	682·66	690·52	698·46	G#	6509·32	6569·36	6644·88
E	80·00	81·47	82·41	F#	723·15	731·56	739·99	A	6826·66	6960·00	7040·00
F	85·33	86·31	87·31	G	768·00	775·08	783·99	A#	7230·77	7373·86	7458·62
F#	90·39	91·45	92·50	G#	813·67	821·17	830·61	B	7680·00	7812·34	7902·14
G	96·00	96·89	98·00	A	853·33	870·00	880·00	C_9	8192·00	8276·88	8372·02
G#	101·71	102·65	103·83	A#	903·85	921·73	932·33	C#	8679·10	8769·04	8869·84
A	106·66	108·75	110·00	B	960·00	976·54	987·77	D	9216·00	9290·48	9397·28
A#	112·98	115·22	116·54	C_6	1024·00	1034·61	1046·50	D#	9764·00	9842·92	9956·08
B	120·00	122·07	123·47	C#	1084·89	1096·13	1108·73	E	10240·00	10428·20	10548·08
C_3	128·00	129·33	130·81	D	1152·00	1161·31	1174·66	F	10922·66	11048·32	11175·32
C#	135·61	137·02	138·59	D#	1220·50	1230·37	1244·51	F#	11570·32	11705·28	11839·84
				E	1280·00	1303·53	1318·51	G	12288·00	12401·32	12543·84

FREQUENCY RANGES OF VARIOUS SOUND SOURCES.



RADIO VALVE FORMULAS.

When A = Grid Voltage
B = Mutual Conductance in mhos.
C = Dynamic Anode resistance in ohms.
D = Anode Voltage.
E = Amplification factor.
F = Anode current.
G = Anode load resistance.
H = Filament or Cathode current.
K = Signal Voltage.
L = Alteration in D ÷ alteration in F.

Maximum power output = $(KE)^2 \div 4\ C$.

E = alteration D ÷ alteration in A.

Stage Gain = $E\ [G \div (C+G)]$.

B = alteration in F ÷ alteration in A.

Voltage output = $E\ [(G \times K) \div (G + C)]$.

Cathode resistor = A ÷ H ohms.

Power output = $[(K \times E) \div (G + C)]^2 \times G$.

Highest undistorted power output = $(K \times E)^2 \div (4.5\ C.)$.

PROPERTIES AND CHARACTERISTICS OF
RESISTANCE MATERIALS

MATERIAL	Resistance relative to COPPER	Resistance in ohms per circular Mil-Foot.	Temperature Coefficient of Resistivity per °C	Resistance in Microhms per cubic Centimetre	Resistance in ohms per square Mil-Foot	Resistance in Microhms per cubic Inch
Copper.	1·0	10·3	+·0039	1·724	8·0	0·68
Steel.	6·4	67·4	+·0043	11·2	53·0	4·41
Aluminium.	1·7	16·9	+·0038	2·82	13·0	1·11
Pure Iron.	5·8	60·2	+·005	10·0	47·0	3·94
Silver.	0·9	9·5	+·0037	1·59	7·5	0·63
Gold.	1·3	14·6	+·0035	2·43	11·0	0·94
Platinum.	5·8	60·2	+·0031	10·0	47·0	3·94
Tin.	6·6	67·5	+·0043	11·4	54·0	4·49
Zinc.	3·3	33·8	+·0036	5·7	27·0	2·25
Lead.	12·7	133·0	+·0039	21·9	104·0	8·63
Nickel.	6·0	61·4	+·0059	10·2	48·0	4·02
Advance.	28·4	295·0	+·000014	49·0	232·0	19·31
Eureka.	28·4	295·0	+·000014	49·0	232·0	19·31
Glowray.	58·0	602·0	+·00001	100·0	473·0	39·4
Climax.	50·4	524·0	+·00069	87·0	412·0	34·28
Constantan.	28·4	295·0	+·000014	49·0	232·0	19·31
Excello.	52·8	547·0	+·00017	91·0	430·0	35·86
Ideal.	28·0	295·0	+·000014	49·0	232·0	19·31
Manganin.	25·5	265·0	+·000014	44·0	208·0	17·33
Platinoid.	24·3	253·0	+·0003	42·0	199·0	16·55
Ia.–Ia.	29·6	307·0	–·000024	51·0	241·0	20·1
Tungsten.	3·3	33·8	+·0044	5·7	27·0	2·25
Monel.	24·3	253·0	+·0021	42·0	199·0	16·55
Alumel.	19·1	199·0	+·0011	33·0	156·0	13·10
Chromel.	44·0	458·0	+·00007	76·0	360·0	29·94
Copel.	28·4	295·0	+·000001	49·0	232·0	19·31
Carbon.	2030·0	21070·0	–·0005	3500·0	16555·0	1379·0
Brightray.	58·0	602·0	+·00019	100·0	473·0	39·4
Dullray.	50·4	525·0	+·0007	87·0	412·0	29·94
Cupro.	15·0	157·0	+·0003	26·0	123·0	10·24
No-Mag.	81·8	848·0	+·00091	141·0	667·0	55·55
Nicrome 5%	52·8	547·0	+·00105	91·0	430·0	35·86
Nicrome 15%	63·8	662·0	+·0002	110·0	520·0	43·34
" 80%20%	63·2	656·0	+·0001	109·0	515·0	42·95
Corronil.	29·0	301·0	+·00065	50·0	236·0	19·7
Redray.	53·9	559·0	+·00026	93·0	440·0	36·65
Mangonic.	8·6	90·2	+·0035	14·95	74·0	5·87
B.B.	23·2	241·0	+·00021	40·0	189·0	15·76
Ferry.	27·8	289·0	+·00002	48·0	227·0	18·91
Zodiac.	20·9	217·0	+·00023	36·0	170·0	14·19
Tarnac.	22·6	235·0	+·000017	39·0	184·0	15·36
Ferrozoid.	48·8	506·0	+·00076	84·0	398·0	33·09
Cromaloy. 2	63·8	662·0	+·00013	110·0	520·0	43·34
" 3	53·9	559·0	+·00013	93·0	440·0	36·65
" 4	58·0	602·0	+·00008	100·0	473·0	39·4
Nickel-Silver. 1	18·0	187·0	+·00027	31·0	147·0	12·22
" " 4	12·2	127·0	+·00047	21·0	100·0	8·28
Platinum-Iridium.	18·0	187·0	+·00082	31·0	147·0	12·22
" -Silver.	18·2	190·0	+·00028	31·4	148·0	12·38
Kromore.	52·2	542·0	+·0002	90·0	426·0	35·46

RESISTANCE WIRE DATA

S.W.G.	NICKEL SILVER WIRE — RESISTANCE — Ohms per 1000 ft. approx.		Amperage required for temperature rise of		MANGANIN WIRE — RESISTANCE — Ohms per 1000 ft. approx.		Amperage required for temperature rise of		PLATINOID WIRE — RESISTANCE — Ohms per 1000 ft. approx.		Amperage required for temperature rise of		Dia. in INCHES
	Ohms per 1000 ft. approx.	Ohms per Ounce approx.	200°C	100°C	Ohms per 1000 ft. approx.	Ohms per Ounce approx.	200°C	100°C	Ohms per 1000 ft. approx.	Ohms per Ounce approx.	200°C	100°C	
8	—	—	—	—	9·6	·008	61	39	9·5	·008	—	—	·160
10	—	—	—	—	15·0	·018	39	27	14·9	·018	—	—	·128
12	—	—	—	—	22·7	·042	28	21	22·7	·042	—	—	·104
14	—	—	—	—	38·3	·12	17·5	11·7	38·4	·12	—	—	·080
16	34	·17	14·2	8·1	59·6	·30	10·1	7·2	59·7	·31	—	—	·064
18	59	·53	9·4	6·1	107	·95	7·6	5·1	108	·95	—	—	·048
20	109	1·7	6·3	4·1	190	2·9	5·1	3·6	189	2·9	—	—	·036
21	—	—	—	—	241	4·9	—	—	—	—	—	—	·032
22	180	5·04	4·2	3·1	315	8·8	3·8	2·6	316	8·7	—	—	·028
23	—	—	—	—	428	15	—	—	—	—	—	—	·024
24	292	12·25	—	—	510	21	—	—	509	22	—	—	·022
25	—	—	—	—	617	32	—	—	—	—	—	—	·020
26	437	27·56	—	—	763	48	—	—	764	48	—	—	·018
27	—	—	—	—	918	70	—	—	—	—	—	—	·0164
28	669	64·37	—	—	1166	112	—	—	1165	112	—	—	·0148
30	917	121	—	—	1600	211	—	—	1601	212	—	—	·0124
32	—	—	—	—	2105	367	—	—	2104	367	—	—	·0108
34	—	—	—	—	2935	704	—	—	2933	705	—	—	·0092
36	—	—	—	—	4303	1520	—	—	4305	1520	—	—	·0076
38	—	—	—	—	6918	3900	—	—	6917	3901	—	—	·006
40	—	—	—	—	10762	9530	—	—	10764	9531	—	—	·0048
42	—	—	—	—	15413	19500	—	—	15416	19500	—	—	·004
44	—	—	—	—	24083	48000	—	—	24087	48000	—	—	·0032
46	—	—	—	—	42816	152000	—	—	48819	152000	—	—	·0024

The above data supplied by courtesy of London Electric Wire Co. & Smiths Ltd. (LEWCOS).

NICKEL CHROME 15% WIRES AND TAPES.

Temperature Co-efficient (20° to 500°C.) ... ... 0.000202 per °C.
Specific Resistance ... ... 110 microhms per cm. cube
Comparative Resistance : Copper = Unity 60
Specific Gravity 8.27
Melting Point ... ... 1,400°C.
Tensile Strength—Annealed Rod ... ... 47 tons per sq. inch
Specific Heat—by weight 0.112

NICKEL CHROME 80/20% WIRES AND TAPES.

Temperature Co-efficient (20° to 500°C.) ... ... 0.000098 per °C.
Specific Resistance ... ... 109 microhms per cm. cube
Comparative Resistance : Copper = Unity 61½
Specific Gravity 8.35
Melting Point ... ... 1375°C.
Tensile Strength—Annealed Rod ... ... 59 tons per sq. inch
Specific Heat—by weight 0.106

NICKEL CHROME 15% RESISTANCE TAPE.

Current necessary to maintain a given temperature rise.
Wire held straight and horizontal in air with free radiation.

Size, Inch.	*Resistance per* 1,000 *yards Ohms.*			*Amperes for a temperature rise of*			*Weight per* 1,000 *yards lbs.*
	100 °*C.*	500 °*C.*	1,000 °*C.*	100 °*C.*	500 °*C.*	1,000 °*C.*	
.025 × .002...	34,713	37,380	38,610	0.46	1.27	2.59	0.453
.025 × .003...	22,671	24,413	25,215	0.65	1.65	3.39	0.720
.025 × .004...	15,114	16,275	16,810	0.80	2.11	4.32	1.058
.025 × .006...	10,832	11,665	12,048	0.91	2.61	5.15	1.501
.025 × .008...	7,734	8,328	8,601	1.14	3.14	6.17	2.086
.03125 × .003	17,124	18,440	19,045	0.76	2.04	4.19	0.949
.03125 × .004	12,564	13,529	13,973	0.82	2.48	5.02	1.316
.03125 × .006	7,929	8,538	8,819	1.05	2.95	6.17	2.070
.03125 × .008	6,072	6,539	6,753	1.33	3.76	7.6	2,672
.03125 × .010	4,839	5,211	5,382	1.50	4.13	8.54	3.383
.050 × .004...	8,934	9,620	9,936	1.11	3.30	6.68	1.875
.050 × .006...	5,295	5,702	5,889	1.46	4.23	8.96	3.168
.050 × .008...	3,741	4,028	4,161	1.79	4.87	11.15	4.362
.050 × .010...	2,968	3,196	3,302	2.05	5.73	12.98	5,024

The above data should be regarded as approximate.

This Table is supplied by courtesy of :—
VACTITE WIRE COMPANY LIMITED, LONDON, S.W. 1.

NICKEL CHROME 15% RESISTANCE WIRE.

Current necessary to maintain a given temperature rise.
Wire held straight and horizontal in air with free radiation.

Size S.W. G.	*Diam. Inch*	*M/m.*	*Resistance per 1,000 yards, Ohms.*			*Amperes for a temperature rise of*			*Weight per 1,000 yards, lbs.*
			15.5 °C.	500 °C.	1,000 °C.	100 °C.	500 °C.	1,000 °C.	
16	.064	1.62	493	530	548	6.6	19.3	42.1	34.6
17	.056	1.42	644	693	716	5.4	16.3	35.0	26.4
18	.048	1.21	876	943	974	4.2	13.1	27.8	19.4
19	.040	1.01	1,262	1,359	1,404	3.2	10.0	20.95	13.5
20	.036	0.91	1,557	1,678	1,733	2.7	8.6	17.80	10.9
21	.032	0.81	1,973	2,124	2,194	2.18	6.75	14.05	8.64
22	.028	0.71	2,577	2,774	2,865	1.92	5.72	11.83	6.62
23	.024	0.60	3,507	3,776	3,901	1.66	4.81	9.73	4.86
24	.022	0.55	4,175	4,495	4,643	1.52	4.37	8.74	4.08
25	.020	0.50	5,049	5,438	5,616	1.39	3.93	7.75	3.37
26	.018	0.45	6,232	6,714	6,934	1.23	3.50	6.67	2.73
27	.0164	0.41	7,513	8,090	8,356	1.10	3.16	6.03	2.27
28	.0148	0.37	9,223	9,931	10,260	1.01	2.83	5.30	1.84
29	.0136	0.34	11,180	11,940	12,430	0.95	2.59	4.77	1.56
30	.0124	0.31	13,140	14,150	14,610	0.88	2.32	4.26	1.29
31	.0116	0.29	15,010	16,170	16,700	0.83	2.16	3.92	1.136
32	.0108	0.27	17,320	18,650	19,260	0.78	2.00	3.59	0.985
33	.0100	0.25	20,200	21,760	22,470	0.73	1.84	3.26	0.844
34	.0092	0.23	23,870	25,700	26,550	0.67	1.68	2.95	0.715
35	.0084	0.21	28,630	30,830	31,840	0.62	1.52	2.64	0.596
36	.0076	0.19	34,980	37,670	38,910	0.57	1.27	2.36	0.487
37	.0068	0.17	43,690	47,050	48,590	0.51	1.21	2.07	0.390
38	.0060	0.15	56,140	60,440	62,430	0.47	1.06	1.77	0.304
39	.0052	0.13	74,710	80,450	83,090	0.42	0.91	1.49	0.228
40	.0048	0.12	87,690	94,420	97,530	0.40	0.84	1.38	0.194
41	.0044	0.111	102,700			—	—	—	0.1632
42	.0040	0.101	124,200			—	—	—	0.1353
43	.0036	0.091	153,200			—	—	—	0.1095
44	.0032	0.081	193,900			—	—	—	0.0864
45	.0028	0.071	253,100			—	—	—	0.0663
46	.0024	0.061	344,600			—	—	—	0.0486
47	.0020	0.050	496,200			—	—	—	0.0339
48	.0016	0.040	781,400			—	—	—	0.0214
49	.0012	0.030	1,420,000				—	—	0.0118
50	.0010	0.025	1,985,000			—	—	—	0.0084

The above data should be regarded as approximate.

This Table is supplied by courtesy of :—

VACTITE WIRE COMPANY LIMITED, LONDON, S.W. 1.

NICKEL CHROME 80/20% RESISTANCE WIRE.

Current necessary to maintain a given temperature rise.
Wire held straight and horizontal in air with free radiation.

Size S.W. G.	Diam. Inch.	M/m.	*Resistance per 1,000 yards, Ohms.* 15.5 °C.	500 °C.	1,000 °C.	*Amperes for a temperature rise of* 100 °C.	500 °C.	1,000 °C.	*Weight per 1,000 yards, lbs.*
16	.064	1.62	480	502	503	6.4	18.75	42.5	34.9
17	.056	1.42	627	655	657	5.3	15.50	35.1	26.7
18	.048	1.21	854	893	895	4.3	12.60	28.3	19.6
19	.040	1.01	1,229	1,286	1,289	3.4	10.00	22.1	13.6
20	.036	0.91	1,518	1,587	1,592	2.9	8.60	18.9	11.0
21	.032	0.81	1,937	2,010	2,015	2.4	7.40	16.0	8.73
22	.028	0.71	2,509	2,624	2,631	1.9	6.30	13.4	6.68
23	.024	0.60	3,415	3,574	3,581	1.5	5.20	10.8	4.91
24	.022	0.55	4,065	4,253	4,263	1.3	4.45	9.5	4.12
25	.020	0.50	4,918	5,145	5,157	1.13	3.95	8.35	3.41
26	.018	0.45	6,072	6,350	6,367	0.99	3.50	7.28	2.76
27	.0164	0.41	7,314	7,654	7,673	0.90	3.14	6.45	2.29
28	.0148	0.37	8,978	9,397	9,419	0.80	2.80	5.65	1.86
29	.0136	0.34	10,635	11,129	11,155	0.75	2.55	5.06	1.57
30	.0124	0.31	12,794	13,388	13,420	0.68	2.30	4.50	1.31
31	.0116	0.29	14,619	15,181	15,334	0.64	2.15	4.15	1.147
32	.0108	0.27	16,863	17,647	17,690	0.60	1.99	3.78	0.994
33	.0100	0.25	19,671	20,585	20,634	0.56	1.84	3.44	0.852
34	.0092	0.23	23,229	24,319	24,377	0.52	1.68	3.12	0.721
35	.0084	0.21	27,874	29,172	29,242	0.48	1.51	2.78	0.601
36	.0076	0.19	34,055	35,643	35,729	0.43	1.34	2.48	0.492
37	.0068	0.17	42,531	44,513	44,621	0.39	1.19	2.19	0.394
38	.0060	0.15	54,647	57,190	57,327	0.35	1.03	1.91	0.306
39	.0052	0.13	72,744	76,118	76,302	0.32	0.90	1.63	0.230
40	.0048	0.12	85,369	89,344	89,557	0.30	0.83	1.51	0.196
41	.0044	0.111	95,950			—	—	—	0.1650
42	.0040	0.101	122,860			—	—	—	0.1365
43	.0036	0.091	151,750			—	—	—	0.1107
44	.0032	0.081	192,180			—	—	—	0.0873
45	.0028	0.071	250,910			—	—	—	0.0669
46	.0024	0.061	341,600			—	—	—	0.0492
47	.0020	0.050	491.770			—	—	—	0.0342
48	.0016	0.040	767,230			—	—	—	0.0217
49	.0012	0.030	1,365,150			—	—	—	0.0119
50	.0010	0.025	1,967,080			—	—	—	0.0085

The above data should be regarded as approximate.

This Table is supplied by courtesy of :—

VACTITE WIRE COMPANY LIMITED, LONDON, S.W. 1.

NICKEL CHROME 5% WIRES AND TAPES.

Temperature Co-efficient (20° to 500°C.)	0.00105 per °C.
Specific Resistance	...91 microhms per cm. cube
Specific Gravity	8.13
Melting Point	1,490°C.
Specific Heat—by weight	0.113

NICKEL CHROME 80/20% RESISTANCE TAPE.

Current necessary to maintain a given temperature rise.

Wire held straight and horizontal in air with free radiation.

Size, Inch.	*Resistance per 1,000 yards, Ohms.*			*Amperes for a temperature rise of*			*Weight per 1,000 yards, lbs.*
	100 °C.	500 °C.	1,000 °C.	100 °C.	500 °C.	1,000 °C.	
.025 × .002...	33,567	34,830	34,914	0.61	1.41	2.92	0.482
.025 × .003...	23,422	24,305	24,363	0.68	1.61	3.40	0.681
.025 × .004...	15,132	15,703	15,740	0.75	2.06	4.28	1.058
.025 × .006...	9,963	10,339	10,364	0.83	2.80	5.37	1.623
.025 × .008...	7,395	7,672	7,692	1.11	3.31	6.27	2.177
.03125 × .003	15,814	16,410	16,450	0.71	2.09	4.53	0.968
.03125 × .004	12,734	13,214	13,246	0.92	2.52	4.83	1.289
.03125 × .006	7,358	7,635	7,654	1.20	3.20	6.26	2.123
.03125 × .008	6,108	6,338	6,368	1.23	3,67	7.28	2.652
.03125 × .010	4,481	4,650	4,661	1.42	4.25	8.90	3.508
.050 × .004...	7,815	8,109	8,129	1.21	3.43	7.36	2.063
.050 × .006...	4,938	5,124	5,136	1.63	4.56	9.55	3.181
.050 × .008...	3,817	3,961	3,971	1.97	5.35	11.47	4.244
.050 × .010...	2,812	2,918	2,925	2.01	5.53	12.36	5.460

The above data should be regarded as approximate.

This Table is supplied by courtesy of :—

VACTITE WIRE COMPANY LIMITED, LONDON, S.W. 1.

FUSE WIRE TABLES

Figures are approximate and for commercial use only

Fusing Current in Amperes.	DIAMETER IN INCHES.				
	Copper.	Aluminium.	Tin.	Allo-Tin.	Lead.
1	·0020	·0028	·0076	·0084	·0084
2	·0036	·0040	·0116	·0136	·0124
3	·0044	·0052	·0148	·018	·0164
4	·0052	·0068	·018	·022	·020
5	·0060	·0076	·022	·024	·024
10	·0100	·0124	·036	·040	·036
15	·0124	·0164	·044	·048	·048
20	·0156	·0180	·052	·064	·060
25	·018	·0220	·064	·072	·072
30	·020	·024	·072	·080	·078
35	·023	·028	·076	·092	·084
40	·024	·030	·084	·096	·096
45	·026	·032	·092	·104	·104
50	·028	·036	·096	·116	·108
60	·032	·040	·110	·128	·124
70	·036	·044	·122	·144	·136
80	·040	·048	·134	·160	·150
90	044	·052	·144	·168	·162
100	·048	·056	·152	·180	·174
120	·052	·064	·176	·202	·196

EUREKA RESISTANCE WIRE

(REGD.)

CURRENT NECESSARY TO MAINTAIN GIVEN TEMPERATURE RISE. WIRE HELD STRAIGHT AND HORIZONTAL IN AIR WITH FREE RADIATION.

Size S.W.G.	Diam. Inch	M/m.	Amperes for a Temperature rise of			Resistance per 1,000 yards at 15·5° C. Ohms.	Weight per 1,000 yards, lbs.
			100° C.	200° C.	300° C.		
8	·160	4·06	29·0	44·5	57·9	34·5	233·5
9	·144	3·65	24·0	37·2	48·7	42·6	189·0
10	·128	3·25	20·1	30·8	40·0	54·0	149·2
11	·116	2·94	18·5	28·1	36·4	65·7	122·8
12	·104	2·64	14·8	22·4	29·0	81·8	98·6
13	·092	2·33	12·6	18·8	24·5	104·4	77·1
14	·080	2·03	10·5	15·5	20·1	138·1	58·4
15	·072	1·82	9·3	13·4	17·4	170·6	47·3
16	·064	1·62	8·1	11·5	15·1	215·9	37·4
17	·056	1·42	7·0	9·8	13·0	281·9	28·6
18	·048	1·21	5·75	8·2	11·0	384	21·0
19	·040	1·01	4·6	6·7	9·2	552	14·6
20	·036	·91	4·1	6·0	8·3	682	11·8
21	·032	·81	3·8	5·4	7·4	864	9·35
22	·028	·71	3·1	4·6	6·5	1128	7·15
23	·024	·60	2·7	4·00	5·5	1535	5·24
24	·022	·55	2·4	3·55	5·0	1826	4·41
25	·020	·50	2·18	3·20	4·06	2211	3·64
26	·018	·45	2·00	2·90	3·60	2729	2·96
27	·0164	·41	1·82	2·68	3·21	3288	2·46
28	·0148	·37	1·66	2·42	2·85	4205	2·00
29	·0136	·34	1·54	2·22	2·58	4781	1·69
30	·0124	·31	1·40	2·00	2·30	5750	1·40
31	·0116	·29	1·30	1·81	2·13	6570	1·23
32	·0108	·27	1·20	1·64	1·94	7581	1·06
33	·0100	·25	1·08	1·46	1·77	8842	·912
34	·0092	·23	·98	1·30	1·60	10440	·771
35	·0084	·21	·85	1·13	1·42	12530	·644
36	·0076	·19	·75	·98	1·26	15310	·526
37	·0068	·17	·66	·83	1·09	19130	·421
38	·0060	·15	·58	·70	·93	24550	·328
39	·0052	·13	·50	·58	·78	32700	·246
40	·0048	·12	·46	·52	·70	38380	·210
41	·0044	·11				45670	·176
42	·0040	·10				55260	·146
43	·0036	·09				68070	·118
44	·0032	·08				86370	·093
45	·0028	·07				112800	·072
46	·0024	·06				153500	·053
47	·0020	·05				221000	·036
48	·0016	·040				345400	·023
49	·0012	·030				614000	·013
50	·0010	·025				884200	·009

The resistance values given above are standard and are subject to the tolerances given in B.S.I. Specification No. 115 of 1939

Approximate Characteristics

Temperature Co-efficient .. .. 0·000014.
Specific Resistance .. .. .. 49 microhms per cm cube
Comparative Resistance Copper—Unity 28
Specific Gravity .. .. 8·92

Thermo E.M.F against Copper (20° to 200° C.) .. .. 0·5 millivolts per ° C
Melting Point .. .. .. 1,250° C.
Tensile Strength .. .. 36 tons per square inch

The above information supplied by courtesy of Lewcos Ltd.

ELECTRICAL CABLE SIZES

NOMINAL AREA Sq. Inch.	OLD STANDARD No. S.W.G.	NEW STANDARD No/inch.	Dia. in Inches	WEIGHT per 1000 yds. in lbs.	MAXIMUM RESISTANCE per 1000 yds. in OHMS.	LENGTH of CIRCUIT per Volt drop in feet.	CAPACITY of single cables in AMPS.
·001	1/20	1/·036	0·036	11·76	24·29	30	4·1
·0015	–	1/·044	0·044	17·58	16·26	30	6·1
·002	–	3/·029	0·062	23·37	12·61	30	7·8
·003	3/20	3/·036	0·078	36·02	8·180	29	12·0
·003	1/16	1/·064	0·064	37·20	7·688	29	12·9
·0045	–	7/·029	0·087	54·39	5·387	28	18·2
·007	7/20	7/·036	0·108	83·81	3·496	33	24·0
·01	–	7/·044	0·132	125·4	2·340	39	31·0
·0145	–	7/·052	0·156	174·9	1·675	45	37·0
·0225	7/16	7/·064	0·192	264·9	1·106	56	46·0
·03	–	19/·044	0·220	340·4	0·8637	61	53·0
·04	19/17	19/·052	0·260	475·5	0·6184	71	64·0
·06	19/16	19/·064	0·320	720·3	0·4085	83	83·0
·075	19/15	19/·072	—	911·6	0·3225	90	97·0
·10	–	19/·083	0·415	1212·0	0·2427	98	119·0
·12	37/16	37/·064	—	1403·0	0·2097	104	130·0
·15	37/15	37/·072	0·504	1776·0	0·1657	112	152·0
·20	–	37/·083	0·581	2360·0	0·1247	123	185·0
·25	–	37/·093	—	2963·0	0·09933	132	214·0
·30	–	37/·103	0·721	3635·0	0·08089	145	240·0
·40	–	61/·093	0·837	4886·0	0·06026	162	288·0
·50	–	61/·103	0·927	5994·0	0·04913	173	332·0
·60	–	91/·093	—	7290·0	0·04040	181	384·0
·75	–	91/·103	1·133	8942·0	0·03294	185	463·0
·85	–	127/·093	—	10175·0	0·02895	190	512·0
1·00	–	127/·103	1·339	12481·0	0·02360	200	595·0

FLEXIBLE CORDS

SIZE	AREA in Sq. Inches	CURRENT RATING In Amps.	RESISTANCE per 1000 yards single core..	MAXIMUM WEIGHT in lbs.	YARDS PER POUND WEIGHT for TWIN SILK (twisted)
14/·0076	·0006	2	39·7	3	17·5
23/·0076	·0010	3	24·2	5	13·3
40/·0076	·0017	5	13·8	10	9·75
70/·0076	·0030	10	7·94	10	6·55
110/·0076	·0048	15	5·05	10	4·65
162/·0076	·0070	20	3·43	10	3·33

MAXIMUM CURRENT RATING OF CABLES

SIZE	Rating in AMPERES A.C. & Voltage drop per 100 feet			
	Cores in one sheath			
	UP TO 4		UP TO 8	
	AMPS.	VOLTS	AMPS.	VOLTS
1/·044	5	2·8	5	2·8
3/·029	5	2·1	5	2·1
3/·036	10	2·8	8	2·4
7/·029	15	2·9	12	2·4
	UP TO 2		UP TO 4	
7/·036	29	3·4	23	2·9
7/·044	38	3·1	30	2·4
7/·052	45	2·7	36	2·2
7/·064	56	-2·1	46	1·75
19/·044	65	2·0	52	1·6

SIZE	Rating in AMPERES A.C. & Voltage drop per 100 feet			
	Cores in one sheath			
	UP TO 2		UP TO 4	
	AMPS.	VOLTS	AMPS.	VOLTS
19/·052	78	1·75	62	1·4
19/·064	102	1·55	82	1·19
19/·083	147	1·35	119	1·04
37/·072	190	1·28	151	0·98
37/·083	229	1·26	183	0·98
37/·103	298	1·28	238	0·98
61/·093	358	1·38	286	1·04
61/·103	413	1·50	330	1·15
91/·103	530	1·80	—	—
127/·103	648	2·10	—	—

CAPACITY OF FUSES IN AMPERES

FUSE RATING in Amps.	TINNED COPPER WIRE Dia.	TINNED COPPER WIRE S.W.G.	STANDARD ALLOY WIRE Dia.	STANDARD ALLOY WIRE S.W.G.	FUSE RATING in Amps.	TINNED COPPER WIRE Dia.	TINNED COPPER WIRE S.W.G.	STANDARD ALLOY WIRE Dia.	STANDARD ALLOY WIRE S.W.G.
1·8	—	—	·0164	27	30	·032	21	—	—
3	·006	38	·024	23	37	·04	19	—	—
5	·0084	35	·032	21	46	·048	18	—	—
8·5	·0124	30	—	—	53	·048	18	—	—
10	·0136	29	—	—	60	·056	17	—	—
15	·02	25	—	—	64	·056	17	—	—
17	·022	24	—	—	83	·072	15	—	—
20	·024	23	—	—	100	·08	14	—	—
24	·028	22	—	—					

REACTANCE CHART

Always use corresponding scales

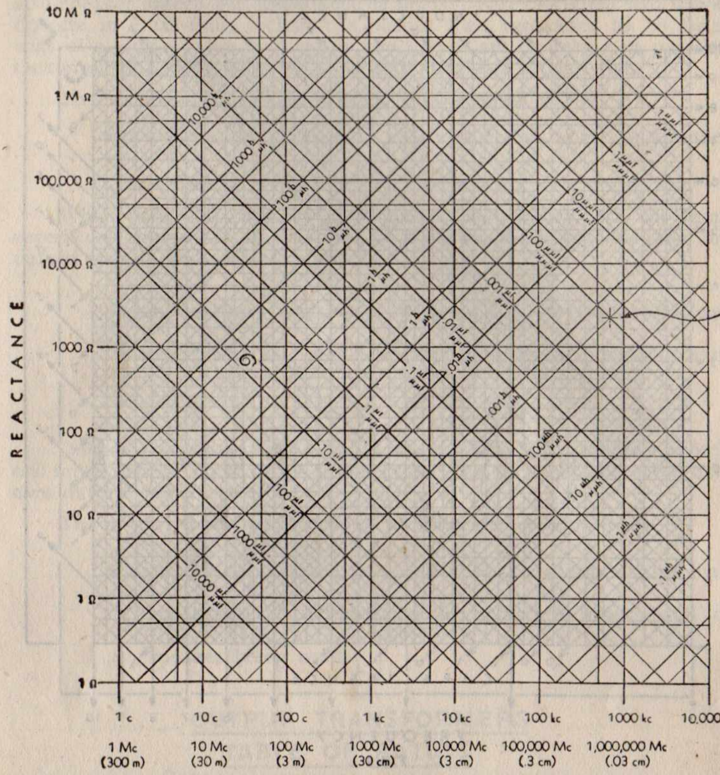


FIG 1

The accompanying chart may be used to find:

(1) The reactance of a given inductance at a given frequency.

(2) The reactance of a given capacitance at a given frequency.

(3) The resonant frequency of a given inductance and capacitance.

In order to facilitate the determination of magnitude of the quantities involved to two or three significant figures the chart is divided into two parts. Figure 1 is the complete chart to be used for rough calculations. Figure 2, which is a single decade of Figure 1 enlarged approximately 7 times, is to be used where the significant two or three figures are to be determined.

TO FIND REACTANCE

Enter the charts vertically from the bottom (frequency) and along the lines slanting upward to the left (capacitance) or to the right (inductance). Corresponding scales (upper or lower) must be used throughout. Project horizontally to the left from the intersection and read reactance.

The above data supplied by courtesy of Claude Lyons Ltd. / General Radio Co., U.S.A.

Always obtain approximate value from Figure 1 before using Figure 2

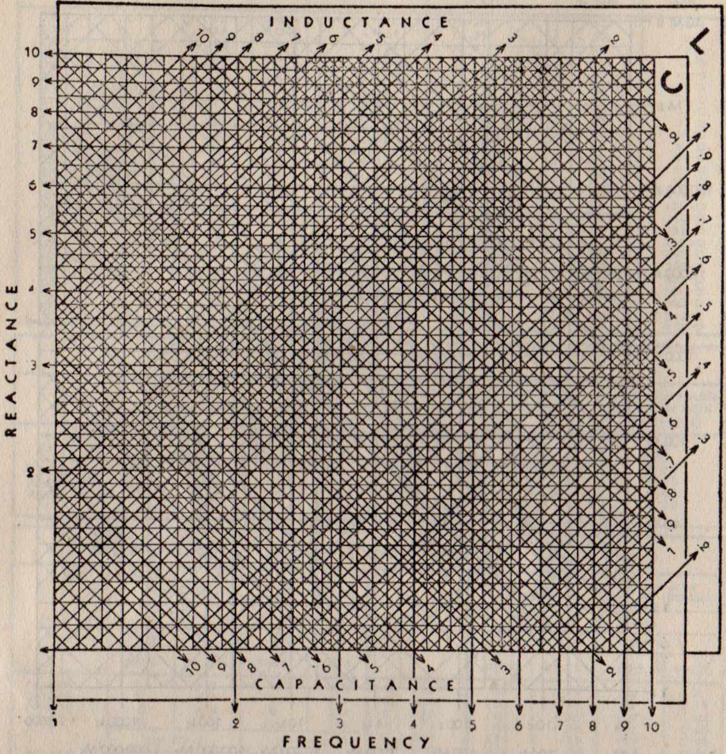


FIG. 2

TO FIND RESONANT FREQUENCY

Enter the slanting lines for the given inductance and capacitance. Project downward from their intersection and read resonant frequency from the bottom scale. Corresponding scales (upper or lower) must be used throughout.

Example: The sample point indicated (Figure 1) corresponds to a frequency of about 700 kc and an inductance of 500 μh, or a capacitance of 100 μμf, giving in either case a reactance of about 2,000 ohms. The resonant frequency of a circuit containing these values of inductance and capacitance is, of course, 700 kc, approximately.

USE OF FIGURE 2

Figure 2 is used to obtain additional precision of reading but does not place the decimal point which must be located from a preliminary entry on Figure 1. Since the chart necessarily requires two logarithmic decades for inductance and capacitance for every single decade of frequency and reactance, unless the correct decade for L and C is chosen, the calculated values of reactance and frequency will be in error by a factor of 3.16.

Example: (Continued.) The reactance corresponding to 500 μh or 100 μμf is 2,230 ohms at 712 kc, their resonant frequency.

The above data supplied by courtesy of CLAUDE LYON LTD. / GENERAL RADIO COMPANY, U.S.A.

SPEAKER OUTPUT TRANSFORMERS FORMULAS.

Ascertain output valve load resistance from "Bernards Valve Manual" No. 30, price 3/6, or from manufacturers data sheets and also speaker speech coil impedance in ohms. NOTE.—When two valves operate in Push-Pull, reckon the output load resistance to be twice that of a single valve, and when two valves are operating in parallel reckon output load resistance to be half that of a single valve.

The speaker output transformer ratio is equal to :—

Square root of {(Optimum valve load resistance) ÷ (speaker speech coil impedance in ohms)}.

When extension speakers are required to be used with the same speech coil impedance as that used in the normal internal speaker, the output transformer ratio is equal to :—

Square root of [Number of speakers × {(optimum valve load resistance) ÷ (single speaker speech coil impedance in ohms.)}]

Output transformer ratio for extra speakers with different speech coil impedances. In this case it is necessary for each speaker to have its own output transformer.

The output transformer ratio of each speaker is equal to :—

Square root of [Number of speakers × {(Optimum valve load resistance) ÷ (Impedance in ohms. of speech coil of speaker being used)}]

OUTPUT TRANSFORMERS
TABLE OF RATIOS

VALVE LOAD (PLATE TO PLATE FOR P.P. OPERATION)		SPEECH COIL IMPEDANCES							
	RATIOS →	2 Ω	3 Ω	5 Ω	8 Ω	10 Ω	15 Ω	20 Ω	25 Ω
4000		44·7	36·5	28·3	22·4	20	16·4	14·1	12·6
5000		50	40·8	31·6	25	22·4	18·3	15·8	14·1
6000		54·8	44·7	34·6	27·4	24·5	20	17·3	15·5
8000		63·3	51·6	40	31·6	28·3	23	20	17·9
10000		70·7	57·7	44·7	35·3	31·6	25·8	22·4	20
12000		77·5	63·3	49	38·7	34·6	28·3	24·5	22
14000		83·7	68·3	53	41·8	37·4	30·6	26·5	23·7
16000		89·4	73	56·6	44·7	40	32·8	28·3	25·3
20000		100	81·6	63·2	50	44·7	36·5	31·6	28·3
25000		111·8	91·3	70·7	55·9	50	40·8	35·3	31·6

COMPARISON BETWEEN
BRITISH & U.S.A. WIRE GAUGES
DIAMETERS IN INCHES

SIZE	4/0	3/0	2/0	0	1	2	3	4	5	6	7
S.W.G.	·400	·372	·348	·324	·300	·276	·252	·232	·212	·192	·176
B.W.G.	·454	·425	·380	·340	·300	·284	·259	·238	·220	·203	·180
B.& S.	·460	·4096	·3648	·3249	·2893	·2576	·2294	·2043	·1819	·1620	·1443

SIZE	8	9	10	11	12	13	14	15	16	17	18
S.W.G.	·160	·144	·128	·116	·104	·092	·080	·072	·064	·056	·048
B.W.G.	·165	·148	·134	·120	·109	·095	·083	·072	·065	·058	·049
B.& S.	·1285	·1144	·1019	·0907	·0808	·072	·0641	·0571	·0508	·0453	·0403

SIZE	19	20	21	22	23	24	25	26	27	28	29
S.W.G.	·040	·036	·032	·028	·024	·022	·020	·018	·0164	·0148	·0136
B.W.G.	·042	·035	·032	·028	·025	·022	·020	·018	·016	·014	·013
B.& S.	·0359	·032	·0285	·0253	·0226	·0201	·0179	·0159	·0142	·0126	·0113

SIZE	30	31	32	33	34	35	36	37	38	39	40
S.W.G.	·0124	·0116	·0108	·010	·0092	·0084	·0076	·0068	·006	·0052	·0048
B.W.G.	·012	·010	·009	·008	·007	·005	·004	—	—	—	—
B.& S.	·0100	·0089	·0079	·0071	·0063	·0056	·005	·0045	·004	·0035	·0031

SIZE	41	42	43	44	45	46	47	48	49	50
S.W.G.	·0044	·0040	·0036	·0032	·0028	·0024	·002	·0016	·0012	·001
B.W.G.	—	—	—	—	—	—	—	—	—	—
B.& S.	·0028	·0025	·0022	·002	·0018	—	—	—	—	—

The above data supplied by courtesy of LEWCOS LTD.

RADIO SOLDER COMPOSITION AND MELTING POINTS

Composition	Percentage	Melting at °F	Composition	Percentage	Melting at °F
LEAD TIN	100 —	452	LEAD TIN	40 60	462
LEAD TIN	90 10	411	LEAD TIN	30 70	494
LEAD TIN	80 20	381	LEAD TIN	20 80	551
LEAD TIN	70 30	366	LEAD TIN	10 90	568
LEAD TIN	60 40	373	LEAD TIN	— 100	617
LEAD TIN	50 50	411			

TEMPERATURE CONVERSION TABLE—
CENTIGRADE AND FAHRENHEIT

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
10	50	210	410	410	770	610	1130	810	1490	1010	1850	1210	2210	1410	2570
20	68	220	428	420	788	620	1148	820	1508	1020	1868	1220	2228	1420	2588
30	86	230	446	430	806	630	1166	830	1526	1030	1886	1230	2246	1430	2606
40	104	240	464	440	824	640	1184	840	1544	1040	1904	1240	2264	1440	2624
50	122	250	482	450	842	650	1202	850	1562	1050	1922	1250	2282	1450	2642
60	140	260	500	460	860	660	1220	860	1580	1060	1940	1260	2300	1460	2660
70	158	270	518	470	878	670	1238	870	1598	1070	1958	1270	2318	1470	2678
80	176	280	536	480	896	680	1256	880	1616	1080	1976	1280	2336	1480	2696
90	194	290	554	490	914	690	1274	890	1634	1090	1994	1290	2354	1490	2714
100	212	300	572	500	932	700	1292	900	1652	1100	2012	1300	2372	1500	2732
110	230	310	590	510	950	710	1310	910	1670	1110	2030	1310	2390	1510	2750
120	248	320	608	520	968	720	1328	920	1688	1120	2048	1320	2408	1520	2768
130	266	330	626	530	986	730	1346	930	1706	1130	2066	1330	2426	1530	2786
140	284	340	644	540	1004	740	1364	940	1724	1140	2084	1340	2444	1540	2804
150	302	350	662	550	1022	750	1382	950	1742	1150	2102	1350	2462	1550	2822
160	320	360	680	560	1040	760	1400	960	1760	1160	2120	1360	2480	1560	2840
170	338	370	698	570	1058	770	1418	970	1778	1170	2138	1370	2498	1570	2858
180	356	380	716	580	1076	780	1436	980	1796	1180	2156	1380	2516	1580	2876
190	374	390	734	590	1094	790	1454	990	1814	1190	2174	1390	2534	1590	2894
200	392	400	752	600	1112	800	1472	1000	1832	1200	2192	1400	2552	1600	2912

The above figures have been arrived at by using the following formulæ:—

$$C^\circ = \frac{5}{9}(F^\circ - 32) \qquad F^\circ = \frac{9}{5}C^\circ + 32$$

The above data supplied by courtesy of London Electric Wire Co. & Smiths Ltd. (LEWCOS)

Wire Abbreviations

The following abbreviations are recognised through the trade as being standard and should therefore be used when ordering or specifying.

S.C.C.	Single Cotton Covered.	Standard	Standard Covering.
D.C.C.	Double Cotton Covered.	Fine	Fine Covering.
T.C.C.	Triple Cotton Covered.	B/D or Brd.	Braided.
Lam	Laminated.	Compd. strand	Compressed strand.
S.W.S.	Single White Silk.	H.D.	Hard Drawn.
D.W.S.	Double White Silk.	S.D.	Soft Drawn.
S.S.C.	Single Silk Covered.	H.C.	High Conductivity.
D.S.C.	Double Silk Covered.	Pl. cu.	Plain copper.
Enam.	Enamelled.	T/d. cu.	Tinned copper.
Enam. & S.S.C	Enamelled & Single Silk Covered.	S.I.R., or S.P.R.	Single lapping of Pure Rubber.
Enam. & D.S.C.	Enamelled & Double Silk Covered	D.I.R., or D.P.R.	Double lapping of Pure Rubber.
Enam. & S.C.C.	Enamelled and Single Cotton Covered.	Pfd.	Paraffined.
		S.W.G.	Standard Wire Gauge.
Enam. & D.C.C.	Enamelled and Double Cotton Covered.	B.W.G.	Birmingham Wire Gauge.
		B. & S.	Brown & Sharp's Gauge.
S.P.C.	Single Paper Covered.	V.C. tape	Varnished cambric tape (also known as "Empire" or "Lino" tape).
D.P.C.	Double Paper Covered.		
T.P.C.	Triple Paper Covered.		

The above data supplied by courtesy of London Electric Wire Co. & Smiths Ltd. (LEWCOS)

SECTIONAL AREA, WEIGHT AND RESISTANCE OF STRANDED CIRCULAR CONDUCTORS

Number of Wires Stranded.	MULTIPLYING CONSTANT.			
	Diameter.	Sectional Area.	Weight	Resistance.
3	2·155	2·94118	3·06000	0·340000
7	3	6·88235	7·12000	0·145299
19	5	18·6471	19·3600	0·0536278
37	7	36·2941	37·7200	0·0275527
61	9	59·8235	62·2000	0·0167158
91	11	89·2353	92·8000	0·0112063
127	13	124·529	129·520	0·00803023
169	15	165·706	172·360	0·00603479

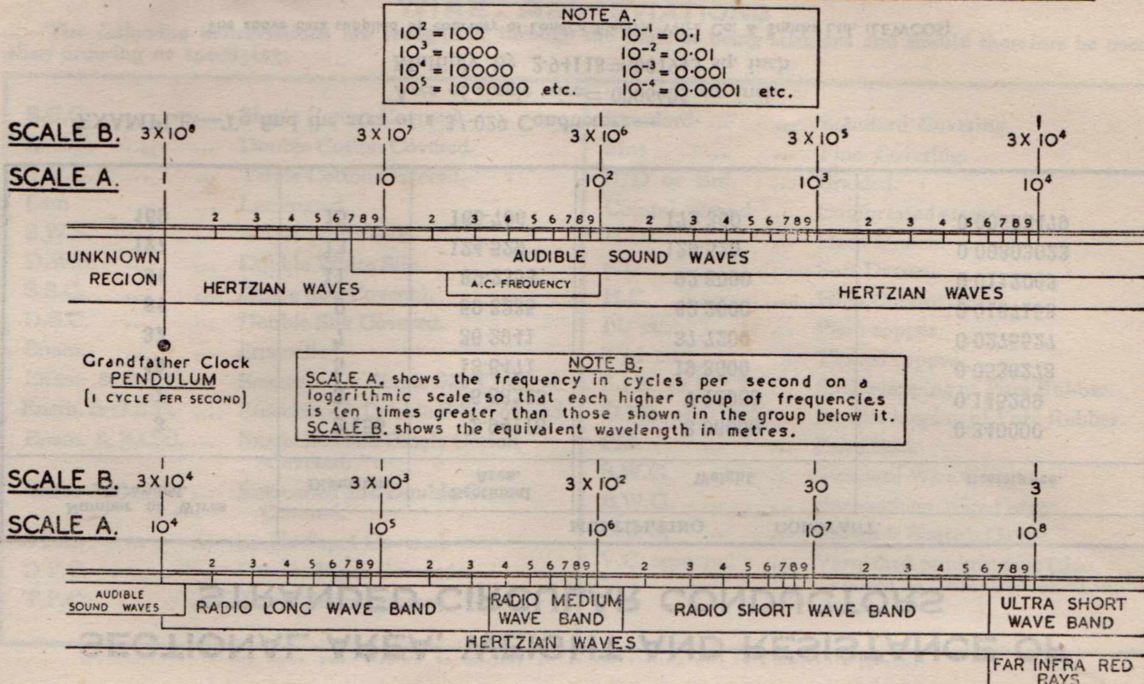
EXAMPLE.—To find the area of a 3/·029 Conductor:—

Area of single wire=·0006605 sq. inch

Multiply by 2·94118=·001943 sq. inch

The above data supplied by courtesy of London Electric Wire Co. & Smiths Ltd. (LEWCOS)

RADIATION FREQUENCY SPECTRUM 1 TO 10^8 CYCLES PER SECOND.



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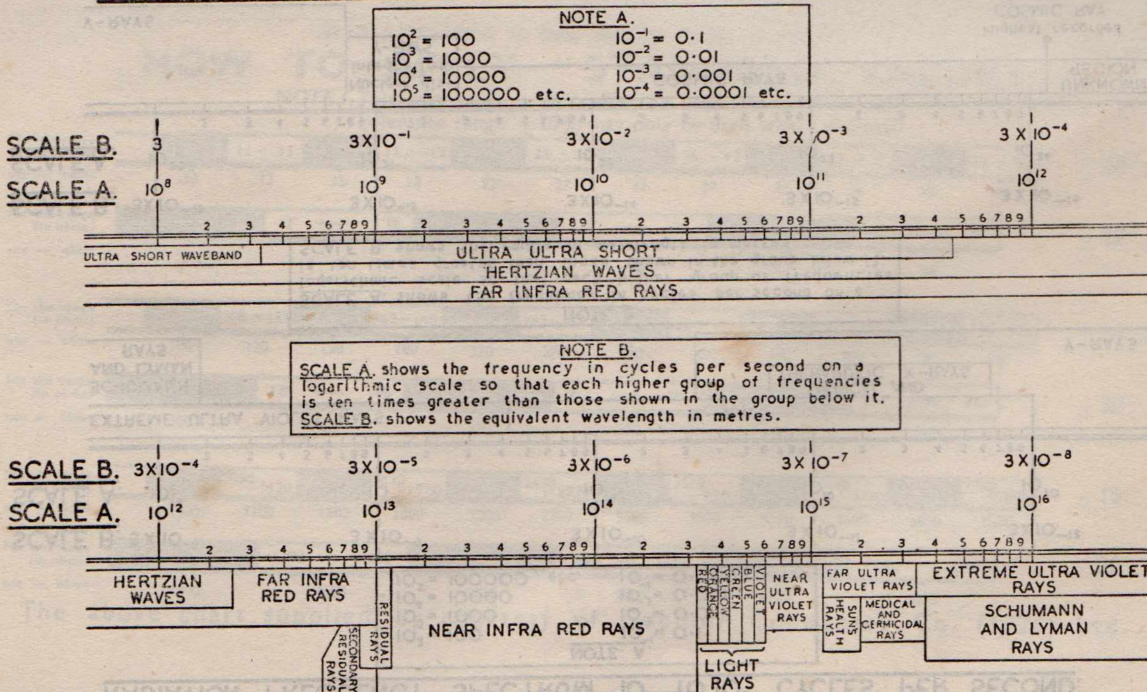
RADIATION FREQUENCY SPECTRUM 10^8 TO 10^{16} CYCLES PER SECOND.



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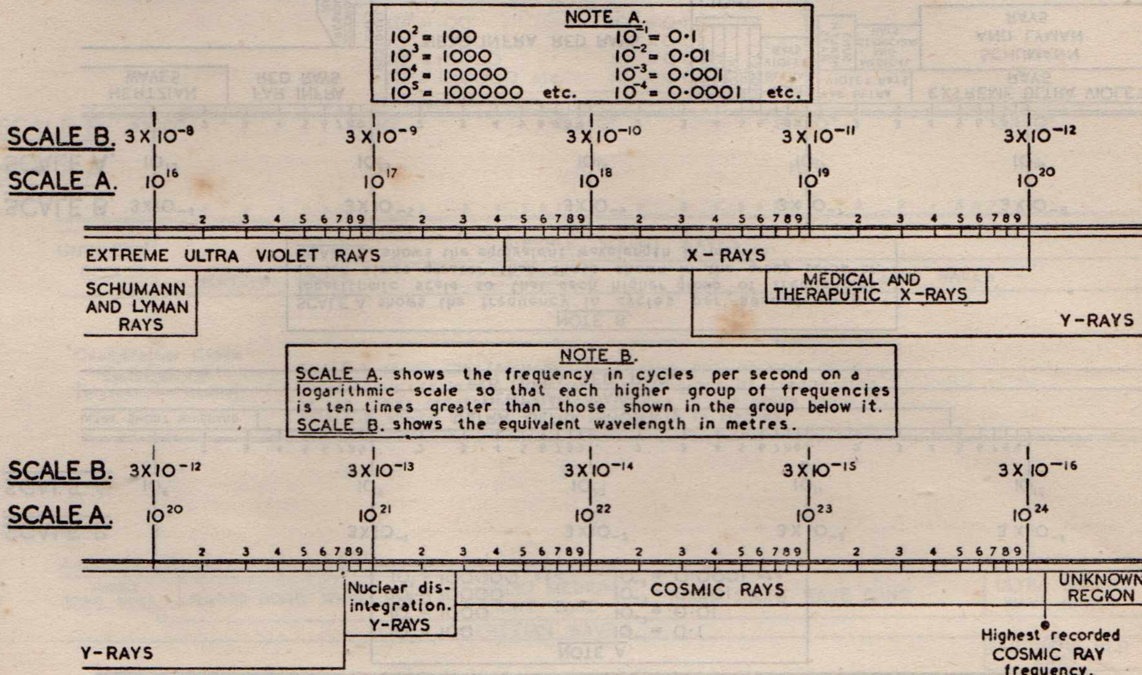
RADIATION FREQUENCY SPECTRUM 10^{16} TO 10^{24} CYCLES PER SECOND.



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STANDARDISATION IN THE USE OF FIXED RESISTORS.

HOW TO APPLY "STANDARD VALUES"

NOTE : Tolerance range $\pm$ 20% must be used wherever possible
Tolerance range $\pm$ 10% may only be used where essential

For the range (in ohms)	10 – 11	11 - 13	14 – 16	17 - 19	20 – 24	25 - 30	30 – 36	36 - 42	43 – 51	52 - 61	62 – 74	74 - 90	$\pm$10%
use — ohms	10	12	15	18	22	27	33	39	47	56	68	82	

For the range (in ohms)	10 —— 12	12 —— 18	18 —— 26	27 —— 39	38 —— 56	55 —— 81	$\pm$20%
use — ohms	10	15	22	33	47	68	

For the range (in ohms)	90 – 110	108 - 132	135 – 165	162 – 198	198 – 242	243 – 297	297 – 363	351 - 429	423 – 517	504 - 616	612 – 748	738 - 902	$\pm$10%
use — ohms	100	120	150	180	220	270	330	390	470	560	680	820	

For the range (in ohms)	80 —— 120	120 —— 180	178 —— 264	264 —— 396	376 —— 564	544 —— 820	$\pm$20%
use — ohms	100	150	220	330	470	680	

For the range (in ohms)	900 – 1100	1080 – 1320	1350 – 1650	1620 – 1980	1980 – 2420	2430 – 2970	2970 – 3630	3510 – 4290	4230 – 5170	5040 – 6160	6120 – 7480	7380 – 9020	$\pm$10%
use — ohms	1000	1200	1500	1800	2200	2700	3300	3900	4700	5600	6800	8200	

For the range (in ohms)	800 —— 1200	1200 — 1800	1760 —— 2640	2640 — 3960	3760 —— 5640	5440 — 8160	$\pm$20%
use — ohms	1000	1500	2200	3300	4700	6800	

The above chart supplied by courtesy of Dubilier Condenser Co. (1925) Ltd.

STANDARDISATION IN THE USE OF RESISTORS.

HOW TO APPLY "STANDARD VALUES"

***NOTE*:** Tolerance range ±20% must be used wherever possible
Tolerance range ±10% may only be used where essential

For the range (in ohms)	9000 – 11000	10800 – 13200	13500 – 16500	16200 – 19800	19800 – 24200	24300 – 29700	29700 – 36300	35100 – 42900	42300 – 51700	50400 – 61600	61200 – 74800	73800 – 90200	±10%
use — ohms	10000	12000	15000	18000	22000	27000	33000	39000	47000	56000	68000	82000	

For the range (in ohms)	8000 — 12000	12000 — 18000	17600 — 26400	26400 — 39600	37600 — 56400	54400 — 81600	±20%
use — ohms	10000	15000	22000	33000	47000	68000	

For the range (in ohms)	90000 – 110000	108000 – 132000	135000 – 165000	162000 – 198000	198000 – 242000	243000 – 297000	297000 – 363000	351000 – 429000	423000 – 517000	504000 – 616000	612000 – 748000	738000 – 902000	±10%
use — ohms	100000	120000	150000	180000	220000	270000	330000	390000	470000	560000	680000	820000	

For the range (in ohms)	80000 — 120000	120000 — 180000	176000 — 264000	264000 — 396000	376000 — 564000	544000 — 816000	±20%
use — ohms	100000	150000	220000	330000	470000	680000	

For the range (in ohms)	.9 Meg – 1.1 Meg	1.08 Meg – 1.32 Meg	1.35 Meg – 1.65 Meg	1.62 Meg – 1.98 Meg	1.98 Meg – 2.42 Meg	2.43 Meg. – 2.97 Meg.	2.97 Meg – 3.63 Meg	3.51 Meg. – 4.29 Meg.	4.23 Meg – 5.17 Meg	5.04 Meg. – 6.16 Meg.	6.12 Meg – 7.48 Meg	7.38 Meg. – 9.02 Meg.	±10%
use — ohms	1.0 Meg	1.2 Meg.	1.5 Meg.	1.8 Meg	2.2 Meg.	2.7 Meg.	3.3 Meg.	3.9 Meg.	4.7 Meg.	5.6 Meg.	6.8 Meg.	8.2 Meg.	

For the range (in ohms)	.8 Meg – 1.2 Meg	1.2 Meg. — 1.8 Meg	1.76 Meg – 2.64 Meg	2.64 Meg.-3.96 Meg.	3.76 Meg – 5.64 Meg	5.44 Meg.-8.16 Meg.	8.0 Meg. 10.0 Meg.	±20%
use — ohms	1.0 Meg.	1.5 Meg.	2.2 Meg.	3.3 Meg.	4.7 Meg.	6.8 Meg	10.0 Meg.	

The above chart supplied by courtesy of Dubilier Condenser Co. (1925) Ltd.

WAVELENGTH FREQUENCY AND L.C. FACTOR TABLES.

To use these tables which give inductance capacity values for Radio Frequencies the following examples are shown :—

1. Given a tuned circuit total capacity .0005 mfd. and inductance 245 microhenries, what is the natural wavelength and frequency? Answer : the L.C. constant is .0005 × 245 = .1225 ; therefore, wavelength is 660 metres and frequency 454.3 Kilocycles.

2. What inductance is needed to tune a .0005 mfd. condenser to 1,900 metres. Answer : L.C. for 1,900 metres = 1.016 ; therefore, inductance is 1.016 divided by .0005 which equals 2.032 microhenries.

3. A circuit with a natural frequency of 1,250 Kc. is required, the tuning coil inductance being 81 microhenries. What capacity should be connected across the coil? Answer : L.C. for 1,250 Kc. = .01624 ; hence capacity is .01622 ÷ by 81 which equals .0002 microfarads.

MULTIPLYING FACTORS FOR OTHER RANGES OUTSIDE THIS TABLE.

(A) If column 1 is multiplied by 10 then read column 2 multiplied by 100, and column 3 divided by 10.

(B) If column 1 is divided by 10, then read column 2 divided by 100 and column 3 multiplied by 10.

(C) If column 2 is multiplied by 10 then column 1 is multiplied by $\sqrt{10}$ and column 3 is divided by $\sqrt{10}$.

(D) If column 2 is divided by 10 then column 1 is divided by $\sqrt{10}$ and column 3 is multiplied by $\sqrt{10}$.

(E) If column 3 is multiplied by 10 then column 1 is divided by 10 and column 2 is divided by 100.

(F) If column 3 is divided by 10 then column 1 is multiplied by 10 and column 2 is multiplied by 100.

W/length Metres.	L. × C. Factor m.f. and m.h.	Frequency Kilocycles.	W/length Metres.	L. × C. Factor m.f. and m.h.	Frequency Kilocycles
1	.00000028	299820.0	55	.0008521	5451.0
2	.00000112	149910.0	60	.001014	4997.0
3	.00000253	99940.0	65	.001188	4613.0
4	.00000451	74955.0	70	.001379	4283.0
5	.00000704	59964.0	75	.001583	3998.0
6	.00001014	49970.0	80	.001801	3748.0
7	.00001383	42831.4	85	.002034	3527.0
8	.00001801	37477.5	90	.002280	3331.0
9	.00002282	33313.3	95	.002541	3156.0
10	.00002816	29982.0	100	.002816	2998.0
15	.0000635	19990.0	105	.003101	2855.0
20	.0001129	14991.0	110	.003404	2726.0
25	.0001754	11990.0	115	.003721	2607.0
30	.0002531	9994.0	120	.004052	2498.0
35	.0003445	8566.0	125	.004402	2399.0
40	.0004503	7495.5	130	.004757	2306.0
45	.0005702	6663.0	135	.005132	2221.0
50	.0007039	5996.4	140	.005518	2142.0

W/length Metres.	L. × C. Factor m.f. and m.h.	Frequency Kilocycles	W/length Metres.	L. × C. Factor m.f. and m.h.	Frequency Kilocycles
145	.005923	2067.0	395	.04392	759.1
150	.006335	1999.0	400	.04503	749.4
155	.006764	1934.0	405	04617	740.3
160	.007204	1873.0	410	.04733	731.3
165	.007661	1817.0	415	.04851	722.5
170	.008134	1763.0	420	.04968	713.9
175	.008622	1713.0	425	.05084	705.5
180	.009120	1665.0	430	.05198	697.3
185	.009631	1620.0	435	.05323	689.2
190	.01016	1578.0	440	.05446	681.4
195	.01070	1539.0	445	.05573	673.8
200	.01129	1499.0	450	.05700	666.3
205	.01182	1463.0	455	.05830	658.9
210	.01239	1428.0	460	.05960	651.8
215	.01301	1395.0	465	06092	644.8
220	.01362	1362.0	470	06225	637.9
225	.01425	1333.0	475	.06356	631.2
230	.01490	1303.0	480	.06485	624.6
235	.01554	1276.0	485	.06624	618.2
240	.01624	1249.0	490	.06757	611.9
245	.01689	1224.0	495	.06898	605.7
250	.01755	1199.0	500	.07039	599.6
255	.01830	1176.0	505	07184	593.7
260	.01902	1153.0	510	07327	587.8
265	.01977	1131.0	515	.07468	582.2
270	.02052	1110.0	520	.07606	576.6
275	.02125	1090.0	525	.07757	571.1
280	.02209	1070.0	530	.07903	565.7
285	.02285	1052.0	535	.08055	560.4
290	.02372	1034.0	540	.08208	555.2
295	.02451	1016.0	545	.08363	550.1
300	.02530	999.4	550	.08518	545.1
305	.02621	983.1	555	.08677	540.2
310	.02704	967.2	560	.08836	535.4
315	.02795	951.8	565	.08986	530.7
320	.02884	936.9	570	.09141	526.0
325	.02975	922.5	575	.09304	521.4
330	.03069	908.6	580	.09467	516.8
335	.03161	895.1	585	.09630	512.5
340	.03250	881.8	590	.09803	508.2
345	.03351	869.1	595	.09973	503.9
350	.03446	856.5	600	.1014	499.7
355	.03552	844.6	605	.1031	495.7
360	.03648	832.8	610	.1047	491.5
365	.03753	821.4	615	.1064	487.5
370	.03856	810.3	620	.1082	483.6
375	.03962	799.5	625	.1099	479.7
380	.04070	789.0	630	.1117	475.9
385	.04173	778.8	635	.1136	472.1
390	.04277	768.7	640	.1154	468.5

W/length Metres.	L.×C. Factor m.f. and m.h.	Frequency Kilocycles.	W/length Metres.	L.×C. Factor m.f. and m.h.	Frequency Kilocycles
645	.1171	464.8	895	.2254	335.0
650	.1188	461.3	900	.2280	333.1
655	.1205	457.7	905	.2306	331.3
660	.1225	454.3	910	.2332	329.5
665	.1244	450.9	915	.2357	327.7
670	.1263	447.6	920	.2381	325.9
675	.1282	444.2	925	.2407	324.1
680	.1302	440.9	930	.2434	322.3
685	.1322	437.7	935	.2461	320.7
690	.1341	434.5	940	.2487	319.0
695	.1360	431.4	945	.2514	317.3
700	.1378	428.3	950	.2541	315.6
705	.1398	425.3	955	.2568	314.0
710	.1419	422.3	960	.2595	312.3
715	.1439	419.3	965	.2621	310.7
720	.1459	416.4	970	.2647	309.1
725	.1479	413.6	975	.2676	307.5
730	.1501	410.7	980	.2704	305.9
735	.1520	407.9	985	.2731	304.4
740	.1540	405.2	990	.2759	302.8
745	.1561	402.4	995	.2788	301.3
750	.1583	399.8	1,000	.2816	299.8
755	.1604	397.1	1,010	.2879	296.9
760	.1625	394.5	1,020	.2927	293.9
765	.1646	391.9	1,030	.2986	291.1
770	.1668	389.4	1,040	.3045	288.3
775	.1691	386.9	1,050	.3105	285.5
780	.1714	384.4	1,060	.3161	282.8
785	.1735	381.9	1,070	.3222	280.2
790	.1756	379.5	1,080	.3283	277.6
795	.1778	377.1	1,090	.3344	275.1
800	.1801	374.8	1,100	.3404	272.6
805	.1824	372.4	1,110	.3468	270.1
810	.1847	370.1	1,120	.3531	267.7
815	.1870	367.9	1,130	.3595	265.3
820	.1893	365.7	1,140	.3660	263.0
825	.1917	363.4	1,150	.3721	260.7
830	.1941	361.2	1,160	.3786	258.5
835	.1963	359.0	1,170	.3853	256.3
840	.1985	356.9	1,180	.3921	254.1
845	.2009	354.8	1,190	.3988	252.1
850	.2034	352.7	1,200	.4052	249.8
855	.2057	350.7	1,220	.4191	245.8
860	.2081	348.6	1,240	.4326	241.7
865	.2106	346.6	1,260	.4470	238.0
870	.2132	344.6	1,280	.4609	234.2
875	.2156	342.7	1,300	.4757	230.6
880	.2179	340.7	1,320	.4905	227.2
885	.2204	338.8	1,340	.5053	223.7
890	.2229	336.9	1,360	.5208	220.4

W/length Metres.	L. × C. Factor m.f. and m.h.	Frequency Kilocycles.	W/length Metres.	L. × C. Factor m.f. and m.h.	Frequency Kilocycles
1,380	.5359	217.3	2,500	1.7597	119.9
1,400	.5517	214.2	2,600	1.9027	115.3
1,420	.5675	211.0	2,700	2.0521	111.0
1,440	.5837	208.2	2,800	2.2071	107.0
1,460	.5999	205.3	2,900	2.3662	103.4
1,480	.6165	202.5	3,000	2.5331	99.9
1,500	.6334	199.9	3,100	2.7052	96.7
1,520	.6502	197.3	3,200	2.8831	93.7
1,540	.6671	194.7	3,300	3.0849	90.9
1,560	.6849	192.3	3,400	3.2552	88.2
1,580	.7028	189.8	3,500	3.4479	85.6
1,600	.7206	187.3	3,600	3.6478	83.3
1,620	.7388	185.1	3,700	3.8539	81.0
1,640	.7573	182.8	3,800	4.0648	78.9
1,660	.7756	180.6	3,900	4.2811	76.9
1,680	.7946	178.4	4,000	4.5007	74.9
1,700	.8135	176.3	4,100	4.7322	73.1
1,720	.8329	174.3	4,200	4.9657	71.4
1,740	.8520	172.3	4,300	5.2061	69.7
1,760	.8720	170.3	4,400	5.4512	68.1
1,780	.8917	168.4	4,500	5,6999	66.6
1,800	.9121	166.5	4,600	5,9561	65.2
1,820	.9327	164.7	4,700	6.2188	63.8
1,840	.9531	162.9	4,800	6.4861	62.5
1,860	.9742	161.2	4,900	6.7592	61.2
1,880	.9949	159.5	5,000	7.038	59.9
1,900	1.0165	157.8	5,100	7.321	58.8
1,920	1.0375	156.2	5,200	7.609	57.7
1,940	1.0598	154.5	5,300	7.911	56.6
1,960	1.0811	153.1	5,400	8.212	55.5
1,980	1.1036	151.4	5,500	8.508	54.5
2,000	1.1257	149.9	5,600	8.829	53.5
2,100	1.2413	142.8	5,700	9.151	52.6
2,200	1.3624	136.2	5,800	9.472	51.7
2,300	1.4894	130.3	5,900	9.809	50.8
2,400	1.6218	124.9	6,000	10.11	49.9

FREQUENCY, INDUCTIVE REACTANCE, AND CAPACITIVE REACTANCE TABLE.

Column 1 is calculated to cover values of 100 to 10 Kc. To cover this and other ranges the following multipliers are used :—

Column 1.	Column 2.	Column 3.
× .0001	× .1	× .01
× .001	× .01	× .1
× .01	× .001	× 1
× .1	× .0001	× 10
× 1	× .00001	× 100
× 10	× .000001	× 1000
× 100	× .0000001	× 10000
× 1000	× .00000001	× 100000
× 10000	× .000000001	× 1000000

To find the capacitive reactance, first obtain the value of Column 2 for the required frequency and multiply this by the correct factor for this frequency, then divide this result by C (which is equal to the number of microfarads capacity of the capacitor) and then multiply the final result by 1,000,000.

When the capacity " C " is quoted in farads, multiply finally the result by 1 instead of by 1,000,000.

When the capacity " C " is quoted in micromicrofarads, multiply finally the result by 1,000,000,000,000 instead of by 1,000,000.

Example :—Find capacitive reactance of a 100 mf condenser at 500 Kc. This is therefore equal to :—

$$\left[\left\{(.31832 \times .000001) \div 100\right\} \times 1000000\right] \text{ohms.} = .00318 \text{ ohms.}$$

To find the inductive reactance, first obtain the value of Column 3 for the required frequency and multiply this by the correct factor for this frequency, then multiply this result by L (which is equal to the number of Henries Inductance of the Inductor).

Example :—Find Inductive reactance of a .005 henry coil at 3,000 Kc. (3 Mc.). This is therefore equal to :—

$$\left[(1884.7 \times 10000) \times .005\right] \text{ohms.} = 94235 \text{ ohms.}$$

COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 1	COLUMN 2	COLUMN 3
Frequency	$1 \div w = 1 \div 2\pi f$	$w = 2\pi f$	Frequency	$1 \div w = 1 \div 2\pi f$	$w = 2\pi f$
100.0	.15915	6283.2	95.5	.16664	6000.3
99.5	.15994	6251.7	95.0	.16751	5969.1
99.0	.16071	6220.5	94.5	.16843	5937.4
98.5	.16157	6189.1	94.0	.16932	5906.1
98.0	.16238	6157.4	93.5	.17022	5874.7
97.5	.16325	6126.1	93.0	.17112	5843.5
97.0	.16408	6094.7	92.5	.17205	5812.1
96.5	.16491	6063.2	92.0	.17298	5780.5
96.0	.16578	6031.7	91.5	.17388	5749.2

Frequency, Inductive Reactance, and Capacitive Reactance Table.

COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 1	COLUMN 2	COLUMN 3
Frequency	$1 \div w = 1 \div 2\pi f$	$w = 2\pi f$	Frequency	$1 \div w = 1 \div 2\pi f$	$w = 2\pi f$
91.0	.17489	5717.6	66.5	.23933	4178.2
90.5	.17587	5686.2	66.0	.24114	4146.9
90.0	.17689	5654.8	65.5	.24298	4115.4
89.5	.17782	5623.6	65.0	.24487	4084.2
89.0	.17883	5589.1	64.5	.24674	4052.7
88.5	.17987	5560.5	64.0	.24868	4021.2
88.0	.18097	5529.1	63.5	.25062	3989.9
87.5	.18188	5497.9	63.0	.25262	3958.4
87.0	.18292	5466.3	62.5	.25468	3927.1
86.5	.18399	5435.1	62.0	.25671	3895.6
86.0	.18505	5403.6	61.5	.25878	3864.2
85.5	.18615	5372.2	61.0	.26091	3832.8
85.0	.18723	5340.6	60.5	.26309	3801.3
84.5	.18834	5309.4	60.0	.26524	3769.8
84.0	.18945	5277.8	59.5	.26749	3738.5
83.5	.19061	5246.4	59.0	.26976	3707.2
83.0	.19176	5215.1	58.5	.27207	3675.7
82.5	.19291	5183.7	58.0	.27441	3644.3
82.0	.19407	5152.1	57.5	.27678	3612.8
81.5	.19529	5120.7	57.0	.27922	3581.5
81.0	.19648	5089.4	56.5	.28169	3550.1
80.5	.19771	5058.1	56.0	.28421	3518.6
80.0	.19892	5026.7	55.5	.28676	3487.1
79.5	.20018	4995.2	55.0	.28921	3455.8
79.0	.20147	4963.6	54.5	.29202	3424.3
78.5	.20275	4932.8	54.0	.29477	3392.8
78.0	.20403	4900.8	53.5	.29748	3361.4
77.5	.20536	4869.4	53.0	.30030	3330.2
77.0	.20669	4838.2	52.5	.30316	3298.7
76.5	.20803	4806.6	52.0	.30606	3267.4
76.0	.20941	4775.3	51.5	.30903	3235.8
75.5	.21081	4743.9	51.0	.31207	3204.3
75.0	.21220	4712.5	50.5	.31516	3173.1
74.5	.21362	4681.1	50.0	.31832	3141.6
74.0	.21507	4649.7	49.5	.32151	3110.2
73.5	.21654	4618.2	49.0	.32479	3078.7
73.0	.21801	4586.7	48.5	.32814	3047.3
72.5	.21953	4555.3	48.0	.33157	3015.8
72.0	.22104	4523.8	47.5	.33504	2984.6
71.5	.22259	4492.5	47.0	.33862	2953.2
71.0	.22415	4461.2	46.5	.34226	2921.8
70.5	.22575	4429.8	46.0	.34612	2890.3
70.0	.22746	4398.3	45.5	.34980	2858.8
69.5	.22901	4366.9	45.0	.35367	2827.4
69.0	.23065	4335.4	44.5	.35764	2796.1
68.5	.23237	4303.9	44.0	.36178	2764.5
68.0	.23406	4272.6	43.5	.36587	2733.2
67.5	.23577	4241.2	43.0	.37012	2701.8
67.0	.23754	4209.8	42.5	.37449	2670.3

Frequency, Inductive Reactance, and Capacitive Reactance Table.

Column 1	Column 2	Column 3	Column 1	Column 2	Column 3
Frequency	$1 \div w = 1 \div 2\pi f$	$w = 2\pi f$	Frequency	$1 \div w = 1 \div 2\pi f$	$w = 2\pi f$
42.0	.37891	2638.9	25.5	.62415	1602.2
41.5	.38356	2607.5	25.0	.63664	1570.8
41.0	.38815	2576.1	24.5	.64954	1539.4
40.5	.39298	2544.7	24.0	.66311	1508.1
40.0	.39779	2513.2	23.5	.67726	1476.4
39.5	.40292	2481.8	23.0	.69244	1445.2
39.0	.40808	2450.4	22.5	.70737	1413.7
38.5	.41338	2419.1	22.0	.72395	1382.3
38.0	.41884	2387.6	21.5	.74024	1350.8
37.5	.42441	2356.1	21.0	.75785	1319.5
37.0	.43015	2324.9	20.5	.77633	1288.2
36.5	.43602	2293.5	20.0	.79563	1256.5
36.0	.44208	2262.0	19.5	.81619	1225.3
35.5	.44833	2230.4	19.0	.83766	1193.8
35.0	.45491	2199.2	18.5	.86031	1162.3
34.5	.46132	2167.6	18.0	.88418	1131.0
34.0	.46812	2136.4	17.5	.90983	1099.5
33.5	.47508	2104.8	17.0	.93623	1068.1
33.0	.48228	2073.4	16.5	.96459	1036.7
32.5	.48977	2042.1	16.0	.99472	1005.2
32.0	.49736	2010.7	15.5	1.0262	973.88
31.5	.50525	1979.1	15.0	1.0611	942.49
31.0	.51301	1947.9	14.5	1.0975	911.07
30.5	.52181	1916.3	14.0	1.1367	879.64
30.0	.53051	1884.7	13.5	1.1788	848.23
29.5	.53952	1853.5	13.0	1.2244	816.82
29.0	.54881	1822.2	12.5	1.2733	785.41
28.5	.55844	1790.6	12.0	1.3261	753.99
28.0	.56841	1759.4	11.5	1.3851	722.56
27.5	.57841	1728.8	11.0	1.4478	691.16
27.0	.58995	1696.5	10.5	1.5157	659.73
26.5	.60060	1665.0	10.0	1.5915	628.32
26.0	.61214	1633.5			

WIRE CALCULATIONS FOR COIL FORMS.

This formula will permit calculation of the number of turns and the length of wire required of any specific diameter selected.

Let A = length of wire in inches required to fill coil winding space entirely.

B = wire diameter in inches.

C = radius of coil form in inches from dead centre to highest point of winding space.

D = radius of coil form in inches from dead centre to lowest point of winding space.

E = available winding length in inches.

F = number of turns of wire to entirely fill actual winding space.

Then $F = E\left[(C - D) \div B^2\right]$ and $A = \left[(3.1416\ E) \div B^2\right]\left[C^2 - D^2\right]$.

OHMS LAW
FOR D.C.

AMPERES = Volts ÷ Resistance.

" = Watts ÷ Volts.

" = $\sqrt{\text{Watts} \div \text{Resistance}}$.

VOLTS = Resistance x Amperes.

" = Watts ÷ Amperes.

" = $\sqrt{\text{Watts} \times \text{Resistance}}$.

WATTS = $[\text{Amperes}]^2 \times$ Resistance.

" = $[\text{Volts}]^2 \div$ Resistance.

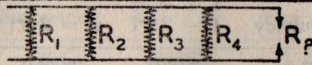
" = Amperes x Volts.

RESISTANCE = Volts ÷ Amperes.

" = $[\text{Volts}]^2 \div$ Watts.

" = Watts ÷ $[\text{Amperes}]^2$

RESISTANCES
IN PARALLEL



$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \text{etc.}}$$

2 PARALLEL RESISTANCES

$$R = [R_1 \times R_2] \div [R_1 + R_2]$$

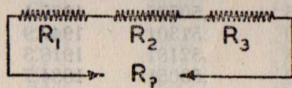
3 PARALLEL RESISTANCES

$$R = \frac{R_1 \times R_2 \times R_3}{[R_1 \times R_2] + [R_2 \times R_3] + [R_3 \times R_1]}$$

4 PARALLEL RESISTANCES

$$R = \frac{R_1 \times R_2 \times R_3 \times R_4}{[R_1 \times R_2 \times R_3] + [R_2 \times R_3 \times R_4] + [R_3 \times R_4 \times R_1] + [R_4 \times R_1 \times R_2]}$$

RESISTANCES
IN SERIES



$$R = R_1 + R_2 + R_3 + \text{etc}$$

OHMS. LAW FOR A.C.

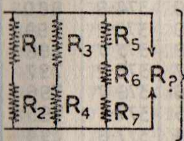
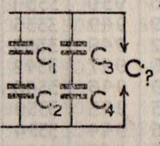
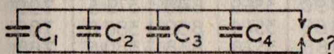
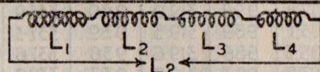
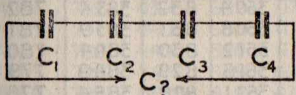
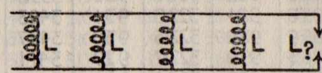
Where I = current in amperes.
Z = impedance in ohms.
E = voltage across Z.
P = wattage.
X = degrees of phase angle.

E = P ÷ (I cos X).
= $\sqrt{PZ \div \cos X}$.
= IZ.

Z = P ÷ (I^2 cos X).
= E ÷ I.
= (E^2 cos X) ÷ P.

P = IE cos X.
= (E^2 cos X) ÷ Z.
= I^2 Z cos X.

I = P ÷ (E cos X).
= E ÷ Z.
= $\sqrt{P \div (Z \cos X)}$.

RESISTANCES IN SERIES-PARALLEL	CONDENSERS IN SERIES-PARALLEL
 $R = \frac{1}{\frac{1}{R_1+R_2}+\frac{1}{R_3+R_4}+\frac{1}{R_5+R_6+R_7}}$	 $C = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}} + \frac{1}{\frac{1}{C_3}+\frac{1}{C_4}}$
CONDENSERS IN PARALLEL	**INDUCTANCES IN SERIES**
 $C = C_1 + C_2 + C_3 + C_4 +$ etc.	 WHERE THERE IS NO MUTUAL INDUCTANCE $L = L_1 + L_2 + L_3 + L_4 +$ etc
CONDENSERS IN SERIES	**INDUCTANCES IN PARALLEL**
 $C = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\frac{1}{C_4}+\text{etc.}}$	 $L = \frac{1}{\frac{1}{L_1}+\frac{1}{L_2}+\frac{1}{L_3}+\frac{1}{L_4}+\text{etc.}}$

WAVELENGTH AND FREQUENCY TABLE.

This table enables all calculations for wavelength and frequency to be arrived at. Although the table only covers a limited scale it is quite easy to cover any range required by the following method : If the figure in column A is multiplied by 10 the answer in column B must be divided by 10, or if the figure in column A is divided by 100 the answer in column B must be multiplied by 100. If column A is used to denote wavelength, then the answer in column B will be in Megacycles, or if column A is used for Frequency in Megacycles, the answer in column B will denote the equivalent wavelength in metres. This table is based on the fact that the frequency in kilocycles is equal to 299,820 ÷ by the wavelength in metres, whilst the wavelength in metres is equal to 299,820 ÷ by the frequency in kilocycles.

FREQUENCY AND WAVELENGTH TABLE

A	B	A	B	A	B	A	B	A	B
299·8	1000	315·6	950	333·1	900	352·7	850	374·8	800
300·1	999	315·9	949	333·5	899	353·1	849	375·2	799
300·4	998	316·2	948	333·9	898	353·6	848	375·7	798
300·7	997	316·6	947	334·2	897	354·0	847	376·2	797
301·0	996	316·9	946	334·6	896	354·4	846	376·7	796
301·3	995	317·3	945	335·0	895	354·8	845	377·1	795
301·6	994	317·6	944	335·4	894	355·2	844	377·6	794
301·9	993	317·9	943	335·7	893	355·6	843	378·2	793
302·2	992	318·3	942	336·1	892	356·1	842	378·6	792
302·5	991	318·6	941	336·5	891	356·5	841	379·0	791
302·8	990	319·0	940	336·9	890	356·9	840	379·5	790
303·1	989	319·3	939	337·3	889	357·4	839	380·0	789
303·5	988	319·6	938	337·6	888	357·8	838	380·5	788
303·8	987	319·9	937	338·0	887	358·2	837	381·0	787
304·1	986	320·3	936	338·4	886	358·6	836	381·4	786
304·4	985	320·7	935	338·8	885	359·0	835	381·9	785
304·7	984	321·0	934	339·2	884	359·5	834	382·4	784
305·0	983	321·4	933	339·5	883	359·9	833	382·9	783
305·3	982	321·7	932	339·8	882	360·4	832	383·4	782
305·6	981	322·0	931	340·3	881	360·8	831	383·9	781
305·9	980	322·3	930	340·7	880	361·2	830	384·4	780
306·3	979	322·7	929	341·1	879	361·6	829	384·9	779
306·6	978	323·1	928	341·5	878	362·1	828	385·4	778
306·9	977	323·4	927	341·9	877	362·5	827	385·9	777
307·2	976	323·8	926	342·3	876	363·0	826	386·4	776
307·5	975	324·1	925	342·7	875	363·4	825	386·9	775
307·8	974	324·5	924	343·0	874	363·9	824	387·4	774
308·1	973	324·8	923	343·4	873	364·3	823	387·9	773
308·4	972	325·2	922	343·8	872	364·7	822	388·4	772
308·8	971	325·5	921	344·2	871	365·2	821	388·9	771
309·1	970	325·9	920	344·6	870	365·7	820	389·4	770
309·4	969	326·2	919	345·0	869	366·1	819	389·9	769
309·8	968	326·6	918	345·4	868	366·5	818	390·4	768
310·1	967	327·0	917	345·8	867	367·0	817	390·9	767
310·4	966	327·3	916	346·2	866	367·4	816	391·4	766
310·8	965	327·7	915	346·6	865	367·9	815	391·9	765
311·0	964	328·0	914	347·0	864	368·3	814	392·4	764
311·3	963	328·4	913	347·4	863	368·8	813	392·9	763
311·7	962	328·8	912	347·8	862	369·2	812	393·4	762
312·0	961	329·1	911	348·2	861	369·6	811	394·0	761
312·3	960	329·5	910	348·6	860	370·1	810	394·5	760
312·7	959	329·9	909	349·0	859	370·6	809	395·0	759
313·0	958	330·2	908	349·4	858	371·1	808	395·5	758
313·3	957	330·6	907	349·8	857	371·5	807	396·0	757
313·6	956	330·9	906	350·2	856	372·0	806	396·6	756
314·0	955	331·3	905	350·7	855	372·4	805	397·1	755
314·3	954	331·7	904	351·1	854	372·9	804	397·6	754
314·6	953	332·1	903	351·5	853	373·4	803	398·2	753
314·9	952	332·4	902	351·9	852	373·8	802	398·7	752
315·3	951	332·8	901	352·3	851	374·3	801	399·2	751

FREQUENCY AND WAVELENGTH TABLE									
A	B	A	B	A	B	A	B	A	B
399·8	750	428·3	700	461·3	650	499·7	600	545·1	550
400·3	749	428·9	699	462·0	649	500·5	599	546·1	549
400·8	748	429·5	698	462·7	648	501·4	598	547·1	548
401·4	747	430·1	697	463·4	647	502·2	597	548·1	547
401·9	746	430·8	696	464·1	646	503·1	596	549·1	546
402·4	745	431·4	695	464·8	645	503·9	595	550·1	545
402·9	744	432·1	694	465·6	644	504·7	594	551·1	544
403·5	743	432·6	693	466·4	643	505·6	593	552·2	543
404·1	742	433·3	692	467·0	642	506·5	592	553·2	542
404·6	741	433·9	691	467·7	641	507·3	591	554·2	541
405·2	740	434·5	690	468·5	640	508·2	590	555·2	540
405·7	739	435·1	689	469·2	639	509·0	589	556·3	539
406·3	738	435·8	688	469·9	638	509·9	588	557·3	538
406·8	737	436·4	687	470·7	637	510·8	587	558·3	537
407·4	736	437·1	686	471·4	636	511·6	586	559·4	536
407·9	735	437·7	685	472·1	635	512·5	585	560·4	535
408·5	734	438·3	684	472·9	634	513·4	584	561·5	534
409·0	733	439·0	683	473·6	633	514·3	583	562·5	533
409·6	732	439·6	682	474·4	632	515·2	582	563·6	532
410·2	731	440·3	681	475·2	631	516·0	581	564·6	531
410·7	730	440·9	680	475·9	630	516·8	580	565·7	530
411·3	729	441·6	679	476·7	629	517·7	579	566·8	529
411·8	728	442·3	678	477·4	628	518·7	578	567·8	528
412·4	727	442·9	677	478·2	627	519·6	577	568·9	527
413·0	726	443·5	676	478·9	626	520·5	576	570·1	526
413·6	725	444·2	675	479·7	625	521·4	575	571·1	525
414·1	724	444·8	674	480·5	624	522·3	574	572·2	524
414·7	723	445·5	673	481·3	623	523·2	573	573·3	523
415·3	722	446·2	672	482·0	622	524·2	572	574·4	522
415·8	721	446·8	671	482·8	621	525·1	571	575·5	521
416·4	720	447·6	670	483·6	620	526·0	570	576·6	520
417·0	719	448·2	669	484·4	619	526·9	569	577·7	519
417·6	718	448·8	668	485·1	618	527·9	568	578·8	518
418·2	717	449·5	667	485·9	617	528·8	567	579·9	517
418·8	716	450·2	666	486·7	616	529·7	566	581·1	516
419·3	715	450·9	665	487·5	615	530·7	565	582·2	515
419·9	714	451·5	664	488·3	614	531·6	564	583·3	514
420·5	713	452·2	663	489·1	613	532·5	563	584·4	513
421·1	712	452·9	662	489·9	612	533·5	562	585·5	512
421·7	711	453·6	661	490·7	611	534·5	561	586·6	511
422·3	710	454·3	660	491·5	610	535·4	560	587·8	510
422·9	709	455·1	659	492·4	609	536·4	559	588·9	509
423·5	708	455·7	658	493·1	608	537·3	558	590·2	508
424·1	707	456·3	657	493·9	607	538·3	557	591·3	507
424·7	706	457·0	656	494·8	606	539·2	556	592·5	506
425·3	705	457·7	655	495·7	605	540·2	555	593·7	505
425·9	704	458·4	654	496·5	604	541·2	554	594·9	504
426·5	703	459·1	653	497·3	603	542·2	553	596·1	503
427·1	702	459·8	652	498·0	602	543·2	552	597·3	502
427·7	701	460·5	651	498·9	601	544·1	551	598·4	501

FREQUENCY AND WAVELENGTH TABLE

A	B	A	B	A	B	A	B	A	B
599·6	500	666·3	450	749·4	400	856·5	350	999·4	300
600·8	499	667·8	449	751·3	399	859·1	349	1003·	299
602·1	498	669·2	448	753·2	398	861·6	348	1006·	298
603·3	497	670·7	447	755·1	397	864·1	347	1009·	297
604·5	496	672·2	446	757·1	396	866·5	346	1013·	296
605·7	495	673·8	445	759·1	395	869·1	345	1016·	295
606·9	494	675·3	444	761·0	394	871·6	344	1020·	294
608·2	493	676·9	443	762·8	393	874·2	343	1024·	293
609·4	492	678·3	442	764·8	392	876·7	342	1027·	292
610·6	491	679·9	441	766·7	391	879·2	341	1030·	291
611·9	490	681·4	440	768·7	390	881·8	340	1034·	290
613·1	489	683·0	439	770·7	389	884·4	339	1037·	289
614·4	488	684·6	438	772·7	388	887·1	338	1041·	288
615·6	487	686·1	437	774·7	387	889·7	337	1045·	287
616·9	486	687·7	436	776·8	386	892·3	336	1048·	286
618·2	485	689·2	435	778·8	385	895·1	335	1052·	285
619·5	484	690·8	434	780·8	384	897·7	334	1056·	284
620·7	483	692·4	433	782·8	383	900·3	333	1059·	283
622·1	482	694·0	432	784·8	382	903·1	332	1063·	282
623·3	481	695·6	431	786·9	381	905·8	331	1066·	281
624·6	480	697·3	430	789·0	380	908·6	330	1070·	280
625·9	479	698·9	429	791·1	379	911·3	329	1074·	279
627·3	478	700·6	428	793·2	378	914·1	328	1078·	278
628·6	477	702·2	427	795·3	377	916·9	327	1082·	277
629·9	476	703·8	426	797·4	376	919·7	326	1086·	276
631·2	475	705·5	425	799·5	375	922·5	325	1090·	275
632·5	474	707·1	424	801·7	374	925·4	324	1094·	274
633·9	473	708·8	423	803·8	373	928·2	323	1098·	273
635·2	472	710·5	422	805·9	372	931·1	322	1102·	272
636·6	471	712·2	421	808·1	371	934·1	321	1106·	271
637·9	470	713·9	420	810·3	370	936·9	320	1110·	270
639·3	469	715·6	419	812·5	369	939·8	319	1115·	269
640·6	468	717·3	418	814·7	368	942·8	318	1119·	268
642·1	467	719·1	417	817·1	367	945·8	317	1123·	267
643·4	466	720·7	416	819·2	366	948·8	316	1127·	266
644·8	465	722·5	415	821·4	365	951·8	315	1131·	265
646·2	464	724·2	414	823·8	364	954·8	314	1136·	264
647·6	463	725·9	413	826·1	363	957·9	313	1141·	263
649·1	462	727·7	412	828·3	362	961·1	312	1145·	262
650·4	461	729·5	411	830·4	361	964·1	311	1149·	261
651·8	460	731·3	410	832·8	360	967·2	310	1153·	260
653·2	459	733·1	409	835·2	359	970·3	309	1158·	259
654·6	458	734·9	408	837·5	358	973·4	308	1162·	258
656·1	457	736·7	407	839·8	357	976·7	307	1167·	257
657·5	456	738·5	406	842·2	356	979·8	306	1171·	256
658·9	455	740·3	405	844·6	355	983·1	305	1176·	255
660·4	454	742·1	404	847·1	354	986·2	304	1180·	254
661·9	453	744·1	403	849·4	353	989·4	303	1185·	253
663·3	452	745·8	402	851·8	352	992·8	302	1190·	252
664·8	451	747·7	401	854·2	351	996·2	301	1195·	251

FREQUENCY AND WAVELENGTH TABLE

A	B	A	B	A	B	A	B	A	B
1199	250	1362	220	1578	190	1873	160	2306	130
1204	249	1369	219	1587	189	1885	159	2323	129
1209	248	1375	218	1595	188	1898	158	2342	128
1214	247	1381	217	1603	187	1910	157	2361	127
1219	246	1388	216	1612	186	1923	156	2380	126
1224	245	1395	215	1620	185	1934	155	2399	125
1229	244	1401	214	1629	184	1947	154	2417	124
1234	243	1407	213	1638	183	1960	153	2438	123
1239	242	1414	212	1647	182	1973	152	2458	122
1244	241	1421	211	1656	181	1986	151	2478	121
1249	240	1428	210	1665	180	2000	150	2498	120
1255	239	1435	209	1675	179	2012	149	2521	119
1260	238	1442	208	1684	178	2025	148	2541	118
1265	237	1448	207	1694	177	2040	147	2563	117
1270	236	1454	206	1703	176	2053	146	2585	116
1276	235	1463	205	1713	175	2067	145	2607	115
1281	234	1470	204	1723	174	2082	144	2630	114
1287	233	1477	203	1733	173	2097	143	2653	113
1293	232	1484	202	1743	172	2110	142	2677	112
1298	231	1492	201	1753	171	2127	141	2701	111
1303	230	1499	200	1763	170	2142	140	2726	110
1309	229	1507	199	1774	169	2157	139	2751	109
1315	228	1514	198	1784	168	2173	138	2776	108
1321	227	1523	197	1794	167	2188	137	2808	107
1327	226	1531	196	1806	166	2204	136	2828	106
1333	225	1538	195	1817	165	2221	135	2855	105
1338	224	1545	194	1828	164	2237	134	2883	104
1344	223	1553	193	1839	163	2254	133	2911	103
1351	222	1562	192	1851	162	2272	132	2939	102
1357	221	1570	191	1862	161	2289	131	2969	101
								2998	100

ENGLISH-GERMAN RADIO VOCABULARY.

a. c. = alternating current Wechselstrom
accordance Abstimmung
acid Säure
adapt anpassen
adapter Zwischenstecker
adjustable condenser variabler Kondensator
adjustable disc condenser Drehkondensator
adjusting slider Kontaktschieber
advance Nickelin
aerial Antenne
aerial change-over switch Antennenumschalter
aerial extension Luftleitergebilde
aerial inductance Antennenselbstinduktion
aerial, plain Einfachantenne
a. f. = audio frequency Hörfrequenz
agate Achat
A. H. = ampere hour Amperestunde
air condenser Luftkondensator
air core Luftkern (d. h. ohne Eisenkern)
air core protecting choke Schutzdrossel ohne Eisenkern
air gap Luftspalt
allotment Verteilung
alloy Legierung
alteration of the coupling Veränderung der Kopplung
alternating current Wechselstrom
alternator Wechselstromgenerator
alternator disc set Generator mit rotierender Funkenstrecke
alum Alaun

ammeter Amperemeter
amperage Amperezahl
ampere-turns Amperewindungen
amplification Verstärkung
amplification factor Verstärkungsgrad
amplifier Verstärker
amplify verstärken
angle Winkel
angular velocity Winkelgeschwindigkeit
antagonistic entgegenwirkend
antenna Luftleiter
antinode Kurvenband
aperture Öffnung
apex Spitze
application Anwendung
arbor Achse
arc Lichtbogen
arc transmitter Lichtbogensender
area turns Windungsfläche
argentan Neusilber
armature, condenser Kondensatorbelegung
armature of a dynamo Anker einer Dynamo
armatures of a condenser wirksame Metallteile eines Kondensators
armour bewehren, armieren
artificial antenna künstliche Antenne
artificial line künstliche Leitung
arrester, earth terminal Erdung über Funkenstrecke
arrester, lightning Blitzableiter
asynchronous discharger Plattenfunkenstrecke
atmospherics Luftstörungen
attenuate dämpfen
attenuation Amplitudenabfall freier Wellen, Dämpfung
audibility factor Hörbarkeit
audio frequency Tonfrequenz
auto-coupling galvanisch-induktive Kopplung
autodyne Rückkopplungsempfänger, Schwingaudion
auto-heterodyne Schwingaudion
auto-room Apparatesaal
auto transformer Spartransformator
auto transmitter automatischer Geber
auxiliary coil Hilfsspule
average value Mittelwert
A. W. G. = American wire gauge Amerikanische Drahtlehre
backstay Pardune
balance, capacity Gegengewicht
balance, electric elektrisches Gleichgewicht
balancing aerial vom Sender entkoppelte Empfangsantenne
ball-shaped kugelförmig
band of frequencies Frequenzbereich
bare wire blanker Draht
beacon, directional gerichtete Strahlung
beacon, radio Richtungssender
beam Strahl
beam transmitting station Einstrahlfunkstelle, Richtsendeanlage
bearing Teilung
beat Überlagerung, Pulsation
beat-frequency Überlagerungsfrequenz
beats heterodyne Überlagerung mit Röhre
beat note Schwebungston
beat receiver Überlagerungsempfänger
beat reception Überlagerungsempfang
bent antenna geknickte Antenne
bell Klingel
bevel wheel Kegelrad
bilateral zweiseitig
blocking of continuous current Gleichstromblockierung
blower Gebläse
blow-out, spark Funkenlöschung
bobbin Spule
boss Nabe
box-kite Kastendrachen
bracket Stütze
branched currents verzweigte Ströme
branched spark verzweigter Funke
brass Messing
braze hartlöten
breaker, circuit Stromunterbrecher
break, hammer Hammerunterbrecher
break spark Unterbrechungsfunke
break, vibrating Hammerunterbrecher
broadcasting Rundfunk
brush, contact Kontaktbürste
brush discharge Büschelentladung
B. S. G. = British Standard Gauge Britische Normallehre
bull variometer Kugelvariometer
busbars Sammelschienen
buzzer Summer
by-pass condenser Überbrückungskondensator

cages Käfigantenne
calibration condenser Eichkondensator
calido Chromnickelstahl
call-bell Alarmglocke
call letter Rufzeichen
capacity earth Gegengewicht
capacity, specific inductive Dielektrizitätskonstante

carbon Kohle
cardboard Pappe
carrier current telephony Hochfrequenztelephonie auf Leitungen
carrier wave Trägerwelle
case Gehäuse
cast iron Gußeisen
catch Haken
cathode ray oscillograph Braunsche Röhre
c. c. = continuous current Gleichstrom
cell, galvanic galvanisches Element
cell, photo Photozelle
cell sensitive to light lichtempfindliche Zelle
cell, wet nasses Element
c. e. m. f. = counter electromotoric force gegenelektromotorische Kraft
centre of gravity Schwerpunkt
cessation Stillstand, Unterbrechung
change of connection for Umschaltung auf
change over switch Umschalter
changer Wandler
change-tune switch Wellenumschalter
changer, frequency Frequenzwandler
charge Ladung
charging switch Ladeschalter
chatter prellen, klappern
choke Drossel
choking coil Drosselspule
circuit Stromkreis
circuit breaker Ausschalter
circuit, magnetic magnetischer Kreis
circular cross-section runder Querschnitt
click ticken, Knackgeräusche
close coupling feste Kopplung
closed circuit current Ruhestrom
closed oscillating circuit geschlossener Schwingungskreis
closer, circuit Stromschließer
coarse mesh grid grobmaschiges Gitter
coated filament, oxide Oxydheizfaden
coating Überzug
coating of the jar Metallbelag der Leydener Flaschen
coating of a condenser Kondensatorbelegung
code, Morse Morseschrift
coherence Frittung
coil Spule
coil antenna Rahmenantenne
common reactance gegenseitige Induktion
concentrator Klinkenumschalter
condenser armature Kondensatorbelegung
condenser circuit Kondensatorkreis
condenser transmitter Kondensatormikrophon
conductance Leitfähigkeit
conduction Übertragung
conductivity spezifische Leitfähigkeit
conductor Leiter
cone antenna Kegelantenne
connection Verbindung
connector Verbindungsklemme
constrained oscillation erzwungene Schwingung
contin'uous current Gleichstrom
continuous wave kontinuierliche Welle
contortion Verzerrung
control steuern
control grid Steuergitter
converter rotierender Umformer
convey übertragen
coordination, inductive Übersprechen
copper Kupfer
core Kern, Ader
core, air ohne Eisenkern
core, iron Eisenkern
core-carbon Dochtkohle
cotton Baumwolle
counterpoise Gegengewicht
counter voltage Gegenspannung
counterweight Gegengewicht
coupled oscillatory circuits gekoppelte Schwingungskreise
couple, thermo- Thermoelement
coupling Kopplung
coupling coefficient Kopplungskoeffizient
coupling, flexible biegsame Verbindung
coupling, reaction Rückkopplung
c. p. s. = cycles per second Perioden/sec
crest Scheitelwert
cross-section Querschnitt
crystal rectifier Kristalldetektor
cube Kubus
cube root Kubikwurzel
cu.cm. Kubikzentimeter
cu.ft. Kubikfuß
current Strom
cusp Wendepunkt
cut-out Ausschalter
c. w. = continuous waves ungedämpfte Wellen
cycles Perioden
cymometer Wellenmesser

damped waves gedämpfte Wellen
damper Schalldämpfer
damping Dämpfung
damping, loss Verlustdämpfung
damping of the antenna radiation Strahlungsdämpfung
damping reduction Dämpfungsreduktion
dampness Feuchtigkeit
dash Morsestrich
d. c. = direct current Gleichstrom
dead stromlos, spannungslos
dead-beat aperiodisch (Grenzwert)
decay Abfall, Dämpfungsfaktor
decaying current abnehmende Stromstärke
decoherence Entfrittung
decreasing amplitude abnehmende Amplitude
decrement Dämpfungsdekrement
decremeter Dämpfungsmesser
deflecting plates Ablenkungselektroden
deflection Durchbiegung, Galvanometerausschlag
deflectional sensitivity Empfindlichkeit des Zeigerausschlags
degree of coupling Kopplungsgrad
demijohn Glasballon
d. f. = direction finding Richtungsbestimmung
delta-connected in Dreiecksschaltung
density Dichte
departure Abweichung
dependence Abhängigkeit
depth Tiefe
derivation Ableitung
design Konstruktion, Ausführung
detune verstimmen
device Vorrichtung, Erfindung
device suspension Aufhängevorrichtung
dielectric strength dielektrische Festigkeit
dielectric substance Dielektrikum
diode valve Zweielektrodenröhre
direct current Gleichstrom
directional aerial gerichtete Antenne
directional reception Richtempfang
directional wireless telegraphy gerichtete Radio-Telegraphie
direction finder Peilempfänger
directive reception gerichteter Empfang
disc Scheibe
disc condenser, adjustable Drehkondensator
disc gap Scheibenfunkenstrecke
disc set, alternator Generator mit rotierender Funkenstrecke
discharge Entladung
discharger Funkenstrecke
displacement current dielektrischer Verschiebungsstrom
disruptive strength Durchschlagsfestigkeit
dissipate zerstreuen
dissipation of energy Energiezerstreuung
distance of transmission Reichweite
distance, sparking Funkenstrecke
distortion Verzerrung
disturbance Störung
distributed capacity verteilte Kapazität
dog Zahn, Klinke
dot Morsepunkt
double-pole switch zweipoliger Schalter
drop, voltage Spannungsabfall
drum Trommel
drum armature Trommelanker
drum winding Trommelwicklung
drummy dumpf
dry cell Trockenelement
dual receiver Reflexempfänger
duplex, working Duplexbetrieb
duration of oscillation Schwingungsdauer
dying oscillation abklingende Schwingung

earth arrester Erdung über Funkenstrecke
earth capacity Gegengewicht
earth connection Erdverbindung
earth screen Gegengewicht
earth terminal arrester Erdung über Funkenstrecke
earth return Erdrückleitung
economical transformer Spartransformator
eddy currents Wirbelströme
efficiency Wirkungsgrad
electron current Elektronenstrom
electron tube Elektronenröhre
elevated conductor Luftleitergebilde
e. m. elektromagnetische Einheiten
embosser Reliefschreiber
e. m. f. elektromotorische Kraft
emission, electron Elektronenemission
emit aussenden
enamel Emaille
end face Stirnfläche
endodyne Schwingungserzeuger (Überlagerer)
engine Maschine
equation Gleichung

equifrequent conductor mitschwingender Leiter
e. s. elektrostatische Einheiten
equi-radial aerial ungerichtete Antenne
even harmonics geradzahlige Oberschwingungen
excite erregen
excitation Erregung
excited, self- selbsterregt
excited, separately fremderregt
exciter Erreger
exciting spark gap Erreger-Funkenstrecke
exhaustion Erschöpfung
extension of antenna Verlängerung der Antenne
extinguisher, spark Funkenlöschung
exude ausscheiden
eyelet Öse

fading Verschwinden der Zeichen
fall in potential Spannungsabfall
fail, signals Zeichen bleiben aus
fan antenna Harfenantenne
fan-shaped antenna Fächerantenne
feeble signals schwache Zeichen
field, electric elektrisches Feld
field-break switch Magnetausschalter
field coil Feldspule
filament Heizfaden
filament battery Heizbatterie
filings Feilspäne
fine mesh grid feinmaschiges Gitter
fixed discharger feste Funkenstrecke
flat copper Flachkupfer
flat square coil Flachspule
flat tuning unscharfes Abstimmen
flexible coupling biegsame Verbindung
flicked off zerhackt
fluctuation Schwankung
flux Kraftfluß
flywheel circuit Schwungradschaltung
force, electromotive elektromotorische Kraft
forced oscillation erzwungene Schwingung
F. P. S. = foot-pound-second-system praktisches engl. Maßsystem
frame aerial Rahmenantenne
freedom from troubles Störungsfreiheit
frequency, limiting Grenzfrequenz
frequency meter Frequenzmesser
ft. = foot Fuß
fundamental oscillation Grundschwingung
funnel-shaped antenna trichterförmige Antenne
fuse Sicherung

gain Gewinn, Verstärkungsgrad
galena Bleiglanz
gauge eichen
gap Spalt
gap, spark Funkenstrecke
gauze Gaze
geared down to untersetzt auf
gear, head Kopffernhörer
generating plant Stromerzeugungsanlage
German silver Neusilber
gilt vergoldet
glow lamp Glühlampe
glow discharger lamp Glimmlampe
granular coherer Körnerfritter
gravity, centre of Schwerpunkt
grid Gitter
grid leak Gitterableitung
grinder atm. Störungen besonderer Art
ground connection Erdverbindung
grounded geerdet
group frequency Frequenz einer Wellengruppe

hammer break Hammerunterbrecher
hanger Luftkabel
hard rubber Hartgummi
harmonic oscillation Oberschwingung
harmonics Oberschwingungen
heart-shape herzförmig
height, effective wirksame Höhe
height of mast Masthöhe
height, radiation Strahlhöhe
Hertzian waves Hertzsche Wellen
heterodyne Überlagerung, Schwingungserzeugung durch Überlagerung
heterodyne receiver Überlagerungsempfänger
h. f. = high frequency Hochfrequenz
high damping große Dämpfung
high frequency Hochfrequenz
high-power station Kraftstation
high-pressure condenser Hochspannungskondensator
high-speed telegraphy Schnelltelegraphie
high tension Hochspannung
homodyne reception Empfang mit Erzeugung der Trägerfrequenz
honeycomb coil Spule mit Wabenwicklung
hot-cathode Glühkathode
hot-wire Hitzdraht
hotwire ammeter Hitzdrahtamperemeter

h. p. = **horse power** Pferdestärke
h. t. = **high tension** Hochspannung

ignition device Zündapparat
image transmission Bildübertragung
impact excitation Stoßerregung
impedance scheinbarer Widerstand
imperfect tuning unscharfe Abstimmung
impression of the signals, clear scharfe Abgrenzung der Zeichen
in. = **inch** Zoll
inaudible unhörbar
incandescent cathode Glühkathode
incidence, angle of Einfallswinkel
indiarubber Gummi
inductance Selbstinduktion
inductance coil Selbstinduktionsspule
induction coil Induktionsspule, Funkeninduktor
inductive capacity, specific Dielektrizitätskonstante
inductive transmitter gekoppelter Sender
indoor aerial Zimmerantenne
inefficient unwirksam
inert träge
initial intensity Anfangsintensität
inker Farbschreiber
inkwriter Farbschreiber
input zugeführte Leistung, Kraftbedarf
insulation Isolation
insulator Isolator
insert einschalten
intensifier Verstärker
interference Störung, besonders durch Interferenz mit anderen Wellen
intermediate circuit Zwischenkreis
interrupter Unterbrecher, Ticker
iron Eisen
iron core Eisenkern
ironclad eisenbewehrt
ironless eisenfrei
ivory Elfenbein
jack Klinke, Umschaltklinke
jam stören
jammings Störungen
jar capacity Flaschenkapazität
jars, Leyden Leydener Flaschen
jet Strahl
jigger Kopplungstransformator
joint Gelenk, Verschluß

kallirotron Verstärker mit Widerstandsübertragern
k. c. = **kilocycles** Kilohertz
keeper of a magnet Magnetanker
kenotron Hochvakuumgleichrichterröhre
key Taste
key, relay Tastrelais
key, sending Sendetaste
kite Drachen
knife switch Messerschalter, Hebelschalter

lamp Röhre
lattice mast Gittermast
lattice coil Spule mit Wabenwicklung
layer Schicht
layer of tin-foil Stanniolbelag
lb = **pound** (*libra*) Pfund
lead Blei, Leitung
leading-in insulator Einführungsisolator
leading-through Durchführung
leak, grid Gitterableitung
leakage Ableitung
leakage flux Streufluß
leaking Ableitung
left-handed thread Linksgewinde
legibility of signals Lesbarkeit von Zeichen
length of spark Funkenlänge
lengthening coil Verlängerungsspule
lens Linse
lever Hebelarm
Leyden jar Leydener Flasche
lightning arrester Blitzableiter
limiting frequency Grenzfrequenz
line Leitung
linkage Verkettung
lines of force Kraftlinien
load Ladung, Last
loading coil Verlängerungsspule
local oscillator Überlagerer
locking device Sperrvorrichtung
long-distance station Großstation
loop antenna Rahmenantenne
loop, current Strombauch
loop of the oscillation Schwingungsbauch
loop, potential Spannungsbauch
loose coupling lose Kopplung
loss damping Verlustdämpfung
low frequency Niederfrequenz
low tension Niederspannung
luminous rays Lichtstrahlen

magnetism Magnetismus
magnification Verstärkung
magnifier Verstärker
magnitude Größe
main-busbars Hauptsammelschienen

main circuit Hauptstromkreis
main switch Hauptschalter
mains, d. c. Gleichstromnetz
manipulation Tastung
marble Marmor
marking contact Zeichenstromkontakt
mast Mast
masthead Mastspitze
mean value Mittelwert
means for tuning Abstimmittel
measure messen
measurement Messung
mesh, coarse grobmaschig
mesh, fine feinmaschig
mesh, grid Gittermasche
message Telegramm
meter Meßinstrument
micrometric spark discharger Funkenmikrometer
M. M. F. = magnetomotive force magnetomotorische Kraft
monitoring device Anrufeinrichtung
movable plates drehbare Platten
multilayer coil mehrlagige Spule
multiple antenna Vielfachantenne
multiple spark gap unterteilte Funkenstrecke
multi turn viele Windungen
mute antenna künstliche Antenne
mutual induction gegenseitige Induktion

natural oscillation Eigenschwingung
natural wave-length Eigenschwingung
network, aerial Luftleitergebilde
nodal point of vibration Schwingungsknoten
node, current Stromknoten
node, potential Spannungsknoten
node, vibration Schwingungsknoten
noise Geräusch
non-inductive induktionsfrei
non-oscillatory aperiodisch
note magnification Tonverstärkung
note of pitch Überlagerungston
note tuning Tonabstimmung, Tonhöhe der Abstimmung

odd harmonics ungradzahlige Oberschwingungen
oil-break switch Ölschalter
one-way in einer Richtung, Simplex
open circuit Arbeitsstromkreis
open oscillating circuit offener Schwingungskreis
opposite phase entgegengesetzte Phase
oscillating valve Senderöhre
oscillation Schwingung
oscillatory circuit Schwingungskreis
oscillion Elektronenröhre
output abgegebene Leistung
overload Überlastung
oxide-coated filament Oxydheizfaden

pancake coil Flachspule
pawl Sperrklinke
partial wave Kopplungswelle
passage of spark Funkenübergang
pasteboard Pappe
p. d. Potentialdifferenz
peak-load Spitzenbelastung
peaky curve spitze Kurve
perforator Lochapparat
phase difference by dielectric loss Verlustwinkel
phase displacement Phasenverschiebung
phase relation Phasenbeziehung
picofarad = Mikromikrofarad
pictures, transmission of Bildübertragung
pitch Tonhöhe, Pech
pitch of the beat note Tonhöhe der Überlagerung
pitch of the signal note Tonhöhe des Zeichens
plain aerial alte Marconi-Antenne
plant Anlage
plate Anode
plate current Anodenstrom
plate supply Anodenbatterie
pliodynatron Doppelgitterröhre
pliotron Elektronenröhre mit sehr gutem Vakuum
plug Kontaktstöpsel
pointed spitz
pole-piece Polschuh
portable station tragbare Station
powder coherer Pulverfritter
practice buzzer Übungssummer
pressboard Preßspan
press switch Druckschalter
printing telegraph Drucktelegraph
propagation of waves Fortpflanzung von Wellen
propagation, velocity of wave- Fortpflanzungsgeschwindigkeit
protecting choke Drosselspule
pulse Wechsel, halbe Periode
puncher Stanzapparat
push-pull amplifier Druck-Zug-Verstärker, Gegentaktverstärker

quench löschen
quenched spark Löschfunken

quenched spark gap Löschfunkenstrecke
quick-break switch Momentschalter
range Reichweite
range of frequencies Frequenzbereich, Spektrum
radiation, Strahlung
radiation into space Ausstrahlung
rapidity of signaling Telegraphiergeschwindigkeit
raw rubber Rohgummi
rays Strahlen
reactance induktiver Widerstand
reaction coupling Rückkopplung
reactor Drosselspule
re-broadcasting Ballsender
receiver Empfänger
receiving aerial Empfangsantenne
recess Nute, Eindrehung
recording telegraph Schreibtelegraph
recorder Schreiber, Schreibtelegraph
rectifier Gleichrichter
regenerative amplifier Rückkopplungsverstärker
reflex circuit Rückkopplungskreis
reluctance magnetischer Widerstand
r. m. s. = root mean square Effektivwert
relay Relais
remote control Fernbed'enung
remote control switch Fernschalter
repeater Relaisübertragung
repeating amplifier Kaskadenverstärker
repeating relay Übertragungsrelais
resistance Widerstand
resonant conductor mitschwingender Leiter
reversal of current Stromumkehrung
reverser, current Stromwender
revolutions Umdrehungen
revolve rotieren
ribbon Flachdraht
right-handed thread Rechtsgewinde
rising current zunehmende Stromstärke
roof-shaped antenna dachförmige Antenne
root Wurzel
rope, steel Stahlpardune
rotating field Drehfeld
rotation frame aerial drehbare Rahmenantenne
r. p. m. = revolutions per minute Umdrehungen in der Minute
rubber Gummi
rubbing contact Reibungskontakt
rush of current Stromstoß
safe carriing capacity maximale Belastbarkeit
safety plug Schmelzsicherung
saturation current Sättigungsstrom
screen Schirm, Skala
screened cabin abgeschirmter Empfangsraum
screening box Schutzkasten
screw Schraube
screwdriver Schraubenzieher
search coil Suchspule
selectivity Störungsfreiheit, Selektivität
self capacitv Eigenkapazität
self exited selbsterregt
self-heterodyne receiver Rückkopplungsempfänger
sending key Sendetaste
sensibility Empfindlichkeit
sensitiveness Empfindlichkeit
sensitivity Empfindlichkeit
separate heterodyne receiver Empfänger mit Überlagerer
series-connected condensers in Serie geschaltete Kondensatoren
series-resonant circuit Resonanzkreis in Reihenschaltung
set Apparatesatz
shaking .Erschütterung
shape of (the) curve Kurvenform
sharply tuned scharf abgestimmt
sharpness of tuning Abstimmschärfe
shielded transformer gepanzerter Transformator
short circuiting device Kurzschließer
short wave condenser Verkürzungskondensator
shortening condenser Verkürzungskondensator
shunt Nebenschluß
shunt regulator Nebenschlußregulator
S. I. C. = specific inductive capacity Dielektrizitätskonstante
side band Seidenband durch Modulation
signal-to-noise ratio Verhältnis von Lautstärke zu Störungen
signal strength Lautstärke
silver Silber
sine curve Sinuskurve
single phase einphasig
single-pole switch einpoliger Schalter
sinusoidal sinusförmig
sketch Skizze
slider, adjusting Schiebekontakt
sliding contact Schiebekontakt
slightly damped schwach gedämpft
slight damping schwache Dämpfung

slip ring Schleifring
slit Schlitz
small-power station Kleinstation
smooth glatt
smooth disc discharger rotierende Funkenstrecke ohne Zacken
smother condenser Ausgleichkondensator
soft iron Weicheisen
soft-iron vane instrument Weicheiseninstrument
solenoid Spule
solution Lösung (in Flüssigkeit)
sourdine Schalldämpfer
spacing contact Trennstromkontakt
span Antennenabspannung
span pole Abspannpfahl
spark Funke
spark coil Funkeninduktor
spark discharge Funkenübergang
sparking distance Funkenstrecke
spark gap Funkenstrecke
spark gap, multiple unterteilte Funkenstrecke
spark micrometer gap Funkenmikrometer
spark, quenched Löschfunken
spark rate Funkenzahl
specific inductive capacity Dielektrizitätskonstanté
speed of signalling Telegraphiergeschwindigkeit
speed, transmitting Sendegeschwindigkeit
spot of light Lichtzeiger
spring Feder
spring drum Federtrommel
square Quadrat
squealing Selbsttönen (von Verstärkern)
squirrel cage aerial Reusenantenne
stage, multi- mehrstufig
starter Anlasser
starting resistance Anlasser
static frequency changer (statischer) Frequenzwandler
statics atmosphärische Störungen
station, long-distance Großstation
station, small-power Kleinstation
steadiness of the wave Konstanz der Wellenlänge
steel Stahl
steep steil
step, to come in in Tritt kommen
step-up transformer Hochtransformator
stop-screw Anschlagschraube
storage battery Akkumulatorenbatterie
straight oscillator geradliniger Oszillator
straight wire ausgespannter Draht
strain-insulator zugfester Antennenisolator
strays atmosphärische Störungen
strength, dielectrice dielektrische Festigkeit
strength, disruptive Durchschlagsfestigkeit
strength, signal Lautstärke
strengthened verstärkt
stress, dielectric dielektrische Beanspruchung
strip, paper Papierstreifen
strongly damped stark gedämpft
studded mit Zähnen versehen
studded disc discharger rotierende Funkenstrecke mit Zähnen
studio Aufnahmreaum
sulphuric acid Schwefelsäure
superimpose überlagern
supply Speisung, Stromzuführung, Stromquelle
support, antenna Antennenbefestigung
surface Oberfläche
suspension device Aufhängevorrichtung
s. w. g. = standard wire gauge
swinging Schwingung
switch Schalter
switch, change-over Umschalter
switch, change-tune Wellenumschalter
switchboard Schalttafel
synchronous spark discharger rotierende Funkenstrecke
syntonic wireless telegraphy abgestimmte drahtlose Telegraphie
syntonisation Abstimmung
syntonise abstimmen
syntonising coil Abstimmspule
syntonising inductance Variometer
syntony Abstimmung

tapper Klopfer
tapping Erschütterung
tension Spannung
terminal Klemme
test Versuch
tester Prüfapparat
testing Prüfung
thermionic amplifier Röhrenverstärker
thermionic valve Elektronenröhre
thermionic valve detector Audionröhre
thermions Thermionen
thermo-couple Thermoelement

thoriated tungsten filament Wolfram-Heizfaden mit Thoroxyd
thread Gewinde
tight coupling feste Kopplung
time of oscillation Schwingungsdauer
timed spark Taktfunken
tin Zinn
tin-foil coating Staniolbelag
toll cable Fernkabel
toll call Ferngespräch
toroidal coil Ringspule
T-shaped antenna T-Antenne
traffic Verkehr
trailing aerial freihängende Antenne
transformer Transformator
transient current Augenblicksstrom
transient potential difference Augenblicksspannung
transmitter Sender
transmitter, inductive gekoppelter Sender
transmitting, aerial Sendeantenne
transmitting insulator Isolator für Sendeantenne
transmitting valve Senderöhre
trembler Selbstunterbrecher
triode Dreielektrodenröhre
troubles Störungen
tube Röhre
tune abstimmen
tuner Abstimmapparat
tungsten Wolfram
tuning Abstimmung
tuning fork Stimmgabel
tuning fork circuit breaker Stimmgabelunterbrecher
turns, ampere- Amperewindungen
twin-coupled condenser doppelt geschalteter Kondensator

umbrella aerial Schirmantenne
undamped waves ungedämpfte Wellen
undulatory movement Schwingung
unidirectional einseitig gerichtet
unit Einheit, Einheitsmaß
unpure unrein
useful damping Nutzdämpfung
useful effect Nutzleistung

valve Röhre
valve receiver Röhrenempfänger
valve transmitter Röhrensender
vertical electric waves stehende elektrische Wellen
vibrating break Hammerunterbrecher
vibration Schwingung
vibration period Schwingungsperiode
voltage Spannung
volumen indicator Lautstärkenmesser
volumen of speech Lautstärke

water-jet Wasserstrahl
wave Welle
wave antenna Horizontal-Antenne (Länge ≈ 1 Wellenlänge)
wave-changing switch Wellenumschalter
wave-length Wellenlänge
wave propagation Fortpflanzung der Wellen
wave-train Wellenzug
wave tuning Wellenlängenabstimmung
wavemeter Wellenmesser
weak coupling lose Kopplung
weakly damped schwach gedämpft
wear Abnutzung
wheel Rad
wheels, train of Räderwerk
whistling Pfeifen
winding Wickelung
wing circuit Anodenstromkreis
wire Draht
wired wireless Hochfrequenztelegraphie auf Leitungen
wireless telegraphy drahtlose Telegraphie
worm Schneckenrad

Y-connected in Sternschaltung
yoke Joch

zincite Rotzinkerz

IMPEDANCE.

Impedance is the whole opposition of a radio circuit or component to the passage of an A.C. at any specific frequency and is, in fact, a combination of reactance and resistance. Numerically its value is denoted in Ohms.

Let A = impedance in ohms.
B = capacity in farads.
C = reactance of induction in ohms.
D = inductance of coil in henries.
E = D.C. resistance in ohms.
G = reactance of capacity in ohms.

$A = G$ ... ... Fig. 31.

$A = E$ ... ... Fig. 32.

$A = C$ ... ... Fig. 33.

$A = \sqrt{G^2 + E^2}$ ... ... Fig. 34.

$A = 1 \div \left(\frac{1}{G_1} + \frac{1}{G_2} \right)$ ... ... Fig. 37.

$A = GC \div (\sqrt{C^2 - G^2})$ ... ... Fig. 41.

$A = CE \div (\sqrt{C^2 + E^2})$ ... ... Fig. 42.

$A = 1 \div \left(\frac{1}{C_1} + \frac{1}{C_2} \right)$ ... ... Fig. 39.

$A = C - G$ ... ... Fig. 35.

$A = \sqrt{C^2 + E^2}$ ... ... Fig. 36.

$A = 1 \div \left(\frac{1}{E_1} + \frac{1}{E_2} \right)$ ... ... Fig. 38.

$A = GE \div (\sqrt{G^2 + E^2})$ ... ... Fig. 40.

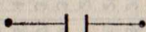


FIG. 31.

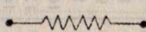


FIG. 32.

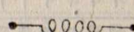


FIG. 33.

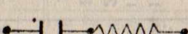


FIG. 34.

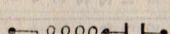


FIG. 35.

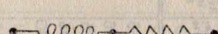


FIG. 36.

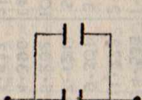


FIG. 37.

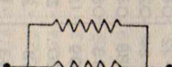


FIG. 38.

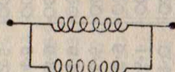


FIG. 39.

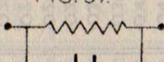


FIG. 40.

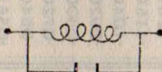


FIG. 41.

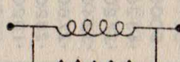


FIG. 42.

COPPER WIRE TABLES

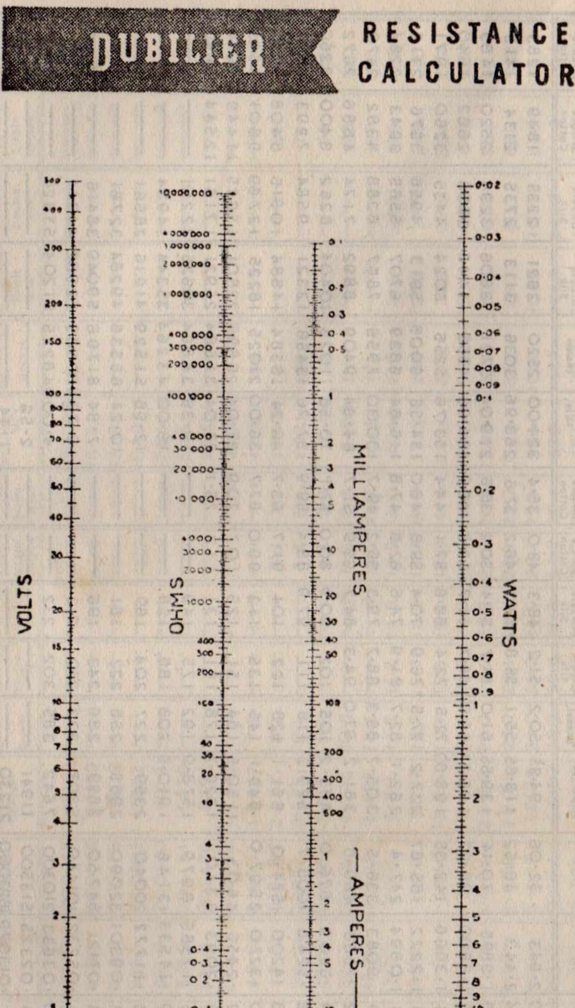
S.W.G.	DIAMETER.	Weight in lbs. per 1000 yds	Resistance in ohms per lb	Resistance in ohms per 1000 yds	TURNS PER INCH CLOSE WOUND					Area of wire in circular Mils.	TURNS PER SQUARE INCH WITH WIRES WOUND SIDE BY SIDE AND EACH LAYER IMMEDIATELY ABOVE THE OTHER				
					Enamel.	Single Silk	Double Silk	Single Cotton	Double Cotton		Enamel	Single Silk	Double Silk	Single Cotton	Double Cotton
7/0	·5000	2271·0	·000053	·12227	—	—	—	—	—	250000	—	—	—	—	—
5/0	·4320	1695·1	·000096	·16379	—	—	—	—	—	186624	—	—	—	—	—
3/0	·3720	1256·9	·000175	·2209	—	—	—	—	—	138384	—	—	—	—	—
1/0	·3240	935·5	·000305	·2912	—	—	—	—	—	104976	—	—	—	—	—
2	·2760	691·9	·000580	·4013	—	—	—	—	—	76176	—	—	—	—	—
4	·2320	488·9	·001161	·5679	—	—	—	—	—	53824	—	—	—	—	—
6	·1920	334·8	·002476	·8292	—	—	—	—	—	36864	—	—	—	—	—
8	·1600	232·5	·005135	1·1941	—	—	—	—	—	25600	—	—	—	—	—
10	·1280	148·82	·012537	1·8657	7·5	—	—	—	—	16384	56	—	—	—	—
11	·1160	112·22	·018587	2·272	8·2	—	—	8·0	7·6	13456	67	—	—	64	58
12	·1040	98·24	·02877	2·826	9·1	—	—	8·8	8·4	10816	83	—	—	77	71
13	·0920	76·88	·04698	3·612	9·4	—	—	9·9	9·3	8464	88	—	—	98	86
14	·0800	58·13	·08216	4·776	10·8	—	—	11·2	10·5	6400	117	—	—	125	110
15	·0720	47·09	·12523	5·897	13·2	—	—	12·5	11·8	5184	174	—	—	157	139
16	·0640	37·20	·2006	6·611	14·8	14·7	14·5	13·9	13·0	4096	219	216	210	193	169
17	·0560	28·48	·3422	9·747	16·9	16·7	16·5	15·7	14·5	3136	285	279	272	246	210
18	·0480	20·93	·6340	13·267	19·7	19·8	19·4	18·0	16·8	2304	388	392	376	324	282
19	·0400	14·533	1·3146	19·105	23·5	23·5	23·0	21·0	19·4	1600	562	552	529	441	376
20	·0360	11·772	2·004	23·59	26·0	26·0	25·3	23·5	21·0	1296	676	676	640	552	441
21	·0320	9·301	3·209	29·85	29·2	29·1	28·3	26·1	23·0	1024	852	847	800	681	529
22	·0280	7·121	5·475	38·99	33·0	33·0	31·9	29·1	25·4	784	1089	1089	1017	846	645
23	·0240	5·232	10·144	53·07	38·3	39·6	37·8	34·2	28·4	576	1467	1568	1428	1169	796
24	·0220	4·396	14·366	63·16	41·6	42·1	36·9	36·7	31·0	484	1730	1772	1361	1346	961
25	·0200	3·633	21·030	76·42	45·5	46·0	43·1	39·6	33·1	400	2070	2116	1857	1568	1095

The above data supplied by courtesy of London Electric Wire Co. & Smiths Ltd. [LEWCOS]

COPPER WIRE TABLES (CONTINUED)

S.W.G.	DIAMETER	Weight in lbs. per 1000 yds.	Resistance in ohms per lb.	Resistance in ohms per 1000 yds	TURNS PER INCH CLOSE WOUND					Area of wire in circular Mils.	TURNS PER SQUARE INCH WITH WIRES WOUND SIDE BY SIDE AND EACH LAYER IMMEDIATELY ABOVE THE OTHER				
					Enamel.	Single Silk	Double Silk	Single Cotton	Double Cotton		Enamel.	Single Silk	Double Silk	Single Cotton	Double Cotton
26	·0180	2·943	32·06	94·35	50·2	51·2	48·3	43·0	35·4	324·00	2520	2621	2333	1849	1253
27	·0164	2·443	46·52	113·65	55·1	55·8	52·3	46·2	37·6	268·96	3036	3113	2735	2134	1413
28	·0148	1·9895	70·14	139·55	61·0	61·7	57·4	50·2	38·6	219·04	37.21	3806	3294	2520	1489
29	·0136	1·6800	98·37	165·27	66·0	66·7	61·7	53·5	40·5	184·96	4356	4448	3806	2862	1640
30	·0124	1·3966	142·35	198·80	72·5	72·4	66·6	57·1	44·4	153·76	5256	5024	4435	3260	1971
31	·0116	1·2222	185·87	227·2	77·5	76·9	70·4	59·8	46·0	134·56	6006	5913	4956	3576	2116
32	·0108	1·0594	247·4	262·1	82·7	81·9	74·6	62·8	47·8	116·64	6839	6707	5565	3943	2284
33	·0100	·9083	336·5	305·7	89·3	88·7	79·3	66·2	49·7	100·00	7956	7867	6288	4382	2470
34	·0092	·7688	469·8	361·2	97·0	94·3	84·7	69·9	51·7	84·64	9409	8892	7174	4886	2672
35	·0084	·6409	676·0	433·2	105	102	90·9	80·0	57·1	70·56	11025	10404	8262	6400	3260
36	·0076	·5246	1008·7	529·2	116	111	97·9	85·4	59·9	57·76	13456	12321	9584	7293	3588
37	·0068	·4200	1574·0	661·1	128	122	104	91·7	63·7	46·24	16384	14884	10816	8408	4057
38	·0060	·3270	2597·0	849·1	145	135	113	99·0	67·7	36·00	21025	18225	12769	9801	4583
39	·0052	·2456	4603	1130·5	164	151	125	107	70·9	27·04	26896	22801	15625	11449	5026
40	·0048	·2093	6340	1326·7	178	161	131	112	75·1	23·04	31684	25921	17161	12544	5640
41	·0044	·17585	8979	1578·9	192	175	149	—	—	19·36	36864	30625	22201	—	—
42	·0040	·14533	13146	1910·5	208	188	158	—	—	16·00	43264	35344	24964	—	—
43	·0036	·11772	20040	2359	227	204	169	—	—	12·96	51529	41616	28561	—	—
44	·0032	·09301	32090	2985	256	222	181	—	—	10·24	65536	49284	32761	—	—
45	·0028	·07121	54750	3899	286	243	196	—	—	7·84	81796	59049	38416	—	—
46	·0024	·05232	101440	5307	333	270	212	—	—	5·76	110889	72900	44944	—	—
47	·0020	·03633	210300	7642	385	302	232	—	—	4·00	148225	91204	53824	—	—
48	·0016	·02325	513500	11941	—	—	—	—	—	2·56	—	—	—	—	—
49	·0012	·013079	1623000	21230	—	—	—	—	—	1·44	—	—	—	—	—
50	·0010	·009083	3365000	30570	—	—	—	—	—	1·00	—	—	—	—	—

The above data supplied by courtesy of London Electric Wire Co. & Smiths Ltd. (LEWCOS)



A straight edge placed acrosss any two known quantities on the Calculator will enable either of the two unknown quantities to be read off.

The above chart supplied by courtesy of Dubilier Condenser Co. (1925) Ltd.

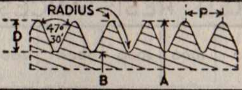
POWER RATINGS OF FIXED RESISTANCES

Wattage Rating ↓	OHMS →	50	100	250	500	750	1000	2000	3000	4000	5000
0·5 Watt	Amps	·1	·07	·045	·032	·025	·022	·016	·013	·011	·010
	Volts	5	7	11	16	20	22	32	39·5	45	50
1·0 Watt	Amps	·141	·10	·063	·045	·036	·032	·022	·018	·016	·014
	Volts	7	10	16	22	27	32	45	55	62·5	71
2·0 Watts	Amps	·2	·141	·089	·061	·051	·045	·032	·026	·022	·020
	Volts	10	14·1	23·1	32·5	39	45	62	77	89	100
3·0 Watts	Amps	·25	·173	·108	·076	·062	·055	·040	·032	·027	·025
	Volts	12·2	17·3	27·2	39	49	55	77	95	110	121
5·0 Watts	Amps	·32	·224	·141	·100	·083	·071	·050	·041	·035	·032
	Volts	15·8	22·4	35·5	50	60	71	100	124	141	159

Wattage Rating ↓	OHMS →	6000	7000	8000	9000	10000	15000	20000	25000	30000
0·5 Watt	Amps	·009	·008	·008	·0075	·007	·0058	·0055	·0045	·004
	Volts	55	59	63	67	71	86	100	110	124
1·0 Watt	Amps	·013	·012	·011	·0105	·010	·008	·007	·0063	·0058
	Volts	77	84	89	95	100	121	141	158	174
2·0 Watts	Amps	·018	·017	·016	·015	·014	·011	·010	·009	·0082
	Volts	110	118	125	135	141	172	200	225	244
3·0 Watts	Amps	·022	·021	·020	·018	·017	·014	·012	·011	·010
	Volts	135	145	154	164	172	213	245	272	300
5·0 Watts	Amps	·029	·027	·025	·023	·022	·018	·016	·014	·013
	Volts	173	188	200	212	225	265	315	355	389

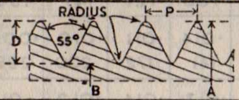
Wattage Rating ↓	OHMS →	40000	50000	75000	100000	200000	250000	500000	750000	1000000
0·5 Watt	Amps	·0035	·003	·0025	·0021	·0015	·0014	·001	·0008	·0007
	Volts	140	159	194	220	321	350	500	612	709
1·0 Watt	Amps	·005	·0043	·0036	·003	·0023	·002	·0014	·0012	·001
	Volts	200	225	275	309	441	500	700	866	1000
2·0 Watts	Amps	·0071	·0063	·0052	·0044	·0032	·0028	·002	·0016	·0014
	Volts	282	317	387	440	631	700	1000	1224	1410
3·0 Watts	Amps	·0087	·0077	·0062	·0055	·004	·0035	·0025	·002	·0017
	Volts	344	386	475	550	770	861	1200	1500	1720
5·0 Watts	Amps	·011	·010	·008	·007	·005	·0045	·003	·0026	·0022
	Volts	448	500	613	707	1000	1120	1581	1937	2250

BRITISH ASSOCIATION THREADS (B.A.)



B.A. Nº	THRDS PER INCH	OUTSIDE DIA "A"	CORE DIA "B"	PITCH "P"	DEPTH "D"	RADIUS "R"
0	25·38	·2362	·1890	·0394	·0236	·0072
1	28·25	·2087	·1663	·0354	·0212	·0064
2	31·35	·1850	·1468	·0319	·0191	·0058
3	34·84	·1614	·1272	·0287	·0172	·0052
4	38·46	·1417	·1105	·0260	·0156	·0047
5	43·10	·1260	·0980	·0232	·0139	·0042
6	47·85	·1102	·0852	·0209	·0125	·0038
7	52·91	·0984	·0758	·0189	·0113	·0034
8	59·17	·0866	·0664	·0169	·0101	·0031
9	64·94	·0748	·0564	·0154	·0092	·0028
10	72·46	·0669	·0503	·0138	·0083	·0025
11	81·97	·0591	·0445	·0122	·0073	·0022
12	90·91	·0511	·0375	·0110	·0066	·0020
13	102·0	·0472	·0354	·0098	·0059	·0018
14	109·9	·0394	·0284	·0091	·0055	·0016
15	120·5	·0354	·0254	·0083	·0050	·0015
16	133·3	·0311	·0221	·0075	·0045	·0014
17	149·3	·0276	·0196	·0067	·0040	·0012
18	169·5	·0244	·0174	·0059	·0035	·0011
19	181·8	·0213	·0147	·0055	·0033	·0010
20	212·8	·0189	·0133	·0047	·0028	·0009
21	232·6	·0165	·0113	·0043	·0026	·0008
22	256·4	·0146	·0100	·0039	·0023	·0007
23	285·7	·0130	·0088	·0035	·0021	·0006
24	323·6	·0114	·0076	·0031	·0019	·0006

BRITISH STANDARD FINE THREADS (B.S.F.)



DIA	OUTSIDE DIA "A"	CORE DIA "B"	THRDS PER INCH	PITCH "P"	DEPTH "D"	RADIUS "R"
7/32	·21875	·1731	28	·03571	·0229	·0049
1/4	·250	·2007	26	·0385	·0246	·0053
9/32	·28125	·2320	26	·0385	·0246	·0053
5/16	·3125	·2543	22	·0454	·0291	·0062
3/8	·375	·3110	20	·050	·0320	·0069
7/16	·4375	·3664	18	·0556	·0356	·0076
1/2	·500	·420	16	·0625	·040	·0086
9/16	·5625	·4825	16	·0625	·040	·0086
5/8	·625	·5335	14	·0714	·0457	·0098
11/16	·6875	·596	14	·0714	·0457	·0098
3/4	·750	·6433	12	·0833	·0534	·0114
13/16	·8125	·7058	12	·0833	·0534	·0114
7/8	·875	·7586	11	·09091	·0582	·0125
1"	1·000	·8719	10	·1000	·064	·0137
1 1/8	1·125	·9827	9	·1111	·0711	·0153
1 1/4	1·250	1·1077	9	·1111	·0711	·0153
1 3/8	1·375	1·2149	8	·1250	·080	·0172
1 1/2	1·500	1·3399	8	·1250	·080	·0172
1 5/8	1·625	1·4649	8	·1250	·080	·0172
1 3/4	1·750	1·567	7	·1428	·0915	·0196
2	2·000	1·817	7	·1428	·0915	·0196
2 1/4	2·250	2·0366	6	·1667	·1067	·0229
2 1/2	2·500	2·2866	6	·1667	·1067	·0229
2 3/4	2·750	2·5366	6	·1667	·1067	·0229
3	3·000	2·7439	5	·2000	·1281	·0275

METRIC TO DECIMAL EQUIVALENTS

M/M	INCH	M/M	INCH	M/M	INCH
·01	·0004	·43	·0169	·85	·0335
·02	·0008	·44	·0173	·86	·0339
·03	·0012	·45	·0177	·87	·0343
·04	·0016	·46	·0181	·88	·0347
·05	·0020	·47	·0185	·89	·0350
·06	·0024	·48	·0189	·90	·0354
·07	·0028	·49	·0193	·91	·0358
·08	·0032	·50	·0197	·92	·0362
·09	·0036	·51	·0201	·93	·0366
·10	·004	·52	·0205	·94	·03701
·11	·0043	·53	·0209	·95	·0374
·12	·0047	·54	·0213	·96	·0378
·13	·0051	·55	·0217	·97	·0382
·14	·0055	·56	·0221	·98	·0386
·15	·0059	·57	·0225	·99	·03898
·16	·0063	·58	·0228	1	·0394
·17	·0067	·59	·0232	2	·0787
·18	·0071	·60	·0236	3	·1181
·19	·0075	·61	·0240	4	·1575
·20	·0079	·62	·0244	5	·1968
·21	·0083	·63	·0248	6	·2362
·22	·0087	·64	·0252	7	·2756
·23	·0091	·65	·0256	8	·315
·24	·0095	·66	·026	9	·3543
·25	·0099	·67	·0264	10	·3937
·26	·0103	·68	·0268	11	·4331
·27	·0106	·69	·0272	12	·4724
·28	·0110	·70	·0276	13	·5118
·29	·0114	·71	·0279	14	·5512
·30	·0118	·72	·0283	15	·5905
·31	·0122	·73	·0287	16	·6299
·32	·0126	·74	·0291	17	·6693
·33	·013	·75	·0295	18	·7082
·34	·0134	·76	·0299	19	·748
·35	·0138	·77	·0303	20	·7874
·36	·0142	·78	·0307	21	·8268
·37	·0146	·79	·0311	22	·8661
·38	·0150	·80	·0315	23	·9055
·39	·0154	·81	·0319	24	·9449
·40	·0158	·82	·0323	25	·9842
·41	·0162	·83	·0327		
·42	·0166	·84	·0331		

B.S.F. TAPPING DRILLS

DIA	DRILL SIZE	DIA	DRILL SIZE	DIA	DRILL SIZE	DIA	DRILL SIZE
1/4	13/64	7/16	"U"	11/16	39/64	1"	7/8
1/4	No 7	1/2	27/64	3/4	21/32	1 1/8	63/64
5/16	"F"	9/16	31/64	13/16	23/32	1 1/4	1 7/64
3/8	"O"	5/8	35/64	7/8	49/64		

B.S.F. CLEARANCE DRILLS

DIA	DRILL SIZE	DIA	DRILL SIZE	DIA	DRILL SIZE	DIA	DRILL SIZE
1/4	17/64	3/8	"V"	11/16	45/64	1 1/8	1 9/64
1/4	"F"	7/16	29/64	3/4	49/64	1 1/4	1 17/64
5/16	21/64	1/2	33/64	13/16	53/64	1 3/8	1 25/64
5/16	"O"	9/16	37/64	7/8	57/64	1 1/2	1 33/64
3/8	25/64	5/8	41/64	1"	1 1/64	1 5/8	1 41/64

RADIO SIGNALING CODES

INTERNATIONAL MORSE

THE ALPHABET

A	·—	N	—·
B	—···	O	———
C	—·—·	P	·——·
D	—··	Q	——·—
E	·	R	·—·
F	··—·	S	···
G	——·	T	—
H	····	U	··—
I	··	V	···—
J	·———	W	·——
K	—·—	X	—··—
L	·—··	Y	—·——
M	——	Z	——··

USEFUL PUNCTUATION & OTHER SIGNS

FULL STOP (.)	·—·—·—
COMMA (,)	——··——
COLON (:)	———···
HYPHEN OR DASH (-)	—····—
FRACTION BAR (/)	—··—·
SEPARATION SIGN (BETWEEN WHOLE NUMBER & FRACTION)	·—··—
BRACKETS [()]	—·——·—
BREAK OR DOUBLE DASH (=)	—···—
INTERROGATION MARK (?)	··——··
ERASE (OR ERROR)	·········
STARTING SIGNAL	—·—·—
END OF MESSAGE	·—·—·
CLOSING DOWN	···—·—
INTERVAL (WAIT)	·—···
MESSAGE RECEIVED	·—·
READY TO RECEIVE	—·—
DISTRESS CALL OR SOS	···———···

NUMERALS

1	·————	6	—····
2	··———	7	——···
3	···——	8	———··
4	····—	9	————·
5	·····	0	—————

ABBREVIATED NUMERALS

1	·—	6	—····
2	··—	7	—···
3	···—	8	—··
4	····—	9	—·
5	·····	0	—

ACCENTED LETTERS

Ä	·—·—	Ñ	——·——
À OR Å	·——·—	Ö	———·
CH	————	Ü	··——
É	··—··		

U.S.A. MORSE

LETTERS

A	·—	O	· ·
B	—···	P	·····
C	·· ·	Q	··—·
D	—··	R	· ··
E	·	S	···
F	·—·	T	—
G	——·	U	··—
H	····	V	···—
I	··	W	·——
J	··—·	X	·—··
K	—·—	Y	·· ··
L	—	Z	··· ·
M	——	&	· ···
N	—·		

NUMERALS

1	·——·	6	······
2	··—··	7	——··
3	···—·	8	—····
4	····—	9	—··—
5	———	0	—

PUNCTUATION MARKS ETC.

PARENTHESIS	····· —· ····· ·· ··
QUOTATION	··—· —·
END OF QUOTATION	··—· —·—·
COLON DASH	—·— ·—··
CAPITALIZED LETTER	·· · ·—··
SMALL LETTER	··———
COLON FOLLOWED BY QUOTATION	—·— ··—·
QUESTION MARK	—··—·
EXCLAMATION MARK	———·
COLON	—·— ··
SEMICOLON	··· ··
PARAGRAPH	————
APOSTROPHE	··—· ·—··
DOLLAR	··· ·—··
CENTS	·· ·
POUND STERLING	— ·—··
SHILLING	··— —
PERCENT	· · ··· · ·
PERIOD	··——··
COMMA	·—·—
HYPHEN	—·· ·—··

ARABIC MORSE

PRONUNCIATION	ARABIC LETTER	MORSE SYMBOL
ALIF	ا	·—
BA	ب	—···
TA	ت	—
THA	ث	—·—·
JEEM	ج	·———
HA	ح	····
KHA	خ	———
DAL	د	—··
DHAL	ذ	———·
RA	ر	·—·
ZAY	ز	———·
SEEN	س	···
SHEEN	ش	————
SAD	ص	—··—
DAD	ض	···—
TA	ط	··—
ZA	ظ	—·——
AIN	ع	·—·—
GHAIN	غ	——·
FA	ف	··—·
QAF	ق	——·—
KAF	ك	—·—
LAM	ل	·—··
MEEM	م	——
NOON	ن	—·
WAW	و	·——
HE	ه	··—··
YA	ي	··
LAM-ALIF	لا	·—··—

GREEK MORSE

ENGLISH NAME	GREEK LETTER	MORSE SYMBOL
ALPHA	Α	·–
BETA	Β	–···
GAMMA	Γ	––·
DELTA	Δ	–··
EPSILON	Ε	·
ZETA	Ζ	––··
ETU	Η	····
THETA	Θ	–·–·
IOTA	Ι	··
KAPPA	Κ	–·–
LAMBDA	Λ	·–··
MU	Μ	––
NU	Ν	–·
XI	Ξ	–··–
OMICRON	Ο	–––
PI	Π	·––·
RHO	Ρ	·–·
SIGMA	Σ	···
TAU	Τ	–
YPSILON	Υ	–·––
PHI	Φ	··–·
CHI	Χ	––––
PSI	Ψ	––·–
OMEGA	Ω	·––
ETA YPSILON	ΗΥ	···–
YPSILON IOTA	ΥΙ	·–––
OMICRON YPSILON	ΟΥ	··–
ALPHA IOTA	ΑΙ	·–·–
ALPHA YPSILON	ΑΥ	··––
EPSILON YPSILON	ΕΥ	–––·
OMICRON IOTA	ΟΙ	––––··

RUSSIAN MORSE

RUSSIAN LETTER	NEAREST EQUIVALENT ENGLISH LETTER	MORSE SYMBOL
А	A	·–
Б	B	–···
В	V	·––
Г	G	––·
Д	D	–··
Е, Э	E	·
Ж	J	···–
З	Z	––··
И	I	··
Й	Y	·–––
К	K	–·–
Л	L	·–··
М	M	––
Н	N	–·
О	O	–––
П	P	·––·
Р	R	·–·
С	S	···
Т	T	–
У	U	··–
Ф	F	··–·
Х	KH	····
Ц	TS	–·–·
Ч	CH	–––·
Ш	SH	––––
Щ	SHCH	––·–
Ъ, Ь	MUTE	–··–
Ы	I	–·––
Ю	YU	··––
Я	YA	·–·–

TURKISH MORSE

LETTER	MORSE SYMBOL
A	·–
B	–···
C	–·–·
Ç	–·–··
D	–··
E	·
F	··–·
Ğ	––·
H	····
I	··
J	·–––
K	–·–
L	·–··
M	––
N	–·
O	–––
Ö	–––·
P	·––·
R	·–·
S	···
Ş	––––
T	–
U	··–
Ü	··––
V	···–
Y	–·––
Z	––··

JAPANESE MORSE (KNOWN AS KATA KANA RADIO CODE)

A ––·–– ア	HA –··· ハ	KA ·–·· カ	MA –··– マ	NA ·–· ナ	RA ··· ラ	SA –·–·– サ	TA –· タ	WA –·– ワ	YA ·–– ヤ
E –·––– エ	HE · ヘ	KE –·–– ケ	ME –···– メ	NE ––·– ネ	RE ––– レ	SE ·–––· セ	TE ·–·–– テ	(W)E ·––·· ヱ	(Y)E –·––– エ
I ·– イ	HI ––··– ヒ	KI –·–·· キ	MI ··–·– ミ	NI –·–· ニ	RI ––· リ	SI ––·–· シ	TI ··–· チ	(W)I ·–··– ヰ	(Y)I ·– イ
O ·–··· オ	HO –·· ホ	KO –––– コ	MO –··–· モ	NO ··–– ノ	RO ·–·– ロ	SO ––––· ソ	TO ··–·· ト	WO ·––– ヲ	YO –– ヨ
U ··– ウ	HU ––·· フ	KU ···– ク	MU – ム	NU ···· ヌ	RU –·––· ル	SU –––·– ス	TU ·––· ツ	(W)U ··– ウ	YU –··–– ユ

N ·–·–· ン

NAN NIGORI ° ··––·

PERIOD . ·–·–·–

QUOTES " ·–·–··

BRACKETS ( ) –·––·–

QUESTION MARK ? ··––··

PARAGRAPH ¶ ·–·–··

NIGORI ゛ ··

HYPHEN – ·––·–

"Q" SIGNALS.

The signals are intended as advice when no question mark follows them.

This code was originally used by wireless telegraphy operators at sea, but it has now become the standard code for use in all forms of Wireless Telegraphic Service.

It should be noted that, in a number of Aeronautical Services the words "True Bearing" and "True Course" are called "Geographical Bearing" and "Geographical Course."

QRA ... What is the name of your station?

QRB ... How far approximately are you from my station?

QRC ... What Company (or Government) settles the accounts for your station?

QRD ... Where are you bound for and where are you from?

QRG ... Will you tell me my exact frequency (wavelength) in kc/s. (or metres)?

QRH ... Does my frequency (wavelength) vary?

QRI ... Is my note good?

QRJ ... Do you receive me badly? Are my signals weak?

QRK ... What is the legibility of my signals (1 to 5)?

QRL ... Are you busy?

QRM ... Are you being interfered with?

QRN ... Are you troubled by atmospherics?

QRO ... Shall I increase power?

QRP ... Shall I decrease power?

QRQ .. Shall I send faster?

QRS .. Shall I send slower?

QRT ... Shall I stop sending?

QRU ... Have you anything for me?

QRV ... Are you ready?

QRW ... Shall I tell..................that you are calling him on............ kc/s. (or..................metres)?

QRX ... Shall I wait. When will you call me again?

QRY ... What is my turn?

QRZ ... Who is calling me?

QSA ... What is the strength of my signals (1 to 5).

QSB ... Does the strength of my signals vary?

QSD ... Is my keying correct? Are my signals distinct?

QSG ... Shall I send..................Telegrams (or one telegram) at a time?

QSJ ... What is the charge per word for..................including your internal telegraph charge?

QSK ... Shall I continue with the transmission of all my traffic? I can hear you through my signals.

QSL ... Can you give me acknowledgment of receipt?

QSM ... Shall I repeat the last telegram I sent you?

QSO ... Can you communicate with..................direct (or through the medium of..................)?

QSP ... Will you re-transmit to..................free of charge?

QSR ... Has the distress call received from...............been cleared?

QST ... General call preceding message addressed to all amateurs.

QSU ... Shall I send (or reply) on...............kc/s. (or metres) and/or on waves of Type A1, A2, A3 or B?

QSV ... Shall I send a series of VVV.................?

QSW ... Will you send on...............kc/s. (or............metres), and/or on waves of Type A1, A2, A3, or B?

QSX ... Will you listen for..................(call sign) on...............kc/s. (or..............metres) ?
QSY ... Shall I change to transmission on ....kc/s. (or ....metres) without changing the type of wave, or shall I change to transmission on another wave ?
QSZ ... Shall I send each word or group twice ?
QTA ... Shall I cancel telegram No............ as if it had not been sent ?
QTB ... Do you agree with my number of words ?
QTC ... How many telegrams have you to send ?
QTE ... What is my true bearing in relation to you ? OR
What is my true bearing in relation to............(call sign) ?
What is the true bearing of............(call sign) in relation to ....(call sign) ?
QTF ... Will you give me the position of my station according to the bearings taken by the direction finding stations which you control ?
QTG ... Will you send your call sign for fifty seconds followed by a dash of ten seconds on ....kc/s. (or............metres) in order that I may take your bearing ?
QTH ... What is your position in latitude and longitude (or by any other way of showing it) ?
QTI ... What is your true course ?
QTJ ... What is your speed ?
QTM ... Send Radio-electric signals and submarine sound signals to enable me to fix my bearing and my distance.
QTO ... Have you left dock (or port) ?
QTP ... Are you going to enter dock (or port) ?
QTQ ... Can you communicate with my station by means of the International code of Signals ?
QTR ... What is the exact time ?
QTU ... What are the hours during which your station is open ?
QUA ... Have you news of.................(call sign of the mobile station) ?
QUB ... Can you give me in this order information concerning visibility, height of clouds, ground wind for.................... (place of observation) ?
QUC ... What is the last message received by you from................. (call sign of the mobile station) ?
QUD ... Have you received the urgency signal sent by................. (call sign of the mobile station) ?
QUF ... Have you received the distress signal sent by................ (call sign of the mobile station) ?
QUG ... Are you being forced to alight in the sea (or to land) ?
QUH ... Will you indicate the present barometric pressure at sea level ?
QUJ ... Will you indicate the true course for me to follow, with no wind, to make for you ?
QUK ... Can you tell me the condition of the sea observed at........... (place or co-ordinates) ?
QUL ... Can you tell me the swell observed at..................(place or co-ordinates) ?
QUM ... Is the distress traffic ended ?

AERONAUTICAL "Q" SIGNALS.

Used especially in Airways Communications by Authority of the F.C.C. in the United States of America.

This code is used chiefly for Aircraft to Aircraft, and Aircraft to ground signalling.

Due to safety grounds, many of the signals have been omitted here and only the most popular are included.

QAA ... At what time do you expect to arrive at.................. ?
QAB ... Are you making for.................. ?
QAC ... Are you returning to.................. ?
QAD ... At what time did you leave...............(place of departure) ?
QAE ... Have you news of...............(Call sign of Aircraft Station) ?
QAF ... At what time did you pass.................. ?
QAG ... Arrange your flight in order to arrive at..................(time) at..................(place), OR
I am arranging my flight in order to arrive at............(time) at..................(place).
QAH ... What is your height ?
QAI ... Has any Aircraft been signalled in my vicinity ?
QAJ ... Shall I try to search for an aircraft in my vicinity (or by any other indication) ?, OR
Shall I try to search for aircraft in my vicinity (or by any other indication) ?
QAK ... Is another aircraft flying in my vicinity involving a risk of collision ?
QAL ... Are you going to land at.................. ?
QAM ... Can you give me the latest meteorological weather report for..................(place of observation) ?
QAN ... Can you give me the latest meteorological report concerning surface wind for..................(place of observation) ?
QAO ... Can you give me the latest meteorological report concerning upper wind for..................(place of observation) ?
QAP ... Shall I listen for you (or for..................) on kilocycles (or metres) ?
QAQ ... Am I in the vicinity of a prohibited area or of.................. prohibited area (name of prohibited area) ?
QAR ... May I stop listening on the watch wave for.........minutes ?
QAS ... You are flying over a prohibited area of over.................. prohibited area (name of prohibited area).
QAT ... Shall I continue to send ?
QAX ... Have you in your aircraft the following person, for whom I have waiting a radiotelegram (here follows the designation of the person as it appears in the address of the radiotelegram, name and qualification) ?
QAZ ... Are you flying in a thunderstorm ?
QBA ... What is the visibility at..................(place) ?
QBB ... What is the height of the cloud base at..................(place) ?
QBC ... Can you transmit to me the meteorological observation at present made by you from the aircraft ?
QBE ... I am about to wind in my aerial.
QBF ... Are you flying in cloud ?
QBG ... Are you flying above cloud ?
QBH ... Are you flying below cloud ?
QBI ... The bad visibility regulations are in force.
QBJ ... At what height is the upper limit of cloud ?
QBM ... Has..................sent any message for me ?

QBN ... Are you flying between two layers of cloud ?
QBT ... You are missing your dots.
QBU ... Are you sure of the accuracy of telegram.................. ?
QBW ... Did you receive the telegram sent at..................(time) ?
QCA ... You are causing delay by your slowness in answering.
QCB ... You are causing delay by answering out of your turn.
QCG ... Shall I stand guard for you in the frequency of.................. kilocycles (wave length of..................metres) ?
QCM ... There seems to be a defect in your transmission.
QCP ... Your note is bad.
QCS ... My reception on long waves has broken flown.
QCT ... My reception on short waves has broken down.
QCY ... I am working on trailing aerial, OR
Work on trailing aerial.
QDB ... Have you sent telegram..................to ?
QDC ... Telegram..................has been sent by wire.
QDD ... Telegram No.............has been refused by..................as not in order. Please inform sender.
QDH ... What is causing the present interference ?
QDK ... Answer in the alphabetical order of the call signs.
QDL ... Do you intend to ask me for a series of bearings.
QDM ... What is the magnetic course to steer with no wind to make for you or for.................. ?
QDO ... Can you have transmitted by..................station on its working wave or on the..................wave its call sign followed by a prolonged dash for.................. minutes, in order to permit me to use my aircraft D F Installation.
QDR ... What is my magnetic bearing in relation to you or to.........?

COMMERCIAL "Z" SIGNALS.

The signals are intended as advice when no question mark follows them.

This code was originally used by wireless telegraphy operators at sea but it is now being used by all Commercial Wireless Telegraphic Companies throughout the world.

ZAL ... Alter your wave length.
ZAN ... We can receive absolutely nothing.
ZAP ... Acknowledge please.
ZBN ... Break, go ahead with new slip.
ZBS ... Your signals blurring.
ZBY ... Break, go back yard (metre).
ZCD ... Your collation is different.
ZCO ... Your collation omitted.
ZCP ... Local receiving conditions poor. Please increase to maximum.
ZCS ... Cease sending.
ZCT ... Send code twice.
ZCW ... Are you in direct communication with . . . . . ?
ZDH ... Your dots are too heavy (long). Adjust lighten. (shorten)
ZDL ... Your dots are too light (short). Adjust heavier. (lengthen)
ZDM ... Your dots missing.
ZDV ... Your dots varying length. Please remedy.
ZFA ... Failing Auto.

ZFB	...	Signals are fading badly.
ZFF	...	Please observe and furnish frame code reports on . . . (code letters and frequency) kilocycles.
ZFS	...	Signals are fading slightly.
ZGF	...	. . . . . signals good for . . . . . . w.p.m.
ZGS	...	Your signals getting stronger.
ZGW	...	Your signals getting weaker.
ZHA	...	How are your conditions for Automatic reception ?
ZHC	...	How are your receiving conditions ?
ZHS	...	Send high speed auto . . . . . . w.p.m.
ZHY	...	We are holding you.
ZIR	...	Your transmitter has strong idle radiation.
ZKG	...	Say when ready to resume.
ZLB	...	Give long breaks please.
ZLD	...	We are getting long dash from you.
ZLS	...	We are suffering from a lightning storm.
ZMO	...	Stand by moment.
ZMP	...	Mispunch or perforator failures.
ZMQ	...	Stand by for . . . . .
ZNB	...	We do not get your breaks. We send twice.
ZNG	...	Receiving conditions no good for code.
ZNN	...	All clear of traffic.
ZOA	...	We have checked transmitter call letters . . . . . . Signals are radiating on air at . . . . . .
ZOH	...	What traffic have you on hand ?
ZOK	...	We are receiving O.K.
ZOR	...	Transmit revs. continuously.
ZPO	...	Send plain once.
ZPP	...	Punch plain only.
ZPR	...	Re run slip at present running.
ZPT	...	Send plain twice.
ZRA	...	Reversed auto tape.
ZRC	...	Can you receive code ?
ZRL	...	Re run slip before one now running.
ZRO	...	Are you receiving O.K. ?
ZSF	...	Send faster.
ZSH	...	Static heavy here.
ZSO	...	Transmit slips once.
ZSR	...	Your signals strong and readable.
ZSS	...	Send slower.
ZST	...	Transmit slips twice.
ZSU	...	Your signals are unreadable.
ZSV	...	Your speed varying.
ZTA	...	Transmit by auto.
ZTH	...	Transmit by hand.
ZUA	...	Our conditions unsuitable for andulator or auto recording.
ZUB	...	We have been unable to break you.
ZVF	...	Signals varying in frequency.
ZVP	...	Send V's please.
ZVS	...	Signals varying in intensity.
ZWC	...	Wipers or clicks here.
ZWO	...	Send words once.
ZWR	...	Your signals weak but readable.
ZWT	...	Send words twice.
ZYS	...	What is your speed of transmission ?

SIGNAL STRENGTH REPORTS.
THE "QSA-R" SYSTEM.

"Q" Readability System.
QSA1—Barely perceptible; unreadable.
QSA2—Weak; readable only now and then.
QSA3—Fairly good; readable with difficulty.
QSA4—Good readable signals.
QSA5—Very good signals; perfectly readable.

"R" Audibility System.
R1—Very weak signals; hardly readable.
R2—Weak signals; barely readable.
R3—Weak signals; but can be read.
R4—Fair signals; easily readable.
R5—Fairly strong signals.
R6—Good signals.
R7—Good strong signals, that come through QRM and QRN.
R8—Very strong signals; heard several feet from the phones.
R9—Extremely strong signals.

"T" Tone System.
T1—("T3, R6") very rough 25 or 60 cycle A.C. tone.
T2—Rough 60 cycle A.C. tone.
T3—Poor A.C. tone. Sounds like no filter.
T4—Fair A.C., small filter.
T5—Nearly pure D.C. tone, good filter, but has key thumps, or back wave, etc.
T6—Nearly pure D.C. tone. Very good filter; keying perfect.
T7—Pure D.C. tone, but has key thumps, back wave, etc.
T8—Pure D.C.
T9—Pure crystal controlled D.C. tone.

THE "RST" SYSTEM.

Readability.
R1—Unreadable.
R2—Barely readable—very few words distinguishable.
R3—Readable with some difficulty.
R4—Readable with practically no difficulty.
R5—Perfectly readable.

Signal Strength.
S1—Faint—signals barely perceptible.
S2—Extremely weak signals.
S3—Weak signals.
S4—Fair signals.
S5—Fairly good signals.
S6—Good signals.
S7—Fairly strong signals.
S8—Strong signals.
S9—Extremely strong signals.

Tone.
T1—Extremely rough, hissing note.
T2—Very rough A.C. note—no trace of musicality.
T3—Rough, low-pitched A.C. note—slightly musical.
T4—Rather rough A.C. note—moderately musical.
T5—Musically modulated note.
T6—Modulated note—slight trace of whistle.
T7—New D.C. note—smooth ripple.
T8—Good D.C. note—minute trace of ripple.
T9—Purest D.C. note.

If the note appears to be crystal controlled, add X following the appropriate number.

AMATEUR OF "HAM" ABBREVIATIONS USUALLY USED IN NON-COMMERCIAL WIRELESS TRAFFIC.

ABT ...	About
AGN ...	Again
AHD ...	Ahead
AHR ...	Another
ANI ...	Any
APRX	Approximate—Approximately
BC ...	Broadcast
BD ...	Bad
B4 ...	Before
BK ...	Break
BN ...	Been
BND ...	Band
BCUZ ...	Because
BTWN	Between
BIZ ...	Business
C ...	See, Yes.
CLR ...	Clear
CN ...	Can
CNT ...	Cant
CK ...	Check
CKT ...	Circuit
CMG ...	Coming
CUD ...	Could
CW ...	Continuous Wave
CUL ...	See you later
CUAGN	See you again
DA ...	Day
DE ...	From
DH ...	Deadhead
DINT ...	Did not
DNT ...	Don't
DX ...	Long distance
ES ...	And
EZ ...	Easy
FB ...	Fine business
FM ...	From
FR ...	For
FRQ ...	Frequency
GA ...	Go ahead
GB ...	Good Bye
GM ...	Good Morning
GN ...	Good Night
GG ...	Going
GT ...	Got Get
GND ...	Ground
HA or HI	Laughter
HM ...	Him
HR ...	Here—Hear
HV ...	Have
HW ...	How

IC ...	I see
ICW ...	Interrupted Continuous Wave
K ...	Go ahead
LID ...	Poor Operator
LIL ...	Little
LFT ...	Left
LST ...	Last—Listen
LTR ...	Letter
MG ...	Motor Generator
MI ...	My
MK ...	Make
MO ...	More
MSG ...	Message
MT ...	Empty
N ...	No
ND ...	Nothing Doing
NG ...	No good
Nil ...	Nothing
NM ...	No more
NR ...	Number
NW ...	Now
OB ...	Old Boy
OL ...	Old Lady
OM ...	Old Man
OP ...	Operator
OT ...	Old Top-Timer
OW ...	Old Woman
PLS ...	Please
PSE ...	Please
PX ...	Press
R ...	OK
RCD ...	Received
RCVR...	Receiver
RI ...	Radio Inspector
SA ...	Say
SEZ ...	Says
SM ...	Some
SW ...	Short Wave
SIG ...	Signal
SKED...	Schedule
TFC ...	Traffic
TMW ...	To-morrow
TR ...	There
TT ...	That
TK ...	Take
TKS ...	Thanks
TNK ...	Think
TNX ...	Thanks
U ...	You
UD ...	You would

AMATEUR ABBREVIATIONS—*continued.*

UL ...	You will	WT ...	What
UR ...	Your	WX ...	Weather
VT ...	Vacuum Tube (Valve)	X ...	Interference
VY ...	Very	XMTR	Transmitter
WA ...	Word after	XTAL...	Crystal
WB ...	Word before	YF ...	Wife
WD ...	Would	YL ...	Young Lady
WF ...	Word following	YR ...	Your
WK ...	Work	30 ...	Finish—end
WL ...	Will—would	73 ...	Best regards
WN ...	When	88 ...	Love and Kisses

INTERNATIONAL AMATEUR PREFIXES.

Prefix	*Country*	*Prefix*	*Country*
AC4	Tibet	FL8	Somali Coast
AR	Syria	FM8	Martinique
CE	Chile	FN	French India
CM	Cuba	FO8	French Oceania, Tahiti
CN1	Tangier Zone	FP8	St. Pierre and Miquelon
CN8	Morocco	FQ8	French Equatorial Africa
CO	Cuba (Phones)	FR8	Reunion
CP	Bolivia	FT8	Tunis
CR4	Cape Verde	FU8	New Hebrides
CR5	Portuguese Guinea	FY8	French Guiana
CR6	Angola	G	England
CR7	Mozambique	G1	Northern Ireland
CR8	Portuguese India	GM	Scotland
CR9	Macao	GW	Wales
CR10	Timor	HA	Hungary
CT1	Portugal	HB	Switzerland
CT2	Azores	HC	Ecuador
CT3	Madeira	HH	Haiti
CX	Uruguay	HI	Dominican Republic
D	Germany	HJ, HK	Colombian Republic
EA	Spain	HP	Panama
EA8	Canary Islands	HR	Honduras
EI	Eire	HS	Siam
EL	Liberia	HZ	Hedjaz
EQ	Iran	I	Italy
ES	Estonia	I7	Ethiopia
F3, F8	France	J	Japan
FA	Algeria	K4	Puerto Rico
FB8	Madagascar	KB4	Virgin Islands
FC8	Clipperton Islands	K5	Canal Zone
FD8	French Togoland	K6	Guam, Hawaii, Samoa, (Wake Is.)
FE8	French Cameroons	K7	Alaska
FF8	French West Africa	KA	Phillipine Islands
FG8	Guadeloupe	LA	Norway
FI8	French Indo-China	LU	Argentine
FK8	New Caledonia	LX	Luxemburg

Prefix	Country	Prefix	Country
LY	Lithuania	VR2	Fiji Islands
LZ	Bulgaria	VR3	Fannings Islands
MX	Manchukuo	VR4	British Solomon Islands
NY	Canal Zone	VR5	Tonga Islands
OA	Peru	VS1, VS2	
OH	Finland	VS3	Malaya
OK	Czechoslovakia	VS4	Borneo
ON	Belgium	VS5	Sarawak
OQ5	Belgian Congo	VS6	Hong Kong
OX	Greenland	VS7	Ceylon
OY	Faroe Islands	VU	India
OZ	Denmark	W	U.S.A.
PA	Netherlands	XE	Mexico
PK	Netherlands East Indies	XT, XU	China
PX	Andorra	XZ	Burma
PY	Brazil	YA	Afghanistan
PZ	Surinam	YI	Iraq
SM	Sweden	YJ, FU8	New Hebrides
SP	Poland	YL	Latvia
ST	Sudan	YM	Danzig
SU	Egypt	YN	Nicaragua
SV	Greece	YR	Roumania
TA	Turkey	YS	Salvador
TF	Iceland	YT, YU	Jugoslavia
U, UE		YV	Venezuela
UK, UX	U.S.S.R.	ZA	Albania
VE	Canada	ZA1	Malta
VK	Australia	ZB1	Gibraltar
VO	Newfoundland	ZC1	Transjordania
VP1	British Honduras	ZC2	Cocos Islands
VP2	Dominica, Grenada, St. Lucia, Antigua	ZC3	Christmas Islands
		ZC4	Cyprus
VP3	British Guiana	ZC6	Palestine
VP4	Trinidad & Tobago	ZD1	Sierra Leone
VP5	Cayman Island, Jamaica, Turks and Caicos Isles	ZD2	Nigeria, Cameroons (Brit.)
		ZD4	Gold Coast, Togoland (Brit.)
VP6	Barbados		
VP7	Bahamas	ZD6	Nyasaland
VQ2	North Rhodesia	ZD7	St. Helena
VQ3	Tanganyika	ZD8	Gambia
VQ4	Kenya	ZE1	South Rhodesia
VQ5	Uganda	ZL	New Zealand
VQ6	British Somaliland	ZM	Samoa (Western)
VQ8	Mauritius	ZP	Paraguay
VR1	Gilbert & Ellice Islands	ZS	South Africa

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FORMULAS AND DATA

CALCULATION OF CAPACITY

CAPACITY OF CONDENSERS

Units.—The capacities given by the following formulas are in micromicrofarads. This unit is 10^{-12} of the farad, the farad being defined as the capacity of a condenser charged to a potential of 1 volt by 1 coulomb of electricity. The micromicrofarad and the microfarad (one-millionth of a farad) are the units commonly used in radio work. Radio writers have occasionally used the cgs electrostatic unit, sometimes called the "centimeter" This unit is 1.1124 micromicrofarads.

In the formulas here given all lengths are expressed in centimeters and all areas in square centimeters. The constants given are correct[31] to 0.1 per cent.

PARALLEL PLATE CONDENSER

Let S = surface area of one side of one plate

τ = thickness of the dielectric

K = dielectric constant ($K = 1$ for air, and for most ordinary substances lies between 1 and 10)

$$C = 0.0885 K \frac{S}{\tau} \text{ micromicrofarads.} \qquad (110)$$

If, instead of a single pair of metal plates, there are N similar plates with dielectric between, alternate plates being connected in parallel,

$$C = 0.0885 K \frac{(N-1)S}{\tau} \qquad (111)$$

In these formulas no allowance is made for the curving of the lines of force at the edges of the plates; the effect is negligible when τ is very small compared with S.

[31] The constants given in the formulas are correct for absolute units. To reduce to international units the values in absolute units should be multiplied by 1.00052. This difference need not be considered when calculations correct to 1 part in 1000 only are required.

Let N = total number of parallel plates

r_1 = outside radius of the plates

r_2 = inner radius of plates

τ = thickness of dielectric

K = dielectric constant

Then, for the position of maximum capacity (movable plates between the fixed plates),

$$C = 0.1390K\frac{(N-1)(r_1^2 - r_2^2)}{\tau} \qquad (112)$$

This formula does not take into account the effect of the edges of the plates, but as the capacity is also affected by the containing case it will not generally be worth while to take the edge effect into account.

Formula (112) gives the maximum capacity between the plates with this form of condenser. As the movable plates are rotated the capacity decreases, and ordinarily the decrease in capacity is proportional to the angle through which the plates are rotated.

ISOLATED DISK OF NEGLIGIBLE THICKNESS

Let d = diameter of the disk

then

$$C = 0.354d \qquad (113)$$

ISOLATED SPHERE

Let d = diameter of the sphere

then

$$C = 0.556\,d \qquad (114)$$

TWO CONCENTRIC SPHERES

Let r_1 = inner radius of outside sphere

r_2 = radius of inside sphere

K = dielectric constant of material between the spheres

$$C = 1.112K\frac{r_1 r_2}{r_1 - r_2} \qquad (115)$$

TWO COAXIAL CYLINDERS

Let r_1 = radius of outer cylinder

r_2 = radius of inner cylinder

K = dielectric constant of material between the cylinders

l = length of each cylinder

$$C = \frac{0.2416l}{\log_{10}\frac{r_1}{r_2}} \qquad (116)$$

This formula makes no allowance for the difference in density of the charge as the ends of the cylinders are approached.

SINGLE LONG WIRE PARALLEL TO THE GROUND

For a single wire of length l and diameter d, suspended at a height h above the ground, the capacity is

$$C=\frac{0.2416l}{\log_{10}\frac{4h}{d}+\log_{10}\left\{\frac{l/2+\sqrt{l^2/4+d^2/4}}{l/2+\sqrt{l^2/4+4h^2}}\right\}} \tag{117}$$

Usually the diameter d may be neglected in comparison with the length l, and the following equations are convenient for numerical computations.

For $\frac{4h}{l}\lesseqgtr 1$,

$$C=\frac{0.2416\,l}{\log_{10}\frac{4h}{d}-k_1} \tag{118}$$

For $\frac{l}{4h}\lesseqgtr 1$,

$$C=\frac{0.2416\,l}{\log_{10}\frac{2l}{d}-k_2} \tag{119}$$

in which the quantities

$$k_1=\log_{10}\left\{\frac{1+\sqrt{1+\left(\frac{4h}{l}\right)^2}}{2}\right\}$$

and

$$k_2=\log_{10}\left\{\frac{l}{4h}+\sqrt{1+\left(\frac{l}{4h}\right)^2}\right\}$$

may be interpolated from Table 6,

These formulas assume a uniform distribution of charge from point to point of the wire.

VERTICAL WIRE

Formula (119), omitting the k_2 in the denominator, is sometimes used to calculate the capacity of a vertical wire. It applies accurately only when h is large compared with l, and gives very rough values for a vertical single-wire antenna, the lower end of which is connected to apparatus at least several meters above the ground.

Let d = the diameter of cross section of the wires

l = length of each wire

h = the height of the wires above the earth

D = distance between centers of the wires.

The capacity is defined as the quotient of the charge on one wire, divided by the difference in potential of the two wires, when the potential of one wire is as much positive as the other is negative.

$$C=\frac{0.1208\,l}{\log_{10}\left\{\frac{l/2+\sqrt{l^2/4+d^2/4}}{l/2+\sqrt{l^2/4+4h^2}}\cdot\frac{4h}{d}\right\}-\log_{10}\left\{\frac{l/2+\sqrt{l^2/4+D^2}}{l/2+\sqrt{l^2/4+D^2+4h^2}}\cdot\frac{\sqrt{D^2+4h^2}}{D}\right\}}\tag{120}$$

In most cases d/l and D/l may be neglected in comparison with unity, and we may write

$$C=\frac{0.1208\,l}{\log_{10}\frac{2D}{d}-\frac{D^2}{8h^2}}\tag{121}$$

TWO PARALLEL WIRES, ONE ABOVE THE OTHER

For the case of one wire placed vertically above the other, the formula (121) may usually be used, taking for the value of h the mean height of the wires, $\frac{h_1+h_2}{2}$. The potential of one wire is assumed to be as much positive as the other is negative.

CAPACITY OF TWO PARALLEL WIRES JOINED TOGETHER

Let l = the length of each wire

D = distance between centers

h = their height above the earth

d = diameter of cross section.

The wires are supposed to be parallel to each other and to lie in a horizontal plane. They are joined together so that they are at the same potential. The capacity is defined as the quotient of the sum of their charges by the potential above the earth.

$$C=\frac{0.4831\,l}{\log_{10}\left\{\frac{l/2+\sqrt{l^2/4+d^2/4}}{l/2+\sqrt{l^2/4+4h^2}}\cdot\frac{4h}{d}\right\}+\log_{10}\left\{\frac{l/2+\sqrt{l^2/4+D^2}}{l/2+\sqrt{l^2/4+D^2+4h^2}}\cdot\frac{\sqrt{4h^2+D^2}}{D}\right\}}\tag{122}$$

which, in those cases where d^2/l^2 and $\left(\frac{D}{2h}\right)^2$ may be neglected in comparison with unity, may be written in the following forms:

For $\frac{4h}{l} \gtreqless 1$,

$$C = \frac{0.4831\, l}{\log_{10}\frac{4h}{d} + \log_{10}\frac{2h}{D} - 2k_1} \tag{123}$$

For $\frac{l}{4h} \gtreqless 1$,

$$C = \frac{0.4831\, l}{\log_{10}\frac{2l}{d} + \log_{10}\frac{l}{D} - 2k_2} \tag{124}$$

The quantities k_1 and k_2 are the same as in (118) and (119) and may be obtained from Table 6,

These formulas assume a uniform distribution of charge along the wire.

CAPACITY OF A NUMBER OF HORIZONTAL WIRES IN PARALLEL

This case is of importance in the calculation of the capacity of certain forms of antenna. The wires are supposed to be joined together, and thus all are at the same potential. Their capacity in parallel is then defined as the quotient of the sum of all their charges by their common potential.

An expression for this case as accurate as the preceding formula (120) for two wires would be very complicated. The following simpler solution is nearly as accurate, and in view of the disturbing effect of trees, houses, and other like objects on the capacity of an antenna, will suffice for ordinary purposes of design.

Let n = number of wires in parallel

D = spacing of wires in parallel, measured between centers

d = diameter of wire

h = height of the wires above the ground

l = length of each wire.

Then if the potential coefficients be calculated as follows:

$$\left.\begin{aligned} p_{11} &= 4.605\left[\log_{10}\frac{4h}{d} - k_1\right] \\ p_{12} &= 4.605\left[\log_{10}\frac{2h}{D} - k_1\right] \end{aligned}\right\} \text{for } \frac{4h}{l} \gtreqless 1, \tag{125}$$

or,

$$\left.\begin{aligned} p_{11} &= 4.605\left[\log_{10}\frac{2l}{d} - k_2\right] \\ p_{12} &= 4.605\left[\log_{10}\frac{l}{D} - k_2\right] \end{aligned}\right\} \text{for } \frac{l}{4h} \gtreqless 1, \tag{126}$$

the approximate capacity of the n wires in parallel will be

$$C = 1.112 l \div \left[\frac{p_{11} + (n-1) p_{12}}{n} - k \right] \tag{127}$$

the quantities k, k_1 and k_2 being obtained from Tables 6 and 7,

Example.—To find the capacity of an antenna of 10 wires 0.16 inch in diameter, in parallel, each wire 110 feet long, the spacing between the wires being 2 feet and their height above the ground 80 feet.

For this case $4h/l = \frac{320}{110}$ or $l/4h = 0.344$ and Table 6 gives $k_2 = 0.146$.

$$2l/d = \frac{2 \times 12 \times 110}{0.16} = 16500, \quad \log_{10} \frac{2l}{d} = 4.2175$$

$$l/D = \frac{110}{2} = 55 \qquad \log_{10} l/D = 1.7404$$

$$\therefore p_{11} = 4.605 \,[4.218 - 0.146] = 18.75$$

$$p_{12} = 4.605 \,[1.740 - 0.146] = 7.340$$

and from formula (127) and Table 7 the capacity is, reducing the length of the wires to cm

$$C = (1.112 \times 110 \times 30.5) \div \left[\frac{18.75 + 9(7.340)}{10} - 2.05 \right]$$

$$= 584 \ \mu\mu f = 0.000584 \ \mu f.$$

Example.—A second antenna of 10 wires, 3/32 inch diameter, 155 feet long, spaced 2.5 feet apart, and stretched at a distance of 64 feet from the earth.

For this case $l/4h = \frac{155}{256} = 0.606, \qquad k_2 = 0.249$

$$2l/d = 39680, \quad \log_{10} \frac{2l}{d} = 4.5986$$

$$l/D = 62, \quad \log_{10} l/D = 1.7924$$

$$p_{11} = 20.04, \ p_{12} = 7.11, \quad \frac{p_{11} + 9p_{12}}{10} - 2.05 = 6.35$$

$$C = \frac{1.112 \times 155 \times 30.5}{6.35} = 0.000829 \ \mu f$$

If the length of the antenna had been 500 feet, with the height unchanged, then $\frac{4h}{l}=\frac{256}{500}=0.512$, $k_1=0.026$, $\log_{10}\frac{4h}{d}=4.5154$, $\log_{10}\frac{2h}{D}=1.7093$; by (125) $p_{11}=20.67$, $p_{12}=7.75$, $k=2.05$,

$$C=\frac{1.112\times 500\times 30.5}{6.99}=0.002426\ \mu f.$$

TABLES FOR CAPACITY CALCULATIONS

TABLE 5.—For Converting Common Logarithms Into Natural Logarithms

Common	Natural	Common	Natural	Common	Natural	Common	Natural
0	0.0000	25.0	57.565	50.0	115.129	75.0	172.694
1.0	2.3026	26.0	59.867	51.0	117.432	76.0	174.996
2.0	4.6052	27.0	62.170	52.0	119.734	77.0	177.299
3.0	6.9078	28.0	64.472	53.0	122.037	78.0	179.602
4.0	9.2103	29.0	66.775	54.0	124.340	79.0	181.904
5.0	11.513	30.0	69.078	55.0	126.642	80.0	184.207
6.0	13.816	31.0	71.380	56.0	128.945	81.0	186.509
7.0	16.118	32.0	73.683	57.0	131.247	82.0	188.812
8.0	18.421	33.0	75.985	58.0	133.550	83.0	191.115
9.0	20.723	34.0	78.288	59.0	135.853	84.0	193.417
10.0	23.026	35.0	80.590	60.0	138.155	85.0	195.720
11.0	25.328	36.0	82.893	61.0	140.458	86.0	198.022
12.0	27.631	37.0	85.196	62.0	142.760	87.0	200.325
13.0	29.934	38.0	87.498	63.0	145.063	88.0	202.627
14.0	32.236	39.0	89.801	64.0	147.365	89.0	204.930
15.0	34.539	40.0	92.103	65.0	149.668	90.0	207.233
16.0	36.841	41.0	94.406	66.0	151.971	91.0	209.535
17.0	39.144	42.0	96.709	67.0	154.273	92.0	211.838
18.0	41.447	43.0	99.011	68.0	156.576	93.0	214.140
19.0	43.749	44.0	101.314	69.0	158.878	94.0	216.443
20.0	46.052	45.0	103.616	70.0	161.181	95.0	218.746
21.0	48.354	46.0	105.919	71.0	163.484	96.0	221.048
22.0	50.657	47.0	108.221	72.0	165.786	97.0	223.351
23.0	52.959	48.0	110.524	73.0	168.089	98.0	225.653
24.0	55.262	49.0	112.827	74.0	170.391	99.0	227.956
						100.0	230.259

The table is carried out to a higher precision than the formulas, e. g., 2.3026 is abbreviated to 2.303 in the formulas.

Examples.—To illustrate the use of such a table, suppose we wish to find the natural logarithm of 37.48. The common logarithm of 37.48 is 1.57380.

If we denote the number 2.3026 by M, then from the table

$$\begin{array}{rl} 1.5 & M=3.4539 \\ .073 & M=\ .1681 \\ .00080 & M=\ .0018 \\ \hline & 3.6238=\log_e 37.48 \end{array}$$

To find the natural logarithm of 0.00748: The common logarithm is $\bar{3}.87390$, which may be written 0.87390−3. Entering the table we find

$$\begin{array}{lrl} & 0.87\quad M=2.00325 & -3\ M=-6.9078 \\ & .0039\ M=\ .00898 & \\ \hline \text{sum} & 2.0122 & \\ & -6.9078 & \\ \hline & -4.8956 & =\text{natural log of } 0.00748 \end{array}$$

TABLE 6.—For Use in Connection with Formulas (118), (119), (123), (124), (125), and (126)

4h/l	k_1	l/4h	k_2	4h/l	k_1	l/4h	k_2
0	0	0	0	0.6	0.035	0.6	0.247
0.1	0.001	0.1	0.043	.7	.045	.7	.283
.2	.004	.2	.086	.8	.057	.8	.318
.3	.009	.3	.128	.9	.069	.9	.351
.4	.016	.4	.169	1.0	.082	1.0	.383
.5	.025	.5	.209				

TABLE 7.—Values of k in Formulas (127) and (146)

n	k	n	k	n	k	n	k
2	0	6	1.18	11	2.22	16	2.85
3	0.308	7	1.43	12	2.37	17	2.95
4	.621	8	1.66	13	2.51	18	3.04
5	.906	9	1.86	14	2.63	19	3.14
		10	2.05	15	2.74	20	3.24

CALCULATION OF INDUCTANCE

GENERAL

In this section are given formulas for the calculation of self and mutual inductance in the more common circuits met with in practice. The attempt is here made, not to present all the formulas available for this purpose, but rather the minimum number required, and to attain an accuracy of about one part in a thousand. So far as has seemed practicable, tables have been prepared to facilitate numerical calculations. In some cases, to render interpolation more certain, the values in the tables are carried out to one more significant figure than is necessary. In such instances, after having obtained the required quantity by interpolation from a table, the superfluous figure may be dropped. In all the tables the intervals for which the desired quantities are tabulated are taken small enough to render the consideration of second differences in interpolation unnecessary.

Most of the formulas given are for low frequencies, this fact being indicated by the subscript zero, thus L_o, M_o. The high-frequency formulas are given where such are known. Fortunately it is possible by proper design to render unimportant the change of inductance with frequency, except in cases where extremely high precision is required.

The usual unit of inductance used in radio work is the microhenry, which is one millionth of the international henry.[32] The

[32] The constants in the formulas for inductance given here refer to absolute units To reduce to international units multiply by 0.99948. Since, however, an accuracy of the order of only one part in a thousand is sought here, it will not be necessary to take this difference into account.

henry is defined as the inductance "in a circuit when the electromotive force induced in this circuit is one international volt, while the inducing current varies at the rate of one ampere per second." 1 henry = 1000 millihenries = 10^6 microhenries = 10^9 *cgs* electromagnetic units.

In the following formulas lengths and other dimensions are expressed in centimeters, unless otherwise stipulated, and the inductance calculated will be in microhenries.

Logarithms are given, either to the natural base ϵ or to the base 10, as indicated. The labor involved in the multiplication of common logarithms by the factor 2.303 to reduce to the corresponding natural logarithms will be very materially reduced by the employment of the multiplication table, Table 5, which is an abridgement of the table for this purpose usually given in collections of logarithms.

All of these formulas assume that there is no iron in the vicinity of the conductor or circuit of which the inductance is to be calculated. Thus, the formulas here given can not be used to calculate the inductance of electromagnets.

SELF-INDUCTANCE OF WIRES AND ANTENNAS

STRAIGHT, ROUND WIRE

If l = length of wire
d = diameter of cross section
μ = permeability of the material of the wire

$$L_0 = 0.002l\left[\log_\epsilon \frac{4l}{d} - 1 + \frac{\mu}{4}\right] \text{ microhenries} \qquad (128)$$

$$= 0.002l\left[2.303 \log_{10} \frac{4l}{d} - 1 + \frac{\mu}{4}\right] \text{ microhenries} \qquad (129)$$

For all except iron wires this becomes

$$L_0 = 0.002l\left[2.303 \log_{10} \frac{4l}{d} - 0.75\right] \qquad (130)$$

For wires whose length is less than about 1000 times the diameter of the cross section $\left(\frac{2l}{d} < 1000\right)$, the term $\frac{d}{2l}$ should be added inside the brackets. These formulas give merely the self-inductance of one conductor. If the return conductor is not far away, the mutual inductances have to be taken into account (see formulas (134) and (136)).

As the frequency of the current increases, the inductance diminishes, and approaches the limiting value

$$L_{\infty}=0.002l\left[2.303 \log_{10} \frac{4l}{d}-1\right] \tag{131}$$

which holds for infinite frequency.

The general formula for the inductance at any frequency is

$$L=0.002l\left[2.303 \log_{10} \frac{4l}{d}-1+\mu\delta\right] \tag{132}$$

where δ is a quantity given in Table 8, as a function of x where

$$x=0.1405d\sqrt{\frac{\mu f}{\rho}} \tag{133}$$

f = frequency.
ρ = volume resistivity of wire in microhm-centimeters
ρ_0 = same for copper
$\mu=1$ for all except iron wires.

For copper at 20° C, $x_0=0.1071\ d\ \sqrt{f}$.

The value a_c of x for a copper wire 0.1 cm in diameter at different frequencies may be obtained from Table 19, For a copper wire d cm in diameter $x_c=10\ d\ a_c$ and for a wire of some other material $x=10\ d\ a_c\sqrt{\mu\frac{\rho_c}{\rho}}$.

The total change in inductance when the frequency of the current is raised from zero to infinity is a function of the ratio of the length of the wire to the diameter of the cross section. Thus, the decrease in inductance of a wire whose length is 25 times the diameter is 6 per cent at infinite frequency; and for a wire 100 000 times as long as its diameter, 2 per cent.

Example.—For a copper wire of length 206.25 cm and diameter 0.25 cm at a wave length of 600 meters, that is $f=500\,000$, the value of x is 18.93, and from Table 8, $\delta=0.037$.

$$\mu=1,\quad \frac{4l}{d}=3300,\quad \log_{10} 3300=3.51851$$

(From Table 5)

$$\log_\epsilon 3300 = 8.0590$$
$$414$$
$$12$$
$$\overline{8.1016}$$

For zero frequency

$$L_0 = 0.4\,[8.102 - 1 + 0.25] = 2.941 \text{ microhenry}$$

For f = 500 000

$$L = 0.4\,[8.102 - 1 + 0.037] = 2.856 \text{ microhenry}$$

a difference of 2.9 per cent out of a possible 3.4 per cent.

For an iron wire of the same length and diameter, assuming a resistivity 7 times as great as that of copper, and a permeability of 100, the value of x is $\sqrt{\frac{100}{7}}$ times as great as for the copper wire, or 71.5, and for this value of x,

$$\delta = 0.010 \text{ (Table 8)}$$

$$L_0 = 0.4\,[32.10] = 12.84\ \mu h$$

$$L = 0.4\,[8.102] = 3.24\ \mu h \text{ at 500 000 cycles.}$$

The limiting value is $L_\infty = 2.84\ \mu h$.

TWO PARALLEL, ROUND WIRES—RETURN CIRCUIT

In this case the current is supposed to flow in opposite directions in two parallel wires each of length l and diameter d. Denoting by D the distance from the center of one wire to the center of the other,

$$L = 0.004\,l\left[2.303\log_{10}\frac{2D}{d} - \frac{D}{l} + \mu\delta\right] \tag{134}$$

The permeability of the wires being μ, and δ being obtained from (133) and Table 8, For low frequency $\delta = 0.25$. This formula neglects the inductance of the connecting wires between the two main wires. If these are not of negligible length, their inductances may be calculated by (132) and added to the result obtained by (134), or else the whole circuit may be treated by the formula (138) for the rectangle below.

Let l = length of bar.
b, c = sides of the rectangular section.

$$L_0 = 0.002\, l \left[2.303 \log_{10} \frac{2l}{b+c} + 0.5 + 0.2235 \frac{(b+c)}{l} \right] \qquad (135)$$

The last term may be neglected for values of l greater than about 50 times $(b+c)$.

The permeability of the wire is here assumed as unity.

RETURN CIRCUIT OF RECTANGULAR WIRES

If the wires are supposed to be of the same cross section, b by c, and length l, and of permeability unity, and the distance between their centers is D,

$$L_0 = 0.004\, l \left[2.303 \log_{10} \frac{D}{b+c} + \frac{3}{2} - \frac{D}{l} + 0.2235 \frac{(b+c)}{l} \right] \qquad (136)$$

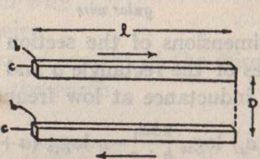


FIG. 178.—*The two conductors of a return circuit of rectangular wires*

For wires of different sizes, the inductance is given by $L_0 = L_1 + L_2 - 2M$ in which the inductances L_1 and L_2 of the individual wires are to be calculated by (135), and their mutual inductance M by (174) below.

SQUARE OF ROUND WIRE

If a is the length of one side of the square and the wire is of circular cross section of diameter d, the permeability of the wire being μ,

$$L = 0.008\, a \left[2.303 \log_{10} \frac{2a}{d} + \frac{d}{2a} - 0.774 + \mu\delta \right] \qquad (137)$$

in which δ may be obtained from Table 8 as a function of the argument x given in formula (133). The value of δ for low frequency is 0.25, and for infinite frequency is 0.

RECTANGLE OF ROUND WIRE

Let the sides of the rectangle be a and a_1, the diagonal $g=\sqrt{a^2+a_1^2}$ and d=diameter of the cross section of the wire. Then the inductance at any frequency is

$$L=0.00921\left[(a+a_1)\log_{10}\frac{4aa_1}{d}-a\log_{10}(a+g)-a_1\log_{10}(a_1+g)\right]$$
$$+0.004\left[\mu\delta\,(a+a_1)+2\,(g+d/2)-2\,(a+a_1)\right] \qquad (138)$$

The quantity δ is obtained by use of (133) and Table 8. Its value for zero frequency is 0.25, and is 0 for infinite frequency.

RECTANGLE OF RECTANGULAR-SECTION WIRE

FIG. 179.—*Rectangle of rectangular wire*

Assuming the dimensions of the section of the wire to be b and c, and the sides of the rectangle a and a_1, then for nonmagnetic material the inductance at low frequency is

$$L_0=0.00921\left[(a+a_1)\log_{10}\frac{2aa_1}{b+c}-a\log_{10}(a+g)-a_1\log_{10}(a_1+g)\right]$$
$$+0.004\left[2g-\frac{a+a_1}{2}+0.447\,(b+c)\right] \qquad (139)$$

where $g=\sqrt{a^2+a_1^2}$

INDUCTANCE OF GROUNDED HORIZONTAL WIRE

If we have a wire placed horizontally with the earth, which acts as the return for the current, the self-inductance of the wire is given by the following formula, in which

l = length of the wire
h = height above ground
d = diameter of the wire
μ = permeability of the wire
δ = constant given in Table 8, to take account of the effect of frequency

$$L=0.004605\,l\left[\log_{10}\frac{4h}{d}+\log_{10}\left\{\frac{l+\sqrt{l^2+d^2/4}}{l+\sqrt{l^2+4h^2}}\right\}\right]$$
$$+0.002\left[\sqrt{l^2+4h^2}-\sqrt{l^2+d^2/4}+\mu l\delta-2h+\frac{d}{2}\right] \qquad (140)$$

which, neglecting $\frac{d}{l}$, as may be done in all practical cases, may be written in the following forms convenient for calculation:

For $\frac{2h}{l} \lesseqgtr 1$,

$$L = 0.002\, l \left[2.3026 \log_{10} \frac{4h}{d} - P + \mu\delta \right] \qquad (141)$$

and for $\frac{l}{2h} \lesseqgtr 1$,

$$L = 0.002\, l \left[2.3026 \log_{10} \frac{4l}{d} - Q + \mu\delta \right] \qquad (142)$$

the values of P and Q being obtained by inteipolation from Table 9,

Mutual Inductance of Two Parallel Grounded Wires.—The two wires are assumed to be stretched horizontally, with both ends grounded, the earth forming the return circuit

Let l = length of each wire

d = diameter of wire

D = distance between centers of the wires

h = height above the earth

Then

$$M = 0.004605\, l \left[\log_{10} \frac{\sqrt{4h^2 + D^2}}{D} + \log_{10} \left\{ \frac{l + \sqrt{l^2 + D^2}}{l + \sqrt{l^2 + D^2 + 4h^2}} \right\} \right]$$
$$+ 0.002 \quad [\sqrt{l^2 + D^2 + 4h^2} - \sqrt{l^2 + D^2} + D - \sqrt{D^2 + 4h^2}] \qquad (143)$$

which, if we neglect $\frac{D^2}{l^2}$ and $\left(\frac{D}{2h}\right)^2$ may be expressed in the following forms:

For $\frac{2h}{l} \lesseqgtr 1$,

$$M = 0.002\, l \left[2.3026 \log_{10} \frac{2h}{D} - P + \frac{D}{l} \right] \qquad (144)$$

and for $\frac{l}{2h} \lesseqgtr 1$,

$$M = 0.002\, l \left[2.3026 \log_{10} \frac{2l}{D} - Q + \frac{D}{l} \right] \qquad (145)$$

the values of the quantities P and Q being obtained by interpolation from Table 9.

The expressions for the inductance of n grounded wires in parallel involve the inductances of the single wires and the mutual inductances between the wires. Even in the case that the wires are all alike and evenly spaced, these expressions are very complicated.

The following approximate equation, which neglects the resistances of wires, is capable of giving results accurate to perhaps 1 per cent, for n wires of the same diameter evenly spaced.

Calculate by equations (141), (142), (144), or (145) the inductance L_1 per unit length of a single wire and the mutual inductance M_1 per unit length of any two adjacent wires using, of course, the actual length in the calculation of the ratios $\frac{2h}{l}$, $\frac{2l}{d}$, etc. Then

$$L = l\left[\frac{L_1 + (n-1)\ M_1}{n} - 0.001\ k\right] \tag{146}$$

in which n is the number of wires in parallel and k is a function of n tabulated in Table 7,

Example.—An antenna of 10 wires in parallel, each wire 155 feet long and $\frac{3}{32}$ inch in diameter, spaced 2.5 feet apart, and suspended at a height of 64 feet above the earth. Find the inductance at 100 000 cycles per second.

We have here $\frac{2h}{l} = \frac{128}{155} = 0.826$, and using this as argument in Table 9, $P = 0.6671$.

From (133) $x = 8.07$, and thence from Table 8, $\delta = 0.087$.

$$\frac{4h}{d} = 256 \times 12 \times \frac{32}{3} = 32\ 768, \quad \log_{10}\frac{4h}{d} = 4.515$$

$$\frac{2h}{D} = \frac{128}{2.5} = 51.2 \qquad \log_{10}\frac{2h}{D} = 1.709$$

Then, from formulas (141) and (144)

$$\begin{aligned} L_1 &= 0.002[4.515 \times 2.3026 - 0.667 + 0.087] \\ &= 0.01963\ \mu h \text{ per cm} \end{aligned}$$

$$\begin{aligned} M_1 &= 0.002[1.709 \times 2.3026 - 0.667 + 0.016] \\ &= 0.006568\ \mu h \text{ per cm.} \end{aligned}$$

From Table 7 we find for $n = 10$, $k = 2.05$, so that the inductance as calculated by (146) is

$$L = 155 \times 30.5 \left[\frac{0.01963 + 9(0.006568)}{10} - 0.00205 \right]$$
$$= 4727 \, [0.00582] = 27.4 \, \mu h.$$

CIRCULAR RING OF CIRCULAR SECTION

If a = mean radius of ring
d = diameter of wire, the inductance at any frequency is, except for values of $\frac{d}{2a} > 0.2$,

$$L = 0.01257 \, a \left\{ 2.303 \log_{10} \frac{16a}{d} - 2 + \mu\delta \right\} \tag{147}$$

in which δ will be obtained from (133) and Table 8, Its value for zero frequency is 0.25.

TUBE BENT INTO A CIRCLE

Let the inner and outer diameters of the annular cross section of the tube be d_1 and d_2, respectively, and the mean radius of the circle a, then neglecting $\frac{d_1^2}{a^2}$ and $\frac{d_2^2}{a^2}$

$$L_0 = 0.01257 \, a \left[2.303 \log_{10} \frac{16a}{d_2} - 1.75 - \frac{d_1^2}{2(d_2^2 - d_1^2)} + 2.303 \frac{d_1^4}{(d_2^2 - d_1^2)^2} \log_{10} \frac{d_2}{d_1} \right] \tag{148}$$

For infinite frequency this becomes

$$L_\infty = 0.01257 \, a \left[2.303 \log_{10} \frac{16a}{d_2} - 2 \right] \tag{149}$$

SELF-INDUCTANCE OF COILS

CIRCULAR COIL OF CIRCULAR CROSS SECTION

For a coil of n fine wires wound with the mean radius of the turns equal to a, the area of cross section of the winding being a circle of diameter d,

$$L_0 = 0.01257 \, an^2 \left\{ 2.303 \log_{10} \frac{16a}{d} - 1.75 \right\} \tag{150}$$

This neglects the space occupied by the insulation between the wires.

TORUS WITH SINGLE-LAYER WINDING

A torus is a ring of circular cross section (doughnut shape).

Let R = distance from axis to center of cross section of the winding

a = radius of the turns of the winding

n = number of turns of the winding

$$L_0 = 0.01257\, n^2 [R - \sqrt{R^2 - a^2}] \qquad (151)$$

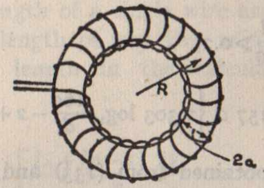


FIG. 180.—*Torus of single layer winding*

TOROIDAL COIL OF RECTANGULAR CROSS SECTION WITH SINGLE-LAYER WINDING

A coil of this shape might also be called a circular solenoid of rectangular section.

Let r_1 = inner radius of toroid (distance from the axis to inside of winding)

r_2 = outer radius of toroid (distance from axis to outside of winding)

h = axial depth of toroid.

Then $L_0 = 0.004606\, n^2\, h \log_{10} \dfrac{r_2}{r_1}$ (152)

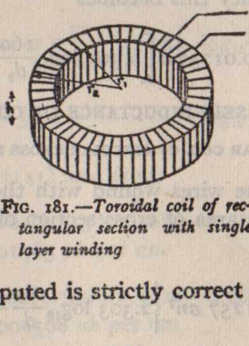


FIG. 181.—*Toroidal coil of rectangular section with single layer winding*

The value so computed is strictly correct only for an infinitely thin winding.

An approximate value is given by

$$L_s = \frac{0.03948\ a^2n^2}{b} K \tag{153}$$

where n = number of turns of the winding, a = radius of the coil, measured from the axis to the center of any wire, b = length of coil = n times the distance between centers of turns, and K is a function of $\frac{2a}{b}$ and is given in Table 10, which was calculated by Nagaoka.

For a coil very long in comparison with its diameter, $K = 1$.

Formula (153) takes no account of the shape or size of the cross section of the wire. Formulas are given below for more accurate calculation of the low-frequency inductance. The inductance at high frequency can not generally be calculated with great accuracy. Formulas which take account of the skin effect, or change of current distribution with frequency, have been developed. The change is very small when the coil is wound with suitably stranded wire. The inductance at high frequencies depends, however, also on the capacity of the coil, which is generally not calculable. If the capacity is known, from measurements or otherwise, its effect upon the inductance can be calculated by

$$L_a = L\ [1 + \omega^2 CL(10)^{-18}] \tag{154}$$

where L_a is the apparent or observed value of the inductance, C is in micromicrofarads, and L in microhenries. The inductance of a coil is decreased by skin effect, and is increased by capacity. The changes due to these two effects sometimes neutralize each other, and in general, formula (153) gives about as good a value of the high-frequency inductance as can be obtained.

Round Wire.—The low-frequency inductance of a coil wound with round wire can be calculated to much higher precision than that of formula (153) by the use of correction terms. Formula (153) gives strictly, the inductance of the equivalent current sheet, which is a winding in which the wire is replaced by an extremely thin tape, the center of each turn of tape being situated at the center of a turn of wire, the edges of adjacent tapes being separated by an infinitely thin insulation. The inductance of the actual coil is obtained from the current-sheet inductance as follows:

Putting L_s = inductance of equivalent cylindrical current sheet, obtained from (153)

L_0 = inductance of the coil at low frequencies

n = number of turns

a = radius of coil measured out to the center of the wire

D = pitch of winding = distance from center of one wire to the center of the next measured along the axis

b = length of equivalent current sheet $= nD$

d = diameter of the bare wire

Then $\quad L_0 = L_s - 0.01257\, na\, (A + B)$ microhenry $\quad$ (155)

in which A is constant, which takes into account the difference in self-inductance of a turn of the wire from that of a turn of the current sheet, and B depends on the difference in mutual inductance of the turns of the coil from that of the turns of the current sheet. The quantities A and B may be interpolated from Tables 11 and 12,

Example.—A coil of 400 turns of round wire of bare diameter 0.05 cm, wound with a pitch of 10 turns per cm, on a form of such a diameter that the mean radius out to the center of the wire is 10 cm.

$$a = 10,\quad b = nD = 40,\quad n = 400,\quad D = 0.1,\quad \frac{d}{D} = 0.5$$

The value of K corresponding to $\frac{2a}{b} = 0.5$ is 0.8181 (Table 10).

$$L_s = 0.03948\,(400)^2\,\frac{100}{40}\,0.8181 = 0.03948 \times 400\,000 \times 0.8181$$

$$= 12\,919 \text{ microhenries}$$

$$= 0.012919 \text{ henry}$$

$$\begin{aligned} \log 0.03948 &= \bar{2}.59638 \\ \log 400\,000 &= 5.60206 \\ \log 0.8181 &= \bar{1}.91281 \\ \hline & \ 4.11125 \end{aligned}$$

Entering Tables 11 and 12 with $\frac{d}{D} = 0.5$, $n = 400$, we find

$$\begin{aligned} A &= -0.136 \\ B &= 0.335 \\ \hline A + B &= 0.199 \end{aligned}$$

The correction in (155) is, accordingly

$$0.01257\,(400)\,10\,(0.199) = 9.99 \text{ microhenries.}$$

The total inductance is 12 919 − 10 = 12 909 microhenries.

Example.—A coil of 79 turns of wire of about 0.8 mm bare diameter. The mean diameter is about 22.3 cm and, for determining the pitch, it was found that the distance from the first to the 79th wire was 9.0 cm.

We have, then,

$$a = 11.15, \quad D = \frac{9.0}{78} = 0.115, \quad b = nD = 79 \times 0.115 = 9.12$$

$$\frac{2a}{b} = 2.445, \quad \frac{d}{D} = \frac{0.08}{0.115} = 0.7$$

The value of K is given by Table 10 as 0.4772, so that

$$L_s = 0.03948\ (79)^2 \frac{(11.15)^2}{9.12}\ 0.4772 = 1602.8 \text{ microhenries}$$

$$\begin{array}{lr} \log 0.03948 = & \bar{2}.59638 \\ 2 \log 79 = & 3.79526 \\ 2 \log 11.15 = & 2.09454 \\ \log 0.4772 = & \bar{1}.67870 \\ \hline & 4.16488 \\ \log 9.12 = & 0.95999 \\ \hline & 3.20489 \end{array}$$

For $n = 79$, $\frac{d}{D} = 0.7$, Tables 11 and 12 give

$$\begin{array}{r} A = 0.200 \\ B = 0.326 \\ \hline (A + B) = 0.526 \end{array}$$

The correction is 0.01257 × 79 × 11.15 × 0.526 = 5.8 microhenries, and the total is 1597.0 microhenries. The measured inductance of this coil is 1595.5.

COIL WOUND WITH WIRE OR STRIP OF RECTANGULAR CROSS SECTION

Approximate values may be obtained for a coil wound with rectangular-section wire or strip by using the simple formula (153), as already explained. More precise values for the low-frequency inductance could be calculated in the same manner as for round wire above, using different values for A and B. It is simpler, however, to use formula (156) below, which applies to the single-layer coil if the symbols are given the following meaning: a = radius measured from the axis out to the center of the cross section of the wire; b = the pitch of the winding D, multiplied by the number of turns n; $c = w$ = the radial dimension of the wire; t = the axial thickness of the wire. The correction for the cross section of the wire is obtained by using formulas (161) and (162), using $\nu = \frac{w}{D}$, $\tau = \frac{t}{D}$.

Example.—A solenoid of 30 turns is wound with ribbon ¼ inch by $\frac{1}{16}$ inch thick, with a winding pitch of ¼ inch to form a solenoid of mean diameter 10 inches.

$$\text{Here } a = 5 \times 2.54 = 12.70 \text{ cm}, \ w = c = \frac{1}{4}(2.54) = 0.635 \text{ cm}$$

$$b = 30 \times \frac{1}{4}(2.54) = 19.05 \text{ cm}, \ c/b = \frac{1}{30}, \ D = 0.635$$

$$t = \frac{1}{16}(2.54)$$

for the equivalent coil. Solving this by Rosa's formula (156), using $\frac{2a}{b} = \frac{4}{3}$, $K = 0.6230$ (Table 10), $\frac{b}{c} = 30$, $B_s = 0.3218$, we find $L_u = 182.55$ μh. The value obtained by Stefan's formula (157) is very slightly in error, being 182.5.

To obtain the correction, we have $\nu = \frac{w}{D} = 1$, $\tau = \frac{1}{4}$, and therefore

$$A_1 = \log_e \frac{2}{1.25} = 0.470$$

$$B_1 = -2\left[\frac{29}{30}0.060 + \frac{28}{30}0.018 + \frac{27}{30}0.008 + \frac{26}{30}0.005 + \cdots + \frac{21}{30}0.001\right] = -0.188$$

so that the correction is (0.01257) 30 (12.70) (0.282) = 1.35 μh, and the total inductance is 183.9.

INDUCTANCE OF POLYGONAL COILS

Such coils, instead of being wound on a cylindrical form, are wrapped around a frame such that each turn of wire incloses an area bounded by a polygon.

No formula has been developed to fit this case, but it is found that the inductance of such a coil (when the number of sides of the polygon is fairly large) may be calculated, within 1 per cent, by assuming that the coil is equivalent to a helix, whose mean radius is equal to the mean of the radii of the circumscribed and inscribed circles of the polygon. That is, if r = the radius of the circumscribed circle, Fig. 182 (which can be measured without difficulty for a polygon for which the number of sides N is an even number), then the modified radius $a_o = r \cos^2 \frac{\pi}{2N}$ is to be used for a in the formulas (153) and (155) of the preceding section.

Examples.—The following table gives the results obtained by this method for some 12-sided polygonal coils, the measured inductance being given for comparison. For $N=12$, $a_0=0.983r$.

Coil	r	a_0	n	D	b	L_0 calculated μh	L_0 measured μh
A	6.35	6.24	23	0.32	7.3	63.0	61.7
B	8.25	8.10	28	.32	9.0	124.7	126.3
C	11.43	11.22	52	.212	11.0	638.0	630.5
D	11.43	11.22	34	.318	10.8	274.9	274.6
E	13.97	13.73	64	.211	13.1	1119.5	1115.5
F	19.05	18.71	117	.158	18.5	5389	5387

MULTIPLE-LAYER COILS

Different formulas are used for long than for short coils. For long coils of few layers, sometimes called multiple-layer solenoids, the inductance is given, approximately, by

$$L_u = L_s - \frac{0.01257 n^2 a c}{b}(0.693 + B_s) \qquad (156)$$

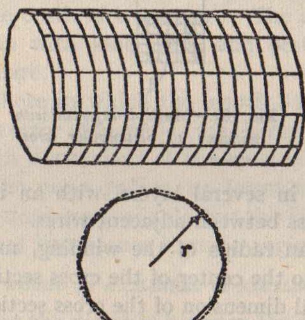


FIG. 182.—*Polygonal coil*

where L_s = inductance, calculated by (153), letting
n = number of turns of the winding
a = radius of coil measured from the axis to the center of cross section of the winding
b = length of coil = distance between centers of turns, times number of turns in one layer
c = radial depth of winding = distance between centers of two adjacent layers times number of layers
B_s = correction given in Table 13, in terms of the ratio $\frac{b}{c}$

Values obtained by this formula are less accurate as the ratio c/a is greater, and may be a few parts in 1000 in error for values of this ratio as great as 0.25, and $\frac{b}{a}$ as great as 5. For accurate results a correction needs to be applied to L_u(see (159) below).

The solution of the problem for short coils is based on that for the ideal case of a circular coil of rectangular cross section. Such a coil would be realized by a winding of wire of rectangular cross

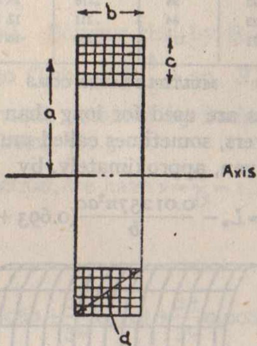


FIG. 183.—*Multiple-layer coil with winding of rectangular cross section*

section, arranged in several layers, with an insulating space of negligible thickness between adjacent wires.

Let a = the mean radius of the winding, measured from the axis to the center of the cross section

b = the axial dimension of the cross section

c = the radial dimension of the cross section

$d = \sqrt{b^2 + c^2}$ = the diagonal of the cross section

n = number of turns of rectangular wire.

Then, if the dimensions b and c are small in comparison with a, the inductance is very accurately given by Stefan's formula, which, for $b > c$, takes the form

$$L_u = 0.01257\,an^2\left[\left(1 + \frac{b^2}{32a^2} + \frac{c^2}{96a^2}\right)\log_e \frac{8a}{d} - y_1 + \frac{b^2}{16a^2}y_2\right]$$
$$= 0.01257\,an^2\left[2.303\left(1 + \frac{b^2}{32a^2} + \frac{c^2}{96a^2}\right)\log_{10} \frac{8a}{d} - y_1 + \frac{b^2}{16a^2}y_2\right] \quad (157)$$

where y_1 and y_2 are constants given in Table 14, For disk or pancake coils, $b<c$, and the formula becomes

$$L_u=0.01257an^2\left[\left(1+\frac{b^2}{32a^2}+\frac{c^2}{96a^2}\right)\log_e\frac{8a}{d}-y_1+\frac{c^2}{16a^2}y_3\right]$$
$$=0.01257an^2\left[2.303\left(1+\frac{b^2}{32a^2}+\frac{c^2}{96a^2}\right)\log_{10}\frac{8a}{d}-y_1+\frac{c^2}{16a^2}y_3\right] \quad (158)$$

in which y_1 and y_3 are given in Table 14,

The constant y_1 is the same function of both b/c and c/b, so that its argument, in any given case, is the ratio of the smaller dimension to the larger; y_2 and y_3 are functions of c/b and b/c, respectively, the arguments being not greater than unity in either case. The error due to the neglect of higher order terms in $\frac{b}{a}$ and $\frac{c}{a}$ in formulas (157) and (158) becomes more important the greater the diagonal of the cross section is, in comparison with the mean radius, but even in the most unfavorable case, c/b small, the inaccuracy with values of the diagonal as great as the mean radius does not exceed one-tenth of 1 per cent. The accuracy is greater with disk coils than with long coils, and best of all when the cross section is square.

For long coils (those in which the length b is greater than the mean radius a), the error of formula (157) becomes rapidly greater. In cases where both dimensions of the cross section are large, in comparison with the mean radius, no formulas well adapted to numerical computations are available, but this is not to be regarded as a case of practical importance in radio engineering.

COIL OF ROUND WIRE WOUND IN A CHANNEL OF RECTANGULAR CROSS SECTION

If we suppose that the distance between the centers of adjacent wires in the same layer is D_1, and that the distance between the centers of wires in adjacent layers is D_2, then the dimensions of the cross section of the equivalent coil with uniform distribution of the current over the cross section will be given by $b=n_1D_1$, $c=n_2D_2$, where n_1 and n_2 are, respectively, the number of turns per layer, and the number of layers.

The inductance of the equivalent coil calculated by formulas (156), (157), or (158), using these dimensions and the same mean radius as the actual coil, is a very close approximation to the value for the actual coil, unless the percentage of the cross section occupied by insulating space is large.

When such is the case, the correction to the inductance, given in the following formula, may be added:

$$\Delta L = 0.01257\,an\left[2.30\log_{10}\frac{D}{d}+0.138+E\right] \qquad (159)$$

in which D = distance between centers of adjacent wires

d = diameter of the bare wire

E = a term depending on the number of turns and their arrangement in the cross section. Its value may with sufficient accuracy be taken as equal to 0.017. The correction in (159) should, in any case, be roughly calculated, to see if it need be taken into account.

Example.—Suppose a coil of winding channel $b=c=1.5$ cm, wound with 15 layers of wire, with 15 turns per layer, the mean radius of the winding being 5 cm. Diameter of bare wire = 0.08 cm.

In this case formula (158) gives

$$n=225,\ d^2=4.5,\ \frac{d^2}{a^2}=\frac{4.5}{25}=0.18,\ b/c=1,\ y_1=0.8483,\ y_2=0.816$$

$$L_u=(0.01257)(5)(225)^2\left[\left\{1+\frac{3(0.3)^2+(0.3)^2}{96}\right\}\log_e\frac{8}{\sqrt{0.18}} -0.8483+\frac{(0.3)^2}{16}0.816\right]$$

$\log 8 = 0.90309$	2.76310*	$1.00375 \log \frac{8a}{d} = 2.9478$
$\frac{1}{2}\log 0.18 = \bar{1}.62764$	$.17269$	$-y_1 = -.8483$
	$.00104$	
		2.0995
$\log_{10}\frac{8a}{d} = 1.27545$	$2.93683 = \log_e \frac{8a}{d}$	$\frac{0.09}{16}0.816 = .0046$
		2.104

$\log_{10} 2.104 = 0.32305$

$2\log_{10} 225 = 4.70436$

$\log_{10} 0.01257 = \bar{2}.09934$ $\qquad L_u = 6694$ microhenries.

$\log_{10} 5 = 0.69897$

3.82572

The correction for insulation is found from (159), as follows:

$$\frac{D}{d}=\frac{0.1}{0.08}=\frac{5}{4},\ \log_{10}\frac{5}{4}=0.09691,\ \log_e\frac{5}{4}=0.223$$

0.138

$E = 0.017$

0.378

correction = (0.01257) (5) (225) 0.378 = 3.34μh

* See Table 5.

The total inductance is 6697 microhenries = 6.697 millihenries.

The correction could, in this case, have been safely neglected.

Example.—A coil of 10 layers of 100 turns per layer, mean radius = 10 cm, the wires being spaced 0.1 cm apart.

For this case $n = 1000$, $a = 10$, $b = 10$, $c = 1$.

Using formula (156) with $\frac{2a}{b} = 2$, $K = 0.5255$, $b/c = 10$

$$L_s = (0.03948)\frac{\overline{1000}^2\,\overline{10}^2}{10}0.5255 = 207\ 400 \text{ microhenries.}$$

For the correction, Table 13 gives for $\frac{b}{c} = 10$

$$\begin{array}{r} 0.693 \\ B_s = 0.279 \\ \hline 0.973 \end{array}$$

so that the correction $= (0.01257)10^6\frac{10}{10}0.973 = 12\ 200$ and the inductance is

$$L_u = 207\ 400 - 12\ 200 = 195\ 200 \text{ microhenries}$$
$$= 195.2 \text{ millihenries.}$$

The formula (157) gives a value about one part in 900 higher than this.

INDUCTANCE OF A FLAT SPIRAL

Such a spiral may be wound of metal ribbon, or of thicker rectangular wire, or of round wire. In each case, the inductance calculated for the equivalent coil, whose dimensions are measured by the method about to be treated, will generally be as close as 1 per cent to the truth, the value thus computed being too small.

If n wires, Fig. 184, of rectangular cross section are used, whose width in the direction of the axis is w, whose thickness is t, and whose pitch, measured from the center of cross section of one turn to the corresponding point of the next wire is D, then the dimensions of the cross section of the equivalent coil are to be taken as $b = w$, $c = nD$, and as before $d = \sqrt{b^2 + c^2}$.

The mean radius of the equivalent coil is to be taken as $a = a_1 + \frac{1}{2}(n - 1)D$, the distance a_1 being one-half of the distance AB (see Fig. 185) measured from the innermost end of the spiral across the center of the spiral to the opposite point of the innermost turn.

The inductance L_u of the equivalent coil is to be calculated using the above dimensions in (158), assuming for n the same number of turns as that of the spiral.

If *round* wire is employed, the same method is used for obtaining the mean radius a and the dimension c, but it is more convenient to take b as zero, and use for the calculation of the inductance of the equivalent coil the special form of (158) which follows when b is placed equal to zero.

$$L_s = 0.01257\, an^2 \left\{ \log_e \frac{8a}{c} - \frac{1}{2} + \frac{c^2}{96a^2}\left(\log_e \frac{8a}{c} + \frac{43}{12} \right) \right\}$$

$$= 0.01257\, n^2 a \left\{ 2.303 \log_{10} \frac{8a}{c} - \frac{1}{2} \right.$$

$$\left. + \frac{c^2}{96a^2}\left(2.303 \log_{10} \frac{8a}{c} + \frac{43}{12} \right) \right\} \qquad (160)$$

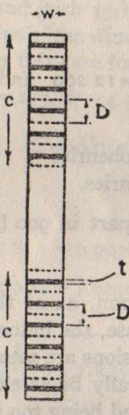


FIG. 184.—*Sectional view of flat spiral wound with metal ribbon*

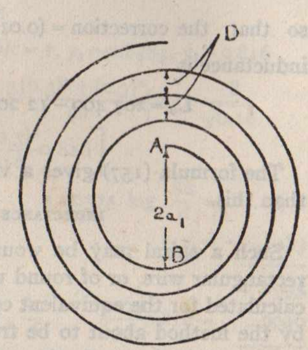


FIG. 185.—*Side view of flat spiral*

The correction for cross section may, in each case, be made by adding $0.01257\, na\, (A_1 + B_1)$ to the value of inductance for the equivalent coil.

For round wires the quantities A_1 and B_1 may be taken as equal to A and B in the Tables 11 and 12, just as in the case of single-layer coils of round wire.

In the case of wire or strip of rectangular cross section the matter is more complicated on account of the two dimensions of the cross section.

If we let $\frac{w}{D} = \nu$ and $\frac{t}{D} = \tau$, then the quantities involved in the calculation of A_1 and B_1 may be made to depend on these two parameters alone. The equations are then with sufficient accuracy:

$$A_1 = \log_e \frac{\nu+1}{\nu+\tau} = 2.303 \log_{10} \frac{\nu+1}{\nu+\tau} \tag{161}$$

$$B_1 = -2\left[\frac{n-1}{n}\delta_{12} + \frac{n-2}{n}\delta_{13} + \frac{n-3}{n}\delta_{14} + \ldots + \frac{1}{n}\delta_{1n}\right] \tag{162}$$

in which δ_{12}, δ_{13}, etc., are to be taken from Table 15,

Example.—For a spiral of 38 turns, wound with copper ribbon whose cross sectional dimensions are 3/8 by 1/32 inch, the inner diameter was found to be $2a_1 = 10.3$ cm and the measured pitch was found to be 0.40 cm.

The dimensions of the equivalent coil of rectangular cross section are, accordingly,

$$b = 3/8 \text{ inch} = 0.953 \text{ cm},$$

$$a = \frac{10.3}{2} + \frac{1}{2}\,37\,(0.4) = 12.55,$$

$$c = 38 \times 0.40 = 15.2.$$

For this coil $b/c = 0.0627$ which gives (Table 14) $y_1 = 0.5604$,

$$y_2 = 0.599, \frac{d^2}{a^2} = 1.472, \log_e \frac{8a}{d} = 1.886.$$

Hence from (158),

$$L_u = (0.01257)(12.55)(38)^2[1.015(1.886) - 0.5604 + 0.055]$$
$$= 323.3 \text{ microhenries.}$$

For this spiral $\nu = 2.38$, $\tau = 0.198$

$$A_1 = 2.303 \log_{10} \frac{3.38}{2.58} = 0.270$$

$$B_1 = -2\left[\frac{37}{38}(0.028) + \frac{36}{38}(0.013) + \frac{35}{38}(0.007) + \frac{34}{38}(0.004)\right.$$
$$\left. + \frac{33}{38}(0.003) + \frac{32}{38}(0.002) + \frac{31}{38}(0.002) + \frac{30}{38}(0.001) + \cdots\right]$$
$$= -0.112, \quad A_1 + B_1 = 0.159$$

and the total correction is $(0.01257)(38)(12.55)(0.159) = 0.95\ \mu h$ so that the total inductance of the spiral is 324.2 microhenries. The measured value was 323.5.

INDUCTANCE OF A SQUARE COIL.

Two cases present themselves

(*a*) A square coil wound in a rectangular cross section.

(*b*) A square coil wound in a single layer.

Let a be the side of the square measured to the center of the rectangular cross section which has sides b and c, and let n be the total number of turns.

Then

$$L_u = 0.008\, an^2 \left[2.303 \log_{10} \frac{a}{b+c} + 0.2235 \frac{b+c}{a} + 0.726 \right] \qquad (163)$$

If the cross section is a square, $b = c$, this becomes

$$L_u = 0.008\, an^2 \left[2.303 \log_{10} \frac{a}{b} + 0.447 \frac{b}{a} + 0.033 \right] \qquad (164)$$

A correction for the insulating space between the wires may be calculated by equation (159) if we replace $0.01257\, an$ therein by

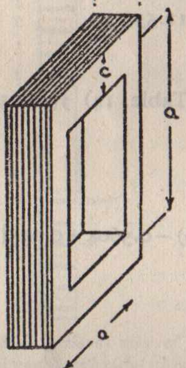


FIG. 186.—*Multiple-layer square coil with winding of rectangular cross section*

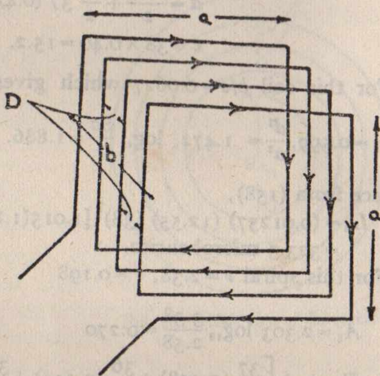


FIG. 187.—*Single-layer square coil*

$0.008\, an$. This correction is additive, but will be negligible unless the insulating space between the wires is large.

SINGLE-LAYER SQUARE COIL

Let a = the side of the square, measured to the center of the wire

n = number of turns

D = pitch of the winding, that is, the distance between the center of one wire and the center of the next (Fig. 187)

$b = nD$

Then

$$L_0 = 0.008\ an^2\left[2.303\ \log_{10}\frac{a}{b} + 0.726 + 0.2231\ \frac{b}{a}\right]$$
$$-0.008\ an\,[A+B] \qquad (165)$$

in which A and B are constants having the same meaning as in (155) to be taken from Tables 11 and 12, if the wires are of round cross section. If the wire is a rectangular strip having a dimension t along the axis of the coil and w perpendicular to it, calculate L_u by (163) and correct for cross section by (161) and (162) and Table 15, using $0.008\ an\ (A_1 + B_1)$.

Example.—Suppose a square coil, 100 cm on a side, wound in a single layer with 4 turns of round wire, 0.1 cm bare diameter, the winding pitch being 0.5 cm.

In this case $n = 4 \qquad d = 0.1 \qquad b = 4 \times 0.5 = 2.0$

$a = 100 \qquad D = 0.5$

The main term in formula (165) gives

$$0.008 \times 100 \times 16\left[2.303\ \log_{10}\frac{100}{2} + 0.726 + 0.004\right]$$
$$= 12.8\,[3.912 + 0.726 + 0.004] = 59.42 \text{ microhenries}$$

Entering Tables 11 and 12, with $\frac{d}{D} = \frac{0.1}{0.5} = 0.2$ and $n = 4$,

$$\begin{aligned} A &= -1.053 \\ B &= \underline{\ \ 0.197} \\ \text{sum} &= -0.856 \end{aligned}$$

$0.008\ an\,[-0.856] = -2.74$ microhenries,
so that $L_u = 59.42 + 2.74 = 62.16$ microhenries.

This result may be checked by computing the self-inductance L_1 of a single turn and the mutual inductances M_{pq} of the individual turns, and summing them up.

Thus we find

$$\begin{aligned} 4\,L_1 &= 22.65 \\ 6M_{12} &= 21.74 \\ 4M_{13} &= 12.29 \\ 2M_{14} &= \underline{\ \ 5.50} \\ &\ 62.18 \text{ microhenries.} \end{aligned}$$

Formula (165) applies only when the length b is small compared with the side of the square a.

Let the sides of the rectangle be a and a_1, the dimensions of the cross section b and c, and the number of turns n, $g=\sqrt{a^2+a_1^2}$

$$L_u = 0.00921\ (a+a_1)\ n^2\left[\log_{10}\frac{2aa_1}{b+c}-\frac{a}{a+a_1}\log_{10}(a+g)\right.$$
$$\left.-\frac{a_1}{a+a_1}\log_{10}(a_1+g)\right]+0.004\ (a+a_1)\ n^2\left[2\left(\frac{g}{a+a_1}\right)\right.$$
$$\left.-\frac{1}{2}+0.447\frac{(b+c)}{(a+a_1)}\right] \qquad (166)$$

Correct for cross section by (159) for round wire.

SINGLE-LAYER RECTANGULAR COIL

Let a and a_1 be the sides of the rectangle, D the pitch of the winding, $b=nD$, and n the number of turns. Then

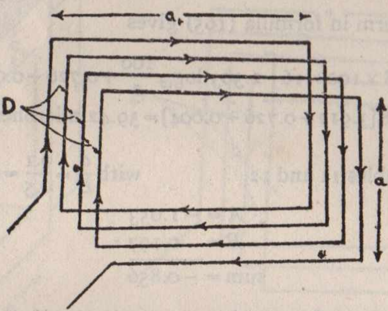


FIG. 188.—*Single-layer rectangular coil.*

$$L_0 = 0.00921\ (a+a_1)\ n^2\left[\log_{10}\frac{2aa_1}{b}\ \frac{a}{a+a_1}\log_{10}(a+g)\right.$$
$$\left.\frac{a_1}{a+a_1}\log_{10}(a_1+g)\right]+0.004\ (a+a_1)\ n^2\left[\frac{2g}{a+a_1}\right.$$
$$\left.-\frac{1}{2}+0.447\ \frac{b}{a+a_1}\right]-0.004\ (a+a_1)\ n\ (A+B) \qquad (167)$$

where A and B are to be taken from Tables 11 and 12, if the coil is wound with round wire. If wound with strip, take $b=nD$ and c = radial thickness of strip. Calculate L_u by (166) and correct for cross section by (161), (162), and Table 15.

Let a_0 and a'_0 be the outside dimensions of the coil, measured between centers of the wire, D the pitch of the winding, measured between the centers of adjacent wires (Fig. 189), n the number of complete turns, d the diameter of the bare wire, $c = nD$.

$g = \text{diagonal} = \sqrt{a^2 + a_1^2}$, $a = a_0 - (n-1)D$, $a_1 = a'_0 - (n-1)D$.

Then

$$L_0 = L_u - 0.004\ n(a + a_1)(A + B)$$

where

$$L_u = 0.009210\ n^2 \left[(a + a_1)\log_{10}\frac{2aa_1}{c} - a \log_{10}(a + g) - a_1 \log_{10}(a_1 + g) \right] + 0.004\ n^2 \left[2g - \frac{a + a_1}{2} + 0.447\ c \right] \quad (168)$$

and A and B are constants to be taken from Tables 11 and 12 for round wire. If the coil is wound with rectangular strip, put b = width of the strip, and $c = nD$, and calculate L_u by (166) using for A and B the values A_1 and B_1 of (161) and (162) Table 15.

FLAT SQUARE COIL

If a_0 be here the side of the square, measured between centers of two outside wires, and $a = a_0 - (n-1)D$, the nomenclature being as in the previous section,

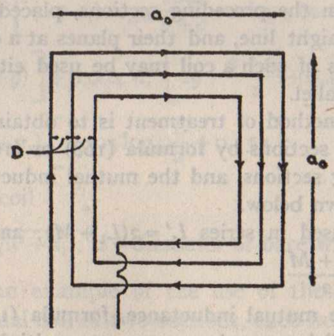


FIG. 189.—*Flat square coil.*

$$L_0 = L_u - 0.008\ n\ a\ (A + B)$$

in which

$$L_u = 0.008\ n^2 a \left[2.303 \log_{10}\frac{a}{c} + 0.2235\frac{c}{a} + 0.726 \right] \quad (169)$$

For round wire the constants A and B are given in Tables 11 and 12. If the coil is wound with strip proceed as for rectangular flat coils of strip, above.

Example.—A coil of 4 turns of 0.22 cm stranded wire was found to have $a_0 = 102$ cm, the pitch of the winding being $D = 2.25$ cm. Here

$$a = 102 - 3 \times 2.25 = 95.25$$
$$c = 4 \times 2.25 = 9.0$$

$$L_0 = 0.008 \times 16 \times 95.25 \left[2.303 \log_{10} \frac{95.25}{9.0} + 0.2235 \frac{9.0}{95.25} + 0.726 \right]$$

$$= 16 \times 0.762 \; [2.359 + 0.021 + 0.726] = 37.87 \; \mu h$$

For

$$n = 4 \text{ and } \frac{d}{D} = \frac{0.22}{2.25} = 0.098, \text{ Tables 11 and 12 give}$$

$$A = -1.767, \text{ and } B = 0.197$$

the correction is $0.008 \times 4 \times 95.25 \; (-1.570) = -4.79 \; \mu h$ so that $L_0 = 37.87 + 4.79 = 42.66$ microhenries.

The measured value, uncorrected for lead wires was 44.5 microhenries.

DOUBLE FLAT RECTANGULAR COIL

Such a coil consists of two similar flat, rectangular coils, such as are treated in the preceding sections, placed with their axes in the same straight line, and their planes at a distance x apart. The two sections of such a coil may be used either singly, or in series, or in parallel.

The general method of treatment is to obtain the inductance L_1 of the single sections by formula (168) or (166), as described in the preceding sections, and the mutual inductance of the two sections, as shown below.

Then when used in series $L' = 2(L_1 + M)$, and when used in parallel $L'' = \dfrac{L_1 + M}{2}$

To obtain the mutual inductance, formula (183) or (184) for two equal, parallel rectangles or squares, multiplied by the product of the number of turns of the two, should be used, putting for the dimensions of the rectangles a and a_1 as defined under (168) and (169) and for the distance D in (183) or (184) a modified distance r given by the expression

$$r = kc, \; c = nD, \; (x/c \text{ small})$$

in which

$$2.303 \log_{10} k = 2.303 \frac{x^2}{c^2} \log_{10} \frac{x}{c} + \pi \frac{x}{c} - \frac{3}{2} - \frac{3}{2}\frac{x^2}{c^2} - \frac{1}{12}\frac{x^4}{c^4} \quad (170)$$

When x is not small in comparison with c, r will have to be calculated by the equation

$$\log_{10} r = \frac{x^2}{c^2} \log_{10} x + \frac{1}{2}\left(1 - \frac{x^2}{c^2}\right) \log_{10} (c^2 + x^2) + \frac{\left(2\frac{x}{c} \tan^{-1}\frac{c}{x} - \frac{3}{2}\right)}{2.303} \quad (171)$$

When the distance x between the planes of the coils is chosen equal to the pitch D of their windings, the calculation of their inductance, when joined in series, may be obtained in a simpler manner. Putting $b = 2D$ and $n_1 = 2n$, the number of turns of the two windings in series,

$$L' = 0.008\, n_1^2 a \left[2.303 \log_{10} \frac{a}{b+c} + 0.2235 \frac{b+c}{a} + 0.726\right]$$

$$+ 0.008\, n_1 a \left[2.303 \log_{10} \frac{D}{d} + 0.153\right] \quad (172)$$

for a square coil, and

$$L' = 0.009210\, n_1^2 \left[(a + a_1) \log_{10} \frac{2aa_1}{b+c} - a \log_{10} (a+g)\right.$$

$$\left. - a_1 \log_{10} (a_1 + g)\right] + 0.004\, n_1^2 \left[2g - \frac{a+a_1}{2} + 0.447(b+c)\right]$$

$$+ 0.004\, n_1 (a + a_1) \left[2.303 \log_{10} \frac{D}{d} + 0.153\right] \quad (173)$$

for a rectangular coil

$$g = \sqrt{a^2 + a_1^2}, \quad d = \text{diameter of bare wire.}$$

Example.—As an example of the use of these formulas, take the case of an actual coil of two sections, each being a flat, square coil of 5 turns of 0.12 cm wire, wound with a pitch of $D = 1.27$ cm, the distance of the planes of the coils being $x = 1.27$ cm. The length of a side of the outside turn was 101 cm.

Putting $n = 5$, $a = 101 - 4 \times 1.27 = 95.9$, $c = 5 \times 1.27 = 6.35$, and $d/D = 0.1$, formula (169) gives $L_1 = 66.28 + 6.14 = 72.42 \mu h$, for a single section.

To obtain the mutual inductance, we find by (170) for

$$\frac{x}{c}=\frac{1.27}{6.35}=0.2$$

$$2.303 \log_{10} k=2.303\times0.04\,(-0.699)+0.2\,\pi-\frac{3}{2}-\frac{3}{2}(0.04)-\frac{1}{12}(0.0016)$$

$$=-0.0644+0.6283-1.5-0.06-0.0001$$

$$=-0.9962$$

$$\log_{10} k=-0.4326=\bar{1}.5674$$

$$k=0.3693 \text{ and } r=0.3693\times6.35=2.344$$

Putting this value of r in place of D in (184) with $a=95.9$

$$M=0.008\times5\times5\left[2.303\times95.9 \log_{10}\left(\frac{191.8\times95.93}{231.5\times2.344}\right)+135.62 - 191.86+2.34\right]=56.82\ \mu h$$

For the two coils in series, then

$$L'=2(72.42+56.82)=258.5\ \mu h$$

and for the parallel arrangement

$$L''=\frac{72.42+56.82}{2}=64.6\ \mu h$$

The inductance of the coils in series may also be found by putting $a=95.9$, $b=6.35$, $c=2.54$, $n_1=10$ in (163) and (159) and we find $L \doteq 239.8+18.8=258.6\ \mu h$ in agreement with the other method.

MUTUAL INDUCTANCE

The following formulas for mutual inductance hold strictly only for low frequencies. In general, however, the values will be the same at high frequencies.

TWO PARALLEL WIRES OR BARS SIDE BY SIDE

Let l = length of each wire or bar.
D = distance between centers of the wires.

FIG. 190.—*Two parallel wires side by side*

The following expression is exact when the wires have no appreciable cross section, but is sufficiently exact even when the cross section is large if l is great compared with D. Within these limits the shape is immaterial.

$$M = 0.002\left[2.303\, l \log_{10} \frac{l+\sqrt{l^2+D^2}}{D} - \sqrt{l^2+D^2} + D\right] \quad (174)$$

$$= 0.002 l\left[2.303 \log_{10} \frac{2l}{D} - 1 + \frac{D}{l}\right] \text{nearly.} \quad (175)$$

TWO WIRES END TO END WITH THEIR AXES IN LINE

Let the lengths of the two wires be l and m, their radii being supposed to be small. Then,

$$M = 0.002303\left[l \log_{10} \frac{l+m}{l} + m \log_{10} \frac{l+m}{m}\right] \quad (176)$$

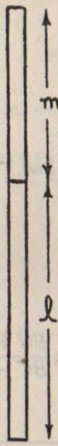


FIG. 191.—*Two wires end to end in same straight line*

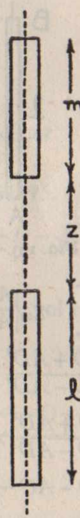


FIG. 192.—*Two wires in same straight line but separated*

TWO WIRES WITH THEIR AXES IN THE SAME STRAIGHT LINE BUT SEPARATED

Let their lengths be l and m and the distance between the nearer ends be Z.

$$M = 0.002303\,[(l+m+Z)\log_{10}(l+m+Z) + Z\log_{10} Z - (l+Z)\log_{10}(l+Z) - (m+Z)\log_{10}(m+Z)] \quad (177)$$

If AD, AD', AC, AC', etc., represent the distances shown in the figure, the general formula is

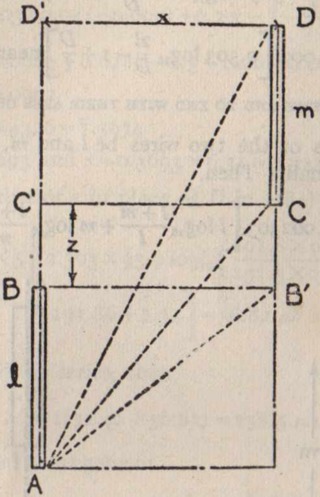


FIG. 193.—*Two wires with axes in parallel lines*

$$\left.\begin{aligned} M = 0.001151 \Bigg[& l \log_{10}\left\{\frac{AD+AD'}{AD-AD'} \times \frac{AC-AC'}{AC+AC'}\right\} \\ & + m \log_{10}\left\{\frac{AD+AD'}{AD-AD'} \times \frac{BD-BD'}{BD+BD'}\right\} \\ & + Z \log_{10}\left\{\frac{AD+AD'}{AD-AD'} \times \frac{AC-AC'}{AC+AC'} \times \frac{BD-BD'}{BD+BD'} \times \frac{BC+BC'}{BC-BC'}\right\}\Bigg] \\ & - 0.001\ (AD - AC - BD + BC) \end{aligned}\right\} \quad (178)$$

the distances being $AD' = l + m + Z$, $AD = \sqrt{x^2 + (l + m + Z)^2}$, etc. This formula holds for $Z = 0$, but not when one wire overlaps on the other.

When they overlap, as in Fig. 194,

$$M = M_{1,34} + M_{23} + M_{24} \quad (179)$$

in which $M_{1,34}$ is to be calculated by the general formula, using $Z = 0$ and putting the segment PV for l and ST for m, while for M_{24} the length VR is put for l and WT for m with $Z = 0$. The mutual inductance M_{23} of the overlapping portions is obtained by (174).

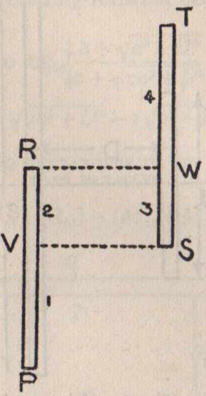


Fig. 194.—*Two wires with axes in parallel lines; a particular case of Fig. 193*

Special Cases.—For the case shown in Fig. 195

$$M = 0.001\left[2.303l\log_{10}\left(\frac{l+\sqrt{D^2+l^2}}{D}\right)+D-\sqrt{D^2+l^2}\right] \quad (180)$$

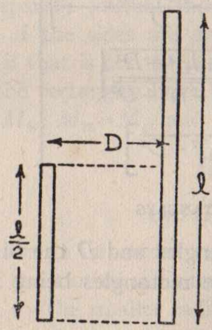


Fig. 195.—*Two wires with axes in parallel lines; another particular case of Fig. 193*

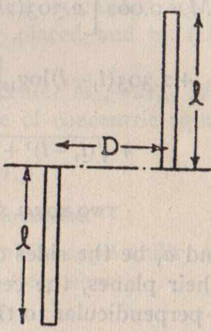


Fig. 196.—*Two wires with axes in parallel lines, with one end of each on the same perpendicular*

and for the wires of Fig. 196

$$M = 0.001\left[4.605l\log_{10}\left(\frac{2l+\sqrt{D^2+4l^2}}{l+\sqrt{D^2+l^2}}\right)-\sqrt{D^2+4l^2} + 2\sqrt{D^2+l^2}-D\right] \quad (181)$$

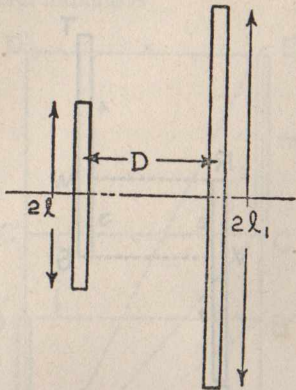


FIG. 197.—*Two parallel symmetrically placed wires*

Putting for the lengths of the two wires $2l$ and $2l_1$ ($2l$ the shorter) and for their distance apart D

$$M = 0.002\left[2.303(2l)\log_{10}\left\{\frac{l+l_1+\sqrt{(l+l_1)^2+D^2}}{D}\right\}\right.$$
$$+2.303(l_1-l)\log_{10}\left\{\frac{l+l_1+\sqrt{(l+l_1)^2+D^2}}{l_1-l+\sqrt{(l_1-l)^2+D^2}}\right\} \tag{182}$$
$$\left.+\sqrt{(l_1-l)^2+D^2}-\sqrt{(l+l_1)^2+D^2}\right]$$

TWO EQUAL PARALLEL RECTANGLES

Let a and a_1 be the sides of the rectangles and D the distance between their planes, the centers of the rectangles being in the same line, perpendicular to these planes

$$M = 0.009210\left[a\log_{10}\left\{\frac{a+\sqrt{a^2+D^2}}{a+\sqrt{a^2+a_1^2+D^2}}\times\frac{\sqrt{a_1^2+D^2}}{D}\right\}\right.$$
$$\left.+a_1\log_{10}\left\{\frac{a_1+\sqrt{a_1^2+D^2}}{a_1+\sqrt{a^2+a_1^2+D^2}}\times\frac{\sqrt{a^2+D^2}}{D}\right\}\right] \tag{183}$$
$$+0.008\left[\sqrt{a^2+a_1^2+D^2}-\sqrt{a^2+D^2}-\sqrt{a_1^2+D^2}+D\right]$$

If a is the side of each square and D is the distance between their planes, then the preceding formula becomes

$$M = 0.01842\left[a \log_{10}\left\{\frac{a+\sqrt{a^2+D^2}}{a+\sqrt{2a^2+D^2}} \times \frac{\sqrt{a^2+D^2}}{D}\right\}\right] \qquad (184)$$
$$+0.008\left[\sqrt{2a^2+D^2} - 2\sqrt{a^2+D^2} + D\right]$$

MUTUAL INDUCTANCE OF TWO RECTANGLES IN THE SAME PLANE WITH THEIR SIDES PARALLEL

$$M = (M_{16}+M_{38}+M_{45}+M_{27}) - (M_{18}+M_{25}+M_{36}+M_{47}) \qquad (185)$$

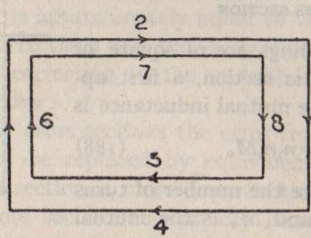


FIG. 198.—*Two rectangles in the same plane with their sides parallel*

the separate mutual inductances being calculated by formula (182), if the sides are symmetrically placed, and by (182) and (178) if that is not the case.

If the rectangles have a common center $M_{16} = M_{38}$, $M_{45} = M_{27}$, $M_{18} = M_{36}$, $M_{25} = M_{47}$ and for the case of concentric squares, we have

$$M = 4(M_{16} - M_{18}) \qquad (186)$$

TWO PARALLEL COAXIAL CIRCLES

This is an important case because of its applicability in calculating the mutual inductances of coils (see below)

Let a = the smaller radius (Fig. 199)

A = the larger radius.

D = the distance between the planes of the circles.

Then

$$\frac{r_2}{r_1} = \sqrt{\frac{\left(1-\frac{a}{A}\right)^2+\frac{D^2}{A^2}}{\left(1+\frac{a}{A}\right)^2+\frac{D^2}{A^2}}}$$

must be calculated, and

$$M = F\sqrt{Aa} \tag{187}$$

where F may be obtained by interpolation in Table 16 for the calculated value of $\frac{r_2}{r_1}$

r_1 = the longest distance between the circumferences.

r_2 = the shortest distance between the circumferences.

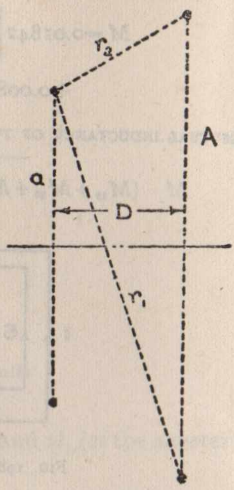


FIG. 199.—*Cross sections of two parallel coaxial circles*

TWO COAXIAL CIRCULAR COILS OF RECTANGULAR CROSS SECTION

If the coil windings are of square, or nearly square, cross section, a first approximation to the mutual inductance is

$$M = n_1 n_2 M_0 \tag{188}$$

where n_1 and n_2 are the number of turns on the two coils and M_0 is the mutual inductance of two coaxial circles, one located at the center of the cross section of one of the coils and the other at the center of the cross section of the other.

Thus, if

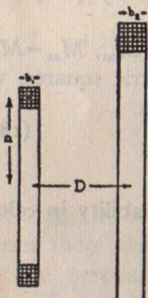


FIG. 200.—*Two parallel coaxial coils with windings of rectangular cross section*

a = mean radius of one coil, measured from the axis to the center of cross section,

A = mean radius, similarly measured, of the other coil,

D = distance between the planes passed through the centers of cross section of the coils, perpendicular to their common axis (Fig. 200).

the value M_0 will be computed by formula (187) and Table 16, using the values of a, A, and D, just defined.

If the cross sections of the windings are square, this value will not be more than a few parts in a thousand in error, even with relatively large cross sectional dimensions, except when the coils are close together.

A more accurate value for coils of square cross section may be obtained by supposing the two parallel circles to remain at the distance D, but to have radii

$$a_1 = a\left(1 + \frac{b_1^2}{24\,a^2}\right) \text{ and } A_1 = A\left(1 + \frac{b_2^2}{24\,A^2}\right) \tag{189}$$

where b_1 and b_2 are the dimensions of the square cross sections corresponding to the coils of mean radius a and A, respectively.

When the correction factors in (189) are only a few parts in 1000, the values of r_2/r_1, and hence F, are very little affected, and the fractional correction to the mutual inductance, to allow for the cross sections, is approximately equal to the geometric mean of the fractional corrections to a and A, so that an estimate of the magnitude of the correction to the mutual inductance may be gained with little labor.

With rectangular cross sections the error from the assumption that the coils may be replaced by equivalent filaments at the center of the cross section is more important than in the case of coils of square cross section and rapidly increases as the axial dimension of one or both of the cross sections is increased, in relation to the distance D between the median planes. The error may, easily, be as great as 1 per cent or more in practical cases.

An estimate of the magnitude of the error, in any case, may be made by dividing the coils up into two or more sections of, as nearly as possible, square cross section, and assuming that each portion of the coil may be replaced by a circular filament at the center of its cross section.

Suppose that coil A is divided into two equal parts, and replaced by two filaments 1, 2, while coil B is likewise replaced by two filaments 3, 4, then, assuming that each filament is associated with a number of turns which is the same fraction of the whole number of turns in the coil as the area of the section is to the whole cross sectional area (one-half in this case) we have

$$\begin{aligned} M &= \frac{n_1}{2}\,\frac{n_2}{2}\,M_{13} + \frac{n_1 n_2}{4}\,M_{14} + \frac{n_1 n_2}{4}\,M_{23} + \frac{n_1 n_2}{4}\,M_{24} \\ &= n_1 n_2 \left(\frac{M_{13} + M_{14} + M_{23} + M_{24}}{4}\right) \end{aligned} \tag{190}$$

in which M_{13} is the mutual inductance of the two circular filaments 1 and 3, etc.

For a discussion of more accurate methods for correcting for the cross section of coils, the reader is referred to Bulletin, Bureau of Standards, 8, pages 33–43; 1912.

If the coils are of the nature of solenoids of few layers, it is best to use the formulas for the mutual inductance of coaxial solenoids given in the next section.

Example.—Suppose two coils of square cross section 2 cm on a side, the radii being, $a=20$, $A=25$, and the distance between their median planes being $D=10$ cm (Fig. 201). Further, suppose that one coil has 100 turns and the other 500.

Then

$$\frac{r_2}{r_1}=\sqrt{\frac{\left(1-\frac{20}{25}\right)^2+\left(\frac{10}{25}\right)^2}{\left(1+\frac{20}{25}\right)^2+\left(\frac{10}{25}\right)^2}}=\sqrt{\frac{0.20}{3.40}}=0.24253$$

From Table 16 we find, corresponding to this value of $\frac{r_2}{r_1}$,

$F=0.01113$. Therefore, from (187)

$$M_0=0.01113\sqrt{25\times 20}=0.2489\mu h$$

and

$$M=n_1n_2M_0=100\times 500\times 0.2489$$
$$=12\,445 \text{ microhenries}$$
$$=0.012445 \text{ henry.}$$

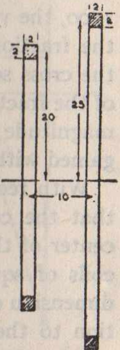


FIG. 201.—*Example of two parallel coaxial coils with windings of rectangular cross section*

If we take account of the cross sections we have from (189)

$$a_1=20\left(1+\frac{2^2}{24\times 20^2}\right)=20\ (1.00042)$$

$$A_1=25\left(1+\left(\frac{2}{25}\right)^2\frac{1}{24}\right)=25\ (1.00027)$$

so that the correction factor to the mutual inductance will be of the order of about $\sqrt{1.00042\times 1.00027}$, or the mutual inductance should be increased by about 3.5 parts in 10 000 only.

Example.—Fig. 202 shows two coils of rectangular cross section. For coil P, $a=20$, $b_1=2$, $c_1=3$, $n_1=600$. For coil Q, $A=25$, $b_2=4$, $c_2=1$, $n_2=400$ and $D=10$. If, first, we replace each coil by a circular filament at the center of its cross section, we have the same value of M_0 as in the previous example, and

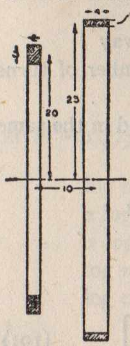


Fig. 202.—*Another example of Fig. 200*

$$M = 600 \times 400 \times 0.2489 \text{ microhenries.}$$

More precise formulas, involving a good deal of computation, show that the true value is

$$M = 600 \times 400 \times 0.249844,$$

so that the approximate value is about 3.8 parts in 1000 too small.

Each coil is then subdivided into two sections and filaments p, q, r, s, imagined to pass through the center of cross section of each of these subdivisions: The data for these filaments are as follows:

Radius	Filaments	a	A	D	r_2/r_1	F
p 19.25	pr	19.25	25	9	0.2365	0.01140
q 20.75	ps	19.25	25	11	.2722	.009872
r 25	qr	20.75	25	9	.2135	.01255
s 25	qs	20.75	25	11	.2506	.01077

We find then

$$M = 600 \times 400 \left\{ \frac{0.2501 + 0.2166 + 0.2858 + 0.2452}{4} \right\} = 600 \times 400 \times 0.24942$$

a result which is 1.7 in 1000 too small.

The increase in accuracy is hardly commensurate with the increased labor.

MUTUAL INDUCTANCE OF COAXIAL SOLENOIDS NOT CONCENTRIC

Gray's formula, given for this case, supposes that each coil approximates the condition of a continuous thin winding, that is, a current sheet.

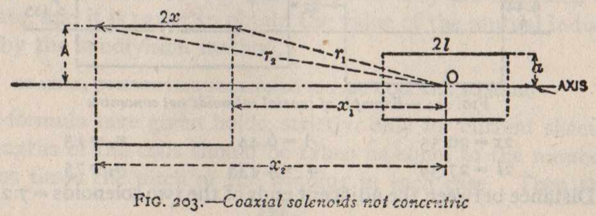


Fig. 203.—*Coaxial solenoids not concentric*

Let a = the smaller radius, measured from the axis of the coil to the center of the wire

A = the larger radius, measured in the same way

$2l$ = length of the coil of smaller radius = number of turns times the pitch of winding

$2x$ = length of the coil of larger radius, measured in the same way

n_1 and n_2 = total number of turns on the two coils

D = axial distance between centers of the coils

$x_1 = D - x \qquad r_1 = \sqrt{x_1^2 + A^2}$

$x_2 = D + x \qquad r_2 = \sqrt{x_2^2 + A^2}$

Then

$$M = 0.009870 \frac{a^2 A^2 n_1 n_2}{2x \cdot 2l}\left[K_1 k_1 + K_3 k_3 + K_5 k_5\right] \qquad (191)$$

in which

$$K_1 = \frac{2}{A^2}\left(\frac{x_2}{r_2} - \frac{x_1}{r_1}\right),\ k_1 = 2l$$

$$K_3 = \frac{1}{2}\left(\frac{x_1}{r_1^5} - \frac{x_2}{r_2^5}\right),\ k_3 = a^2 l\left(3 - 4\frac{l^2}{a^2}\right)$$

$$K_5 = -\frac{A^2}{8}\left[\frac{x_1}{r_1^9}\left(3 - 4\frac{x_1^2}{A^2}\right) - \frac{x_2}{r_2^9}\left(3 - 4\frac{x_2^2}{A^2}\right)\right]$$

$$k_5 = a^4 l\left(\frac{5}{2} - 10\frac{l^2}{a^2} + 4\frac{l^4}{a^4}\right)$$

This formula is most accurate for short coils with relatively great distance between them. In the case of long coils it is sometimes necessary to subdivide the coil into two or more parts. The mutual inductance of each of these parts on the other coil having been found, the total mutual inductance is obtained by adding these values.

Example.—

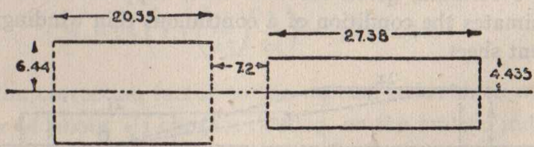


Fig. 204.—*Example of coaxial solenoids not concentric*

$2x = 20.55$	$A = 6.44$	$n_1 = 15$
$2l = 27.38$	$a = 4.435$	$n_2 = 75$

Distance between the adjacent ends of the two solenoids = 7.2 cm.

Then

$$x_1 = 20.89 \qquad k_1K_1 = 0.04294$$
$$x_2 = 41.44 \qquad k_3K_3 = .01827$$
$$k_5K_5 = .00519$$
$$\overline{0.06640}$$

and $M = 0.009870\left(\dfrac{a^2A^2n_1n_2}{2x\ \ 2l}\right)0.06640 = 1.069$ microhenries

$$\begin{array}{lll} \log 0.009870 & = \bar{3}.99432 & \\ 2 \log a & = 1.29378 & \log 2x = 1.31281 \\ 2 \log A & = 1.61778 & \log 2l = 1.43743 \\ \log n_1n_2 & = 3.05115 & \overline{2.75024} \\ \log 0.06640 & = \bar{2}.82217 & \\ & \overline{2.77920} & \\ & 2.75024 & \\ & \overline{0.02896} = \log M & \end{array}$$

Dividing the longer coil into two sections C and D of 37 and 38 turns, respectively, and repeating the calculation for the mutual inductance of these sections on the other coil R (Fig. 204).

$$\begin{array}{ll} \text{For } M_{RC} & \text{For } M_{RD} \\ k_1K_1 = 0.04889 & k_1K_1 = 0.01155 \\ k_3K_3 = .00652 & k_3K_3 = .00061 \\ k_5K_5 = .00005 & \overline{0.01216} \\ \overline{0.05546} & \end{array}$$

and $M = M_{RC} + M_{RD} = 0.8917 + 0.1956 = 1.087\ \mu h.$

Further subdivision showed that this last value is not in error by more than 5 parts in 10 000.

The criterion as to the necessity of subdivision is the rapidity with which the terms k_1K_1, k_3K_3, etc., fall off in value. In the first case k_7K_7 and k_9K_9 are not negligible. The expressions for these quantities are not here given because they are laborious to calculate, and it is easier to obtain the value of the mutual inductance by the subdivision method.

COAXIAL, CONCENTRIC SOLENOIDS (OUTER COIL THE LONGER)

The formula here given holds, strictly, only for current sheets. The lengths of the coils should be taken as equal to the number of turns times the pitch of the winding in each case. Then the mutual inductance of the current sheets is not appreciably different from that of the coils.

Let a = smaller radius
A = larger radius
$2x$ = equivalent length of outer coil
$2l$ = equivalent length of inner coil
$g = \sqrt{x^2 + A^2}$ = diagonal.

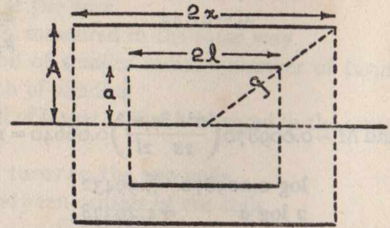


FIG. 205.—*Coaxial concentric solenoids, outer coil being longer*

Then

$$M = \frac{0.01974\ a^2 n_1 n_2}{g}\left[1 + \frac{A^2 a^2}{8g^4}\left(3 - 4\frac{l^2}{a^2}\right)\right] \qquad (192)$$

This formula is more accurate, the shorter the coils and the greater the difference of their radii, but in most practical cases the accuracy is ample. In many cases the second term in (192) is negligible, and it is a good plan to make a preliminary rough calculation of this term to see whether it will need to be considered. In the case of long coils, and of coils of nearly equal radii, the terms neglected in this formula may be as great as 1 per cent. A criterion of rapid convergence is, in general, the smallness of $\frac{a^2A^2}{g^4}$, but the magnitude of the coefficient $\left(3 - 4\frac{l^2}{a^2}\right)$ and the corresponding coefficients of terms neglected in (192) may in some cases modify this condition for rapid convergence materially.

Example.—

$$2x = 30 \qquad 2l = 5 \qquad g = \sqrt{250} \qquad \frac{a^2A^2}{g^4} = \frac{4}{625}$$

$$A = 5 \qquad a = 4$$

$$n_1 = 300 \qquad n_2 = 200$$

$$0.01974\ \frac{a^2 n_1 n_2}{g} = 1198.5$$

$$M = 1198.5\ (1 + .00115) = 1199.9 \text{ microhenries.}$$

For the case, however, where

$$2x = 30 \qquad a = 2 \qquad n_1 = 300$$

$$2l = 24 \qquad A = 5 \qquad n_2 = 960$$

although the value of $\frac{a^2A^2}{g^4} = \frac{1}{5000}$ only, the coefficient $\left(3-4\frac{l^2}{a^2}\right)$ $= 141$, (the length of the coil is great compared with its radius) so that the term in $\frac{a^2A^2}{g^4}$ is -0.0282, and investigation of the complete formula shows that the succeeding terms are -0.0127 and -0.0048, so that their neglect will give an error of over 1.5 per cent.

CONCENTRIC COAXIAL SOLENOIDS (OUTER COIL THE SHORTER)

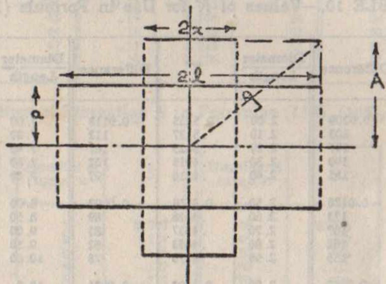


FIG. 206.—*Coaxial concentric solenoids, outer coil being shorter*

In this case we have to put $g = \sqrt{l^2 + A^2}$, and the formula is

$$M = 0.01974 \frac{a^2 n_1 n_2}{g}\left[1 + \frac{A^2 a^2}{8g^4}\left(3 - 4\frac{x^2}{a^2}\right)\right] \qquad (193)$$

which is rapidly convergent in most cases.

TABLES FOR INDUCTANCE CALCULATIONS

TABLE 8.—Values of δ in Formulas (132), (134), (137), (138), (140), (141), (142), and (147), for Calculating Inductance of Straight Wires at Any Frequency

x	δ	x	δ
0	0.250	12.0	0.059
0.5	.250	14.0	.050
1.0	.249	16.0	.044
1.5	.247	18.0	.039
2.0	.240	20.0	.035
2.5	0.228	25.0	0.028
3.0	.211	30.0	.024
3.5	.191	40.0	.0175
4.0	.1715	50.0	.014
4.5	.154	60.0	.012
5.0	0.139	70.0	0.010
6.0	.116	80.0	.009
7.0	.100	90.0	.008
8.0	.088	100.0	.007
9.0	.078	∞	.000
10.0	.070		

TABLE 9.—Constants P and Q in Formulas (141), (142), (144), and (145)

$\frac{2h}{l}$	P	$\frac{l}{2h}$	Q	$\frac{2h}{l}$	P	$\frac{l}{2h}$	Q
0	0	0	1.0000	0.6	0.5136	0.6	1.2918
0.1	0.0975	0.1	1.0499	.7	.5840	.7	1.3373
.2	.1900	.2	1.0997	.8	.6507	.8	1.3819
.3	.2778	.3	1.1489	.9	.7139	.9	1.4251
.4	.3608	.4	1.1975	1.0	.7740	1.0	1.4672
.5	.4393	.5	1.2452				

TABLE 10.—Values of K for Use in Formula (153)

$\frac{\text{Diameter}}{\text{Length}}$	K	Difference	$\frac{\text{Diameter}}{\text{Length}}$	K	Difference	$\frac{\text{Diameter}}{\text{Length}}$	K	Difference
0.00	1.0000	−0.0209	2.00	0.5255	−0.0118	7.00	0.2584	−0.0047
.05	.9791	203	2.10	.5137	112	7.20	.2537	45
.10	.9588	197	2.20	.5025	107	7.40	.2491	43
.15	.9391	190	2.30	.4918	102	7.60	.2448	42
.20	.9201	185	2.40	.4816	97	7.80	.2406	40
0.25	0.9016	−0.0178	2.50	0.4719	−0.0093	8.00	0.2366	−0.0094
.30	.8838	173	2.60	.4626	89	8.50	.2272	86
.35	.8665	167	2.70	.4537	85	9.00	.2185	79
.40	.8499	162	2.80	.4452	82	9.50	.2106	73
.45	.8337	156	2.90	.4370	78	10.00	.2033	....
0.50	0.8181	−0.0150	3.00	0.4292	−0.0075	10.0	0.2033	−0.0133
.55	.8031	146	3.10	.4217	72	11.0	.1903	113
.60	.7885	140	3.20	.4145	70	12.0	.1790	98
.65	.7745	136	3 30	.4075	67	13.0	.1692	87
.70	.7609	131	3.40	.4008	64	14.0	.1605	78
0.75	0.7478	−0.0127	3.50	0.3944	−0.0062	15.0	0.1527	−0.0070
.80	.7351	123	3.60	.3882	60	16.0	.1457	63
.85	.7228	118	3.70	.3822	58	17 0	.1394	58
.90	.7110	115	3.80	.3764	56	18.0	.1336	52
.95	.6995	111	3.90	.3708	54	19.0	.1284	48
1.00	0.6884	−0.0107	4.00	0.3654	−0.0052	20.0	0.1236	−0.0085
1.05	.6777	104	4.10	.3602	51	22 0	.1151	73
1.10	.6673	100	4.20	.3551	49	24 0	.1078	63
1.15	.6573	98	4.30	.3502	47	26 0	.1015	56
1.20	.6475	94	4.40	.3455	46	28.0	.0959	49
1.25	0.6381	−0.0091	4.50	0.3409	−0.0045	30.0	0.0910	−0.0102
1.30	.6290	89	4.60	.3364	43	35.0	.0808	80
1.35	.6201	86	4.70	.3321	42	40.0	.0728	64
1.40	.6115	84	4 80	.3279	41	45.0	.0664	53
1.45	.6031	81	4.90	.3238	40	50.0	.0611	43
1.50	0.5950	−0 0079	5.00	0.3198	−0.0076	60.0	0.0528	−0.0061
1.55	.5871	76	5.20	.3122	72	70.0	.0467	48
1.60	.5795	74	5.40	.3050	69	80.0	.0419	38
1.65	.5721	72	5.60	.2981	65	90.0	.0381	31
1.70	.5649	70	5.80	.2916	62	100.0	.0350	....
1.75	0.5579	−0.0068	6.00	0.2854	−0.0059			
1.80	.5511	67	6.20	.2795	56			
1.85	.5444	65	6.40	.2739	54			
1.90	.5379	63	6.60	.2685	52			
1.95	.5316	61	6.80	2633	49			

TABLE 11.—Values of Correction Term A in Formulas (155), (165), (168), and (169)

$\frac{d}{D}$	A	Difference	$\frac{d}{D}$	A	Difference	$\frac{d}{D}$	A	Difference
1.00	0.557	−0.051	0.40	−0.359	−0.052	0.15	−1.340	−0.069
0.95	.506	54	.38	.411	54	.14	1.409	74
.90	.452	57	.36	.465	57	.13	1.483	80
.85	.394	61	.34	.522	61	.12	1.563	87
.80	.334	65	.32	.583	64	.11	1.650	96
0.75	0.269	−0.069	0.30	−0.647	−0.069	0.10	−1.746	−0.105
.70	.200	74	.28	.716	74	.09	1.851	.118
.65	.126	80	.26	.790	80	.08	1.969	.133
.60	.046	87	.24	.870	87	.07	2.102	.154
.55	− .041	95	.22	.957	96	.06	2.256	.173
0.50	−0.136	−0.041	0.20	−1.053	−0.051	0.05	−2.439	−0.223
.48	.177	43	.19	1.104	54	.04	2.662	.288
.46	.220	44	.18	1.158	57	.03	2.950	.405
.44	.264	47	.17	1.215	61	.02	3.355	.693
.42	.311	48	.16	1.276	64	.01	4.048	....

TABLE 12.—Values of Correction B in Formulas (155), (165), (168), and (169)

Number of turns, n	B	Number of turns, n	B
1	0.000	40	0.315
2	.114	45	.317
3	.166	50	.319
4	.197	60	.322
5	.218	70	.324
6	0.233	80	0.326
7	.244	90	.327
8	.253	100	.328
9	.260	150	.331
10	.266	200	.333
15	0.286	300	0.334
20	.297	400	.335
25	.304	500	.336
30	.308	700	.336
35	.312	1000	.336

TABLE 13.—Values of B_s for Use in Formula (156)

$\frac{b}{c}$	B_s	$\frac{b}{c}$	B_s
1	0.0000	16	0.3017
2	.1202	17	.3041
3	.1753	18	.3062
4	.2076	19	.3082
5	.2292	20	.3099
6	0.2446	21	0.3116
7	.2563	22	.3131
8	.2656	23	.3145
9	.2730	24	.3157
10	.2792	25	.3169
11	0.2844	26	0.3180
12	.2888	27	.3190
13	.2927	28	.3200
14	.2961	29	.3209
15	.2991	30	.3218

TABLE 14.—Constants Used in Formulas (157) and (158)

b/c or c/b	y_1	Difference	c/b	y_2	Difference	b/c	y_3	Difference
0	0.5000	0.0253	0	0.125	0.002	0	0.597	0.002
0.025	.5253	237	....	....	....	....	....	....
.05	.5490	434	0.05	.127	5	0.05	.599	3
.10	.5924	386	.10	.132	10	.10	.602	6
0.15	0.6310	0.0342	0.15	0.142	0.013	0.15	0.608	0.007
.20	.6652	301	.20	.155	16	.20	.615	9
.25	.6953	266	.25	.171	20	.25	.624	9
.30	.7217	230	.30	.192	23	.30	.633	10
0.35	0.7447	0.0198	0.35	0.215	0.027	0.35	0.643	0.011
.40	.7645	171	.40	.242	31	.40	.654	11
.45	.7816	144	.45	.273	34	.45	.665	12
.50	.7960	121	.50	.307	37	.50	.677	13
0.55	0.8081	0.0101	0.55	0.344	0.040	0.55	0.690	0.012
.60	.8182	83	.60	.384	43	.60	.702	13
.65	.8265	66	.65	.427	47	.65	.715	14
.70	.8331	52	.70	.474	49	.70	.729	13
0.75	0.8383	0.0039	0.75	0.523	0.053	0.75	0.742	0.014
.80	.8422	29	.80	.576	56	.80	.756	15
.85	.8451	19	.85	.632	59	.85	.771	15
.90	.8470	10	.90	.690	62	.90	.786	15
0.95	0.8480	0.0003	0.95	0.752	0.064	0.95	0.801	0.015
1.00	.8483	....	1.00	.816	....	1.00	.816	....

TABLE 15.—Values of Constants in Formula (162)

	Values of δ_{12}						ν	Values of δ_{13}			
	$\tau=0$	0.1	0.3	0.5	0.7	0.9		$\tau=0$	0.3	0.6	0.9
0	0.114	0.113	0.106	0.092	0.068	0.030	0	0.022	0.020	0.014	0.004
0.5	.090	.089	.083	.070	.049	.020	0.5	.021	.019	.014	.004
1.0	064	.064	.059	.050	.034	.013	1.0	.019	.018	.013	.004
1.5	047	.046	.043	.036	.025	.009	2.0	.015	.015	.010	.003
2.0	.035	.035	.032	.027	.018	.007	4.0	.008	.008	.005	.002
3.0	022	.022	.020	.017	.011	.004	6.0	.005	.005	.004	.001
4.0	.015	.015	.014	.012	.008	.003	10.0	.003	.003	.002	.005
6.0	008	.008	.008	.006	.004	.002					
8.0	006	006	.005	.004	.003	.001					
10.0	.004	.004	.004	.003	.002	.001					

ν	Values of δ_{14}				ν	Values of δ_{15}			
	$\tau=0$	0.3	0.6	0.9		$\tau=0$	0.1	0.5	0.9
0	0.009	0.009	0.006	0.002	0	0.005	0.005	0.004	0.001
1	.009	.008	006	.002	5	.003	.003	.002	.001
3	.007	.006	.004	.001	10	.002	.002	.001	.000
5	004	.004	.003	.001					
10	.002	.002	.001	.000					

ν	Values of δ_{16}			ν	Values of δ_{17}			ν	Values of δ_{18}		
	$\tau=0$ and 0.1	0.5	0.9		$\tau=0$ and 0.1	0.5	0.9		$\tau=0$ and 0.1	0.5	0.9
0	0.003	0.003	0.001	0	0.002	0.002	0.001	0	0.002	0.001	0.000
5	.002	.002	.000	5	.002	.001	.000	5	.001	.001	.000
10	.001	.001	.000	10	.001	.001	.000	10	.001	.001	.000

NOTE.—The maximum values of all further values of the δ's are 0.001 or less.

TABLE 16.—Values of F in Formula (187) for the Calculation of the Mutual Inductance of Coaxial Circles

r_2/r_1	F	Difference
0	∞	
0.010	0.05016	−0.00120
.011	4897	109
.012	4787	100
0.013	4687	−0.00093
.014	4594	87
.015	4507	81
.016	4426	148
.018	4278	132
0.020	0.04146	−0.00119
.022	4027	109
.024	3918	100
.026	3818	93
.028	3725	86
0.030	3639	−0.00081
.032	3558	76
.034	3482	71
.036	3411	68
.038	3343	64
0.040	0.03279	−0.00061
.042	3218	58
.044	3160	55
.046	3105	53
.048	3052	51
0.050	0.03001	−0.00226
.060	2775	191
.070	2584	164
.080	2420	144
.090	2276	128
0.100	0.02148	−0.00116
.11	2032	104
.12	1928	96
.13	1832	89
.14	1743	82
0.15	0.01661	−0.00075
.16	1586	71
.17	1515	66
.18	1449	62
.19	1387	59
0.20	0.01328	−0.00055
.21	1273	52
.22	1221	50
.23	1171	47
.24	1124	45
0.25	0.010792	−0.000425
.26	10366	408
.27	0.009958	388
.28	9570	371
.29	9199	355

r_2/r_1	F	Difference
0.30	0.008844	−0.000341
.31	8503	328
.32	8175	314
.33	7861	302
.34	7559	290
0.35	0.007269	−0.000280
.36	6989	270
.37	6720	260
.38	6460	249
.39	6211	241
0.40	0.005970	−0.000232
.41	5738	225
.42	5514	217
.43	5297	210
.44	5087	202
0.45	0.004885	−0.000195
.46	4690	189
.47	4501	183
.48	4318	178
.49	4140	171
0.50	0.003969	−0.000166
.51	3803	160
.52	3643	156
.53	3487	150
.54	3337	146
0.55	0.003191	−0.000141
.56	3050	137
.57	2913	133
.58	2780	128
.59	2652	125
0.60	0.002527	−0.000120
.61	2407	117
.62	2290	113
.63	2177	109
.64	2068	106
0.65	0.001962	−0.000103
.66	1859	99
.67	1760	96
.68	1664	93
.69	1571	90
0.70	0.001481	−0.000087
.71	1394	84
.72	1310	81
.73	1228	78
.74	1150	76
0.75	0.0010741	−0.0000731
.76	10010	704
.77	9306	680
.78	8626	653
.79	7973	628

r_2/r_1	F	Difference
0.80	0.0007345	−0.0000604
.81	6741	579
.82	6162	555
.83	5607	531
.84	5076	507
0.85	0.0004569	−0.0000484
.86	4085	460
.87	3625	437
.88	3188	413
.89	2775	389
0.90	0.0002386	−0.0000365
.91	2021	341
.92	1680	316
.93	1364	290
.94	1074	263
0.95	0.00008107	−0.00002351
.96	5756	2046
.97	3710	1706
.98	2004	1301
.99	703	703
1.00	0	....
0.950	0.00008107	−0.00000494
.952	7613	482
.954	7131	470
.956	6661	458
.958	6202	446
0.960	0.00005756	−0.00000436
.962	5320	421
.964	4899	409
.966	4490	397
.968	4093	383
0.970	0.00003710	−0.00000370
.972	3340	356
.974	2984	341
.976	2643	327
.978	2316	312
0.980	0.00002004	−0.00000296
.982	1708	278
.984	1430	262
.986	1168	242
.988	926	223
0.990	0.00000703	−0.00000201
.992	502	177
.994	326	148
.996	177	115
.998	062	62

DESIGN OF INDUCTANCE COILS

71. DESIGN OF SINGLE-LAYER COILS

The problems of design of single-layer coils may be broadly classified as of two kinds.

(1) Where it is required to design a coil which shall have a certain desired inductance with a given length of wire, the choice of dimensions of the winding and kind of wire to be used being unrestricted within rather broad limits. This class of problems of design includes a consideration of the question as to what

shape of coil will give the required inductance with the minimum resistance.

(2) Given a certain winding form or frame, what pitch of winding and number of turns will be necessary, if a certain inductance is to be obtained.

In the following treatment of the problem the inductance of the coil will be assumed as equal to that of the equivalent cylindrical current sheet. This is allowable, since, in general, the correction for the cross section of the wire will not amount to more than 1 per cent of the total inductance, an amount which may be safely neglected in making the design. The formulas to be given may, of course, be used for making a calculation of the inductance of a given coil. Nevertheless, since their practical use is made to depend upon the interpolation of numerical values from a graph, for accurate calculations formulas (153) and (155) should be used.

The inductances of coils of different size, but of identical shape, and the same number of turns, are proportional to the ratio of their linear dimensions. Every formula for the inductance should, accordingly, be capable of expression in terms of some single chosen linear dimension, all the other dimensions occurring in the formula in pairs in the form of ratios.

Two formulas are here developed, the first applicable to the solution of problems of the first class, giving the inductance in terms of the total length of wire l, the second for problems presupposing a winding frame of given dimensions. Both show the dependence of the inductance on the shape of the coil

Coil of Minimum Resistance.—The fundamental relations of the constants of a coil are

$$l = 2\pi a n \qquad b = nD$$

$$L_s = 4\pi^2 n^2 \frac{a^2}{b} K \text{ cgs units}$$

the constant K being a function of the shape factor $\frac{2a}{b}$, diameter ÷ length (Table 10,)

The expression for the inductance may be written as

$$L_s = \frac{2\pi a l n}{b} K$$

and n may be eliminated by substituting for it the expression

$$n = \sqrt{\frac{lb}{2\pi a D}} = \nu\sqrt{\frac{l}{D}},$$

obtained by multiplying together the two expressions involving n above. There results, then

$$L_s = l\sqrt{\pi \frac{2a}{b}\frac{l}{D}}.K \quad \text{cgs units}$$

or

$$L_s = \frac{l^{\frac{3}{2}}}{\sqrt{D}}\frac{K}{1000}\sqrt{\pi\frac{2a}{b}} = \frac{l^{\frac{3}{2}}}{\sqrt{D}}F \text{ microhenries.} \qquad (194)$$

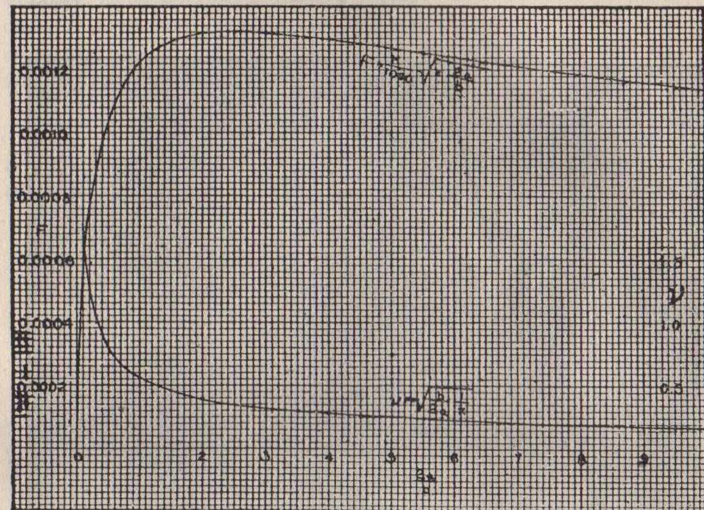


FIG. 207.—*(1) Variation of F with different ratios of coil diameter to length; (2) variations of ν with ratios of diameter to length*

To aid in the use of this formula the curve of Fig. 207 has been prepared, which enables the value of $F = \frac{K}{1000}\sqrt{\pi\frac{2a}{b}}$ to be obtained for any desired value of $\frac{2a}{b}$.. The formula (194) and the curve enable one to obtain with very little labor the approximate value of the inductance which may be obtained in a coil of given shape with given l and D. On the same figure is also plotted the factor $\nu = \sqrt{\frac{b}{\pi 2a}}$ as a function of $\frac{2a}{b}$ (see example below).

Coil Wound on Given Form.—To obtain the second formula, we substitute for n its value $\frac{b}{D}$, and

$$L_s = 4\pi^2 \frac{b^2}{D^2}\frac{a^2}{b}K = 2a\pi^2\left(\frac{2a}{D}\right)^2 \frac{b}{2a} K \text{ cgs units}$$

or

$$L_s = \frac{(2a)^3}{D^2}\left[\frac{\pi^2}{1000}\frac{b}{2a}K\right] \text{microhenries} \qquad (195)$$

and, finally,

$$\frac{(2a)^3}{L_s D^2} = f \qquad (196)$$

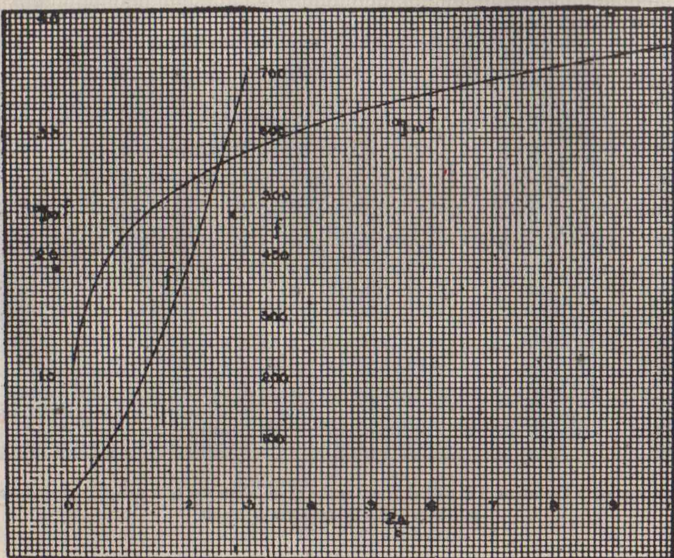


FIG. 208.—*Variation of f and $\log_{10} f$ with $\frac{2a}{b}$*

To aid in making calculations the curves of Fig. 208 have been prepared, which give the values of f and $\log_{10} f = \log_{10}\left[\frac{1000}{\pi^2 K}\frac{2a}{b}\right]$ for different values of $\frac{2a}{b}$. The value of $\log_{10} f$ is plotted, rather than that of f, for large values of $\frac{2a}{b}$, to enable values to be interpolated with greater accuracy.

From formula (194) and Fig. 207 it is at once evident that with a given length of wire, wound with a given pitch, that coil has the greatest inductance, which has such a shape that the ratio $\frac{\text{diameter}}{\text{length}} = 2.46$ approximately. Or, to obtain a coil of a certain desired inductance, with a minimum resistance, this relation should be realized. However, although the inductance diminishes rather rapidly for longer coils than this, changes in the direction of making the coil shorter relative to the diameter are not important over rather wide limits. Naturally, other considerations may modify the design appreciably. These other considerations include the distributed capacity of the coil and the variation of resistance with frequency.

Example.—Given the pitch of winding, the shape of the coil $\left(\frac{2a}{b}\right)$, and the inductance, to determine the length of wire necessary, the dimensions of the coil and the number of turns.

Assuming $D = 0.2$ cm, $\frac{2a}{b} = 2.6$, $L_s = 1000$ microhenries,

By formula (194), $l^{\frac{3}{2}} = \frac{1000\sqrt{0.2}}{0.001322}$, (the value of $F = 0.001322$ being taken from the curve of Fig. 207) or $l = 4850$ cm. The number of turns may be obtained immediately from the relation $n = \sqrt{\frac{l}{D}}\sqrt{\frac{b}{2\pi a}} = \nu\sqrt{\frac{l}{D}}$ and the graph of ν.

$$\begin{array}{ll}
\log 1000 & = 3. \\
\frac{1}{2}\log 0.2 & = \bar{1}.65052 \\
\hline
 & \,2.65052 \\
\log F & = \bar{3}.12123 \\
\hline
\frac{3}{2}\log l & = 5.52929 \\
\frac{1}{2}\log l & = 1.84310 \\
\hline
\log l & = 3.68619
\end{array}$$

Here $n = \sqrt{\frac{4850}{0.2}}\,(0.350) = 54.5$ turns, and $b = nD = 10.9$ cm, while $2a = 2.6 \times 10.9 = 28.3$ cm.

If the pitch of the winding had been assumed greater, or a coil of much larger inductance were required, the design of the coil would call for larger dimensions, and cases may arise where the design may prove unsatisfactory, because the coil would be too large. The effect of changing the length and pitch, the shape being taken constant, may be seen from (194), which shows that $L_s \propto \frac{l^{\frac{3}{2}}}{\sqrt{D}}$, so that a given fractional increase in the length of the wire is more effective in increasing the inductance than the same fractional decrease in the pitch. The number of turns depends on $\sqrt{\frac{l}{D}}$ the shape of the coil being kept the same.

Example.—Formula (194) will also enable the question to be answered as to what pitch must be used if a given length of wire is to be wound with a certain shape of coil to give a desired inductance. If the pitch comes out smaller than the diameter of the proposed wire, the assumed length of wire must be increased.

Suppose that an inductance of 10 000 microhenries is desired with 50 meters of wire, the value of $\frac{2a}{b}$ being taken as 2.6. as before. Then

$$\sqrt{D} = \frac{l^{\frac{3}{2}}}{L_s}F = \frac{(5000)^{\frac{3}{2}}\,0.001322}{10\ 000}, \text{ or } D = 0.00218 \text{ cm},$$

which is manifestly impracticably small.

The maximum inductance attainable with the given length of wire could be found by solving (194) for L with the smallest practicable pitch substituted for D, that value being used for F, which corresponds to the assumed ratio of diameter to length.

Example.—Suppose we have a winding form of given diameter $2a = 10$ cm, how many turns of wire will have to be used for an inductance of $1000\mu h$ if the winding pitch is taken as 0.2, and what will be the axial length of the winding?

From (196)

$$f = \frac{1000}{1000 \times 0.04} = 25 \text{ or } \log_{10} f = 1.398$$

From Fig. 208 this corresponds to a value of $\frac{2a}{b} = 0.225$, or b must be 45 cm, and the number of turns $n = \frac{b}{D} = \frac{45}{0.2} = 225$. Such a coil would be too long to be convenient. A smaller pitch should be used.

Example.—Suppose we have given the same winding form, and we wish to find what pitch is necessary for an inductance of $1000\mu h$, in order that the length of the coil shall not be greater than the diameter.

For

$$\frac{2a}{b} = 1,\ f = 148 \text{ (Fig. 208)}$$

and by (196)

$$D^2 = \frac{(2a)^3}{L_s f} = \frac{1000}{1000 \times 148} \text{ or } D = 0.082$$

This is a pretty close winding, showing that the winding form has rather too small a diameter for a coil of this inductance.

Example.—To find the diameter of a winding form to give an inductance of $1000\mu h$, with a shape ratio $\frac{2a}{b}=2.6$, the pitch being chosen as 0.2 cm.

From (196) we have $(2a)^3=L_s D^2$.

The value of f for $\frac{2a}{b}=2.6$ is (from Fig. 208) given by $\log_{10} f=2.75$ or $f=565$ approximately. Therefore $(2a)^3=1000\times 0.04\times 565$, or $2a=28.2$ cm, which will give $b=10.85$, $n=54.2$.

If, instead, the shape is assumed to be given by $\frac{2a}{b}=1$, then $\log f=2.17$ or $f=148$.

$$(2a)^3=1000\times 0.04\times 148, \text{ or } 2a=18.1 \text{ cm}=b, \text{ and } n=90.5.$$

The values of f taken from Fig. 208 are not so precise as could be calculated from the equation (195), but the accuracy should suffice for this kind of work.

DESIGN OF MULTIPLE-LAYER COILS

For purposes of design we may neglect the correction for cross section of the wire, formula (159), and operate on formulas (157) and (158) alone

Two forms of equation have been found useful, the first involving the length of wire in the coil and the second the mean radius of the coil.

Suppose that the length of the winding l, the distance between the centers of adjacent wires D, shape of cross section $\frac{b}{c}$, and the shape ratio of the coil $\frac{c}{a}$, are given. We obtain an expression for n by multiplying together the fundamental equations,

$$n=\frac{bc}{D^2}=\frac{b}{c}\left(\frac{c}{D}\right)^2 \text{ and } n^2=\frac{l^2}{(2\pi a)^2}$$

which involves ratios of known quantities only.

$$n=\left(\frac{l}{D}\right)^{\frac{2}{3}}\left(\frac{c}{a}\right)^{\frac{2}{3}}\left(\frac{b}{c}\right)^{\frac{1}{3}}\left(\frac{1}{2\pi}\right)^{\frac{2}{3}} \qquad (197)$$

In equation (158) the factor $4\pi a n^2 = 2ln$, and if the value of n just found, be introduced, we have finally for $c>b$

$$L=\sqrt[3]{\frac{2}{\pi^2}}\frac{l^{\frac{5}{3}}}{D^{\frac{2}{3}}}\left(\frac{c}{a}\right)^{\frac{2}{3}}\left(\frac{b}{c}\right)^{\frac{1}{3}}\left[\log_e 8-\log_e\frac{c}{a}-\frac{1}{2}\log_e\left(1+\frac{b^2}{c^2}\right)-y_1\right.$$
$$\left.+\frac{c^2}{16a^2}\left\{y_3+\frac{1}{6}\left(1+3\,\frac{b^2}{c^2}\right)\left[\log_e\frac{8a}{c}-\frac{1}{2}\log_e\left(1+\frac{b^2}{c^2}\right)\right]\right\}\right] \tag{198}$$

and for $b>c$

$$L=\sqrt[3]{\frac{2}{\pi^2}}\frac{l^{\frac{5}{3}}}{D^{\frac{2}{3}}}\left(\frac{c}{a}\right)^{\frac{2}{3}}\left(\frac{b}{c}\right)^{\frac{1}{3}}\left[\log_e 8-\log_e\frac{c}{a}-\log_e\frac{b}{c}-\frac{1}{2}\log_e\left(1+\frac{c^2}{b^2}\right)-y_1\right.$$
$$\left.+\frac{c^2}{16a^2}\frac{b^2}{c^2}\left\{y_2+\frac{1}{2}\left(1+\frac{c^2}{3b^2}\right)\left[\log_e\frac{8a}{c}-\log_e\frac{b}{c}-\frac{1}{2}\log_e\left(1+\frac{c^2}{b^2}\right)\right]\right\}\right] \tag{199}$$

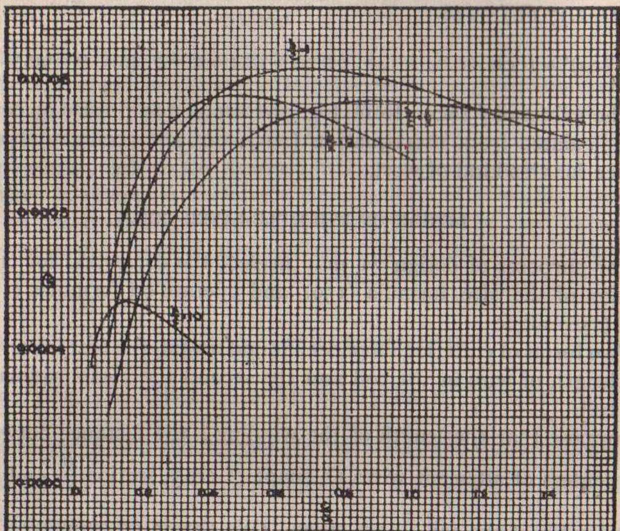


FIG. 209.—*Values of (G) for given values of $\frac{c}{a}$ and $\frac{b}{c}$*

Both of these equations may be written in the form

$$L=\frac{l^{\frac{5}{3}}}{D^{\frac{2}{3}}}\,G \text{ microhenries} \tag{200}$$

in which G is a factor whose value for given values of $\frac{c}{a}$ and $\frac{b}{c}$ may be taken from the curves of Fig. 209.

When l is known

$$a = \sqrt[3]{\frac{l}{2\pi}\,\frac{c}{b}\,\frac{D^2}{(c/a)^2}} \qquad (201)$$

From these curves one can see that, for a square cross section, $b/c = 1$, the inductance of a given length of wire is a maximum for a value of $\frac{c}{a}$ equal to about $\frac{2}{3}$. Investigation shows that this point is, more exactly, $c/a = 0.662$; that is, for a mean diameter of coil $= 3.02$ times the side of the cross section. Further, for a given resistance and shape of coil, the square cross section gives a greater inductance than any other form.

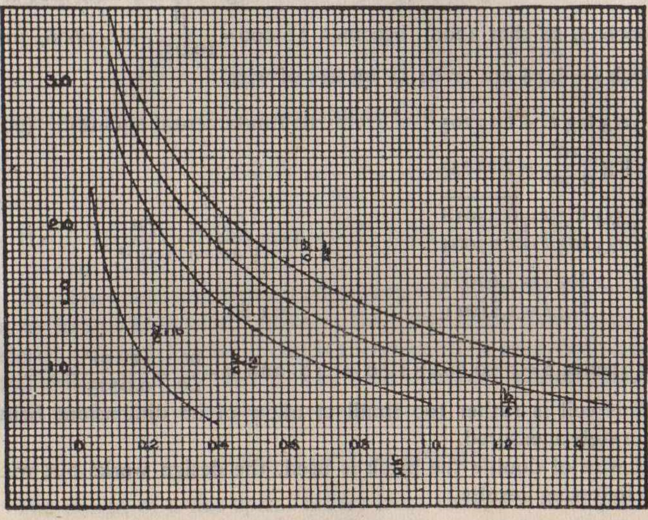


FIG. 210.—*Values of* (g) *for given values of* $\frac{c}{a}$ *and* $\frac{b}{c}$

The second design formula supposes that the dimensions a, c, and $\frac{b}{c}$ of the winding form are given, together with the pitch of the winding. The expressions (157) and (158) for the inductance may then be written

$$L = 0.01257\, a \frac{b^2}{c^2}\left(\frac{c}{D}\right)^4 g \text{ microhenries} \qquad (202)$$

$$= 0.01257\, a n^2 g \qquad (203)$$

The curves of Fig. 210, which give g for different values of $\frac{c}{a}$ and $\frac{b}{c}$ allow of interpolation of the proper value in any given case.

Example.—Suppose we have a wire of such a size that it may be wound 20 turns to the centimeter, and we wish to design a coil to have an inductance of 10 millihenries, to have a square cross section and such a mean radius as to obtain the desired inductance with the smallest resistance (smallest length of the wire).

The latter condition requires that $\frac{c}{a}=0.662$. The given quantities are $D=0.05$ cm, $b/c=1$. From Fig. 209 we find that $G=0.000606$, so that (200) becomes $10\,000=\frac{l^{\frac{5}{3}}}{(0.05)^{\frac{2}{3}}}\,0.000606$, from which $l=6458$ cm or 64.58 meters of wire.

$$
\begin{aligned}
2/3 \log D &= \bar{1}.13265 \\
\log \frac{10^7}{0.606} &= 7.21753 \\
\hline
5/3 \log l &= 6.35018 \\
1/3 \log l &= 1.27004 \\
\hline
2 \log l &= 7.62022 \\
\log l &= 3.81011
\end{aligned}
$$

From the fundamental equation (201)

$$a=\sqrt[3]{\frac{l}{2\pi}\cdot\frac{c}{b}\cdot\frac{D^2}{(c/a)^2}}$$

$$=1.80$$

and thence $b=c=0.662\times 1.80=1.19$, and $n=\frac{bc}{D^2}=\frac{(1.19)^2}{0.0025}=570$

This coil is rather too small to allow of its dimensions being accurately measured.

If wire of double the pitch is used, the design works out with the following results

$$
\begin{aligned}
l &= 85.22 \text{ meters} \qquad & c = b &= 2.08 \\
n &= 432 & a &= 3.18
\end{aligned}
$$

which is more suitable.

Example.—We have a form whose dimensions are $2a=10$, $c=3$, $b=2.4$, wound with wire of such a size that there are 10 turns per cm; that is, $D=0.1$. What is the inductance obtained and what length of wire is used?

$$n=\frac{bc}{D^2}=\frac{3\times 2.4}{0.01}=720$$

From Fig. 210 the interpolated value of g for $\frac{b}{c}=0.8$, $c/a=0.6$ is 1.54 (calculated directly from (158) = 1.552). Accordingly,

$$L=0.01257\times 5\times \overline{720}^2 \times 1.54 = 50\ 160\ \mu h.$$
$$=50.16 \text{ millihenries.}$$

The length of wire is $l=2\pi\, an=10\ \pi\ 720=22\ 600$ cm
$$=226 \text{ meters.}$$

Example.—The same formula might be used to answer the question, How many turns would have to be wound (completely filling this cross section) in order to obtain a desired inductance, say 20 millihenries. From (203),

$$n^2=\frac{L}{0.01257\ ag}=\frac{20\ 000}{(0.01257)\ 5\ (1.54)}=206\ 500$$

or n would be 454, which would mean that

$$D^2=\frac{bc}{454}=\frac{7.20}{454}=0.0158$$

or $D=0.126$, so that the wire would have to wind about 8 turns to the centimeter.

The skin effect and capacity between the layers of the wire are larger in this kind of coil than in the other forms previously considered. A multiple layer coil is therefore to be regarded as undesirable in radio work, and if it be used the cross section should be made small relative to the mean radius.

DESIGN OF FLAT SPIRALS

The design of a flat spiral differs from that of a multiple layer coil in that the actual width b of the tape used (not b/c) is supposed to be a given quantity

The fundamental equations are

$$n=\frac{c}{D} \text{ and } n=\frac{l}{2\pi a},$$

which, on multiplication, give

$$n=\sqrt{\frac{1}{2\pi}\ \frac{c}{a}\ \frac{l}{D}} \qquad (204)$$

and this introduced into the expression $4\pi a n^2 = 2ln$ gives finally

$$L = \frac{l^{\frac{3}{2}}}{\sqrt{D}}\sqrt{\frac{2}{\pi}\frac{c}{a}}\left[\left\{\log_e 8 - \log_e \frac{c}{a} - \tfrac{1}{2}\log_e\left(1+\frac{b^2}{c^2}\right) - y_1\right\}\right.$$
$$\left. + \frac{1}{16}\frac{c^2}{a^2}\left[y_3 + \frac{1}{6}\left(1+\frac{3b^2}{c^2}\right)\left\{\log_e \frac{8a}{c} - \tfrac{1}{2}\log_e\left(1+\frac{b^2}{c^2}\right)\right\}\right]\right]$$
$$= \frac{l^{\frac{3}{2}}}{\sqrt{D}} H \text{ microhenries.} \qquad (205)$$

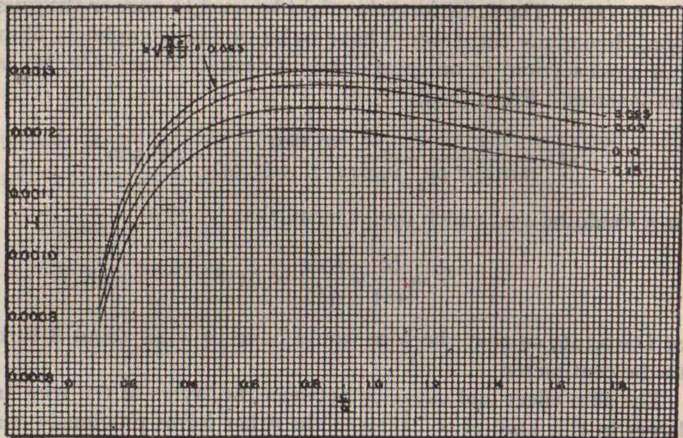


FIG. 211.—*Value of (H) for given values of $\frac{c}{a}$ and $\frac{b}{c}$*

The factor H, which may be determined from the curves of Fig. 211 is a function of c/a and b/c. The latter quantity may be expressed in terms of the known quantities by the equation

$$\frac{b}{c} = b\sqrt{\frac{2\pi}{lD}} \div \sqrt{\frac{c}{a}} \qquad (206)$$

Accordingly, the curves are plotted with H as ordinates, c/a as abscissas, and $b\sqrt{\frac{2\pi}{lD}}$ as parameter

An important deduction which may be made from the curves is that for the maximum inductance with a given length of tape the ratio c/a should be about $\frac{3}{4}$, which means that the opening of the spiral should have a radius nearly as great as the dimension across the turns of the spiral. This point in design is in agreement with the practical observation that turns in the center of the spiral add a disproportionate amount to the high-frequency resistance of the spiral.

Example.—Find the length of tape 0.6 cm wide, wound with a pitch of 0.6 cm, to give an inductance of 200 μh, assuming such proportions that $c/a = 1$. Work out the design.

Since l is not known, the parameter $b\sqrt{\frac{2\pi}{lD}}$ is not known. Assume a value of 0.1 for the latter. Then for the value $c/a = 1$ the curve (Fig. 211) gives $H = 0.00123$.

Thence $l^{\frac{3}{2}} = \frac{200\sqrt{0.6}}{0.00123}$ or $l = 3287$ cm. With this value of l, the parameter is $0.6\sqrt{\frac{2\pi}{1972}}$ or 0.0339, to which the value $H = 0.00128$ corresponds (with $\frac{c}{a} = 1$). Repeating the calculation of l with this value of H, we find $l = 3370$ cm as a second approximation. The next approximation gives a parameter of 0.0335 and the values of H and l are sensibly unchanged.

Using this parameter in (206), $\frac{b}{c} = 0.0335$ or $c = \frac{0.6}{0.0335} = 17.9$ and the value of $a = 17.9$ likewise. The number of turns will be $n = \frac{17.9}{0.6}$ $=$ about $25\frac{1}{2}$.

Example.—We have 17.50 meters of tape 1 cm wide, which we wind with a pitch of 0.5 cm, to such a shape that $c/a = 0.8$.

Here $D = 0.5, l = 1750$ cm, $b = 1$. The parameter is $\sqrt{\frac{2\pi}{875}} = 0.0847$, to which, for $c/a = 0.8$, $H = 0.001248$ corresponds.

$$L = \frac{(1750)^{\frac{3}{2}}}{\sqrt{0.5}} 0.001248 = 129.2\ \mu h$$

$$\frac{b}{c} = \frac{0.0847}{\sqrt{0.8}} = 0.0947, \text{ by equation (206)}$$

$$c = \frac{1}{0.0947} = 10.56 \text{ cm.}$$

$$a = \frac{10.56}{0.8} = 13.2$$

and the number of turns, $n = \frac{10.56}{0.5} = 21$ nearly.

Example.—The problem may arise as to how closely the tape in the preceding case would have to be wound, still keeping $\frac{c}{a}=0.8$, to obtain an inductance of 200 μh.

Changing the pitch D will change the parameter of the curves, and hence H. The changes in the latter will not be important, for small changes in D, so that to a first approximation the inductance will change inversely as $\sqrt{D}$.

Therefore

$$\sqrt{\frac{D}{0.5}}=\frac{129.2}{200}, \text{ or } D=0.2086 \text{ cm.}$$

Calculating the parameter with this value we find 0.1312, and thence $H=0.001216$, so that the second approximation is $\sqrt{D}=\frac{(1750)^{\frac{1}{2}}}{200}(0.001216)$, and $D=0.1981$, and another approximation is 0.197, the parameter being 0.1346. The dimensions are found from

$$\frac{b}{c}=\frac{0.1346}{\sqrt{0.8}}=0.1505 \qquad c=\frac{1}{0.1505}=6.64$$

$$a=\frac{c}{0.8}=8.30 \qquad n=\frac{6.649}{0.197}=34 \text{ nearly.}$$

HIGH-FREQUENCY RESISTANCE

RESISTANCE OF SIMPLE CONDUCTORS

Two principal causes act to increase the resistance of a circuit carrying a current of high frequency, above the value of its resistance with direct current, viz, the so-called skin effect and the capacity between the conductors This section deals exclusively with the skin effect or change of resistance caused by change of current distribution within the conductor

Unfortunately, formulas for the skin effect are available only for the most simple circuits, and for other very common cases in practice only qualitative indications of the magnitude of the increase in resistance can be given.

In what follows

R = the resistance at frequency f

R_0 = the resistance with direct current or very low frequency alternating current.

The quantity of greatest practical interest is not R, but the resistance ratio $\frac{R}{R_0}$. Given this ratio for the desired frequency and the easily measured direct-current resistance, the high-frequency resistance follows at once.

The skin effect in a conductor always depends, in addition to the thickness of the conductor, on the parameter $\sqrt{\frac{2\mu f}{\rho}}\sqrt{\frac{1}{1000}}$ in which μ = permeability of the material, f = frequency of the current, ρ = the volume resistivity in microhm-cms, so that as far as skin effect is concerned, a thick wire at low frequencies may show as great a skin effect as a thin one at much higher frequency.

The skin effect is greater in good conductors than in wires of high resistivity, and conductors of magnetic material show an exaggerated increase of resistance with frequency.

Cylindrical Straight Wires.—For this case accurate values of the resistance ratio are given by the formula and tables here given.

If d is the diameter of the cross section of the wire in cm, the quantity

$$x = \pi d\sqrt{\frac{2\mu f}{\rho}}\sqrt{\frac{1}{1000}} \tag{207}$$

must be calculated (or, in the case of copper, obtained for the desired frequency from Table 19, and formula (209)). Knowing the value of x, the value of $\frac{R}{R_0}$ may be taken at once from Table 17, which gives the value of $\frac{R}{R_0}$ directly for a wide range of values of x.

Table 19 gives values of

$$a_0 = \cdot 0107003\sqrt{f} \tag{208}$$

for a copper wire at 20° C, 0.1 cm in diameter, and at various frequencies. The value of x for a copper wire of diameter d in cm is

$$x_c = 10 d a_c \tag{209}$$

For a material of resistivity ρ and permeability μ, the parameter x may also be simply obtained from the value which holds for a copper wire of the same diameter, by multiplying the latter value by $\sqrt{\mu\frac{\rho_c}{\rho}}$.

The range of Table 19 may be considerably extended by remembering that a is proportional to $\sqrt{f}$ or $\sqrt{\frac{1}{\lambda}}$, where λ is the wave length.

Table 18, will be found useful, when it is desired to determine what is the largest diameter of wire of a given material, which has a resistance ratio of not more than 1 per cent greater than unity. These values are, of course, based on certain assumed values of resistivity; temperature changes and differences of chemical composition will slightly alter the values. In the case of iron wires μ is the effective permeability over the cycle. This will, in general, be impossible to estimate closely. The values given show plainly how important is the skin effect in iron wires.

For a resistance ratio only one-tenth per cent greater than unity the values in Table 18 should be multiplied by 0.55, and for a 10 per cent increase of the high-frequency resistance the diameters given in the table must be multiplied by 1.78.

The formulas above given apply only to wires which are too far away from others to be affected by the latter. For wires near together, as, for example, in the case of parallel wires forming a return circuit, the mutual effect of one wire on the other always increases the ratio $\frac{R}{R_0}$. No formula for calculating this effect is available, but it is only for wires nearly in contact that it is important. At distances of 10 to 20 cm the mutual effect is entirely negligible.

Tubular Conductors.—The resistance ratio of tubular conductors in which the thickness of the walls of the tube is small in comparison with the mean diameter of the tube, may be calculated by the theoretical formula for an infinite plane of twice the thickness of the walls of the tube.

The value of the resistance ratio for this case may be obtained directly from Table 20, page 311, in terms of the quantity

$$\beta = x\tau\sqrt{2 \div d} \tag{210}$$

where

τ = the thickness of the walls of the tube in cm

x = the parameter defined in formula (207).

For copper tubes the parameter β_c may be obtained very simply from the values of a_c in Table 19, and the relation $\beta_c = 10\sqrt{2}\,\tau\, a_c$.

For values of β greater than 4 no table is necessary, since we have simply, with an accuracy always greater than one-tenth of 1 per cent,

$$\frac{R}{R_0}=\beta \tag{211}$$

Sufficient experimental evidence is not available to indicate an accurate method of procedure in the case of tubing where the ratio of diameter to wall thickness is not large. Measurements with tubing in which this ratio is as small as two or three indicate that approximate values of $\frac{R}{R_0}$ for this case may be calculated by using for τ, in the calculation of the parameter β, a value equal to two-thirds of the actual thickness of the walls of the tube.

Tubing which is very thin in comparison with its radius has, for the same cross section, a smaller high-frequency resistance than any other single conductor. For this reason galvanized-iron pipe is a good form of conductor for some radio work, the current all flowing in the thin layer of zinc. A conductor of smaller resistance than a tube of a certain cross section is obtained by the use of very fine strands separated widely from one another; there are practical difficulties, however, in making the separation great enough.

In a return circuit of tubular conductors the distance between the conductors should be kept as great as 10 or 20 cm. For tubular conductors nearly in contact the resistance ratio may be double that for a spacing of a few centimeters.

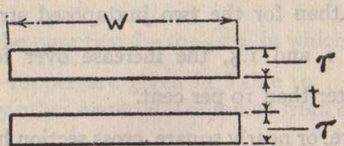


Fig. 212.—*Cross section of strip conductors forming a return circuit with narrow surfaces in the same plane*

Strip Conductors.—If two strips form together a return circuit and they are so placed that there is only a small thickness of dielectric between the wider face of one and the same face of the other (Fig. 212), the resistance ratio may be calculated by formula (210), using for τ the actual thickness of the strip.

As the thickness of the insulating space between the plates is increased, the accuracy of the formula decreases, but the error does not amount to more than a few per cent for values of this thickness as great as several centimeters.

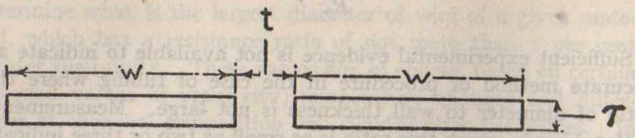


FIG. 213.—*Cross section of strip conductors forming a return circuit with wide surfaces in the same plane*

For a return circuit of strips placed with their wider faces in the same plane (Fig. 213), no formula is available. This is an unfavorable arrangement. As the distance t is reduced below a few centimeters the ratio $\frac{R}{R_0}$ increases rapidly and with the strips very close together may be as great as twice the value for the arrangement of Fig. 212.

For single strips—that is, for return circuits in which the distance between the conductors is so great that there is no appreciable mutual effect between the conductors—formula (210) is inapplicable owing to "edge effect"—the effect of the magnetic field produced by the current in the center of the strip upon the outer portions of the cross section.

Thus the resistance ratio $\frac{R}{R_0}$ is greater in a wide strip than in a narrow one of the same thickness, and in every case the resistance ratio is greater than for the two juxtaposed strips of Fig. 212. For $\frac{R}{R_0}$ between 1 and 1.5, the increase over formula (210) is usually not greater than 10 per cent.

Strips of square, or nearly square, cross section have values of $\frac{R}{R_0}$ not very different from those which hold for round conductors of the same area of cross section, the values being greater for the square strip than for the round conductor whose diameter is equal to the side of the square.

Simple Circuits of Round or Rectangular Wire.—The ratio of the resistance at high frequencies to that with direct current may be accurately obtained from Table 17, for circles or rectangles of round wire and in fact for any circuit of which the length is great compared with the thickness of the wire, provided no considerable portions of the circuit are placed close together. In the latter case, the resistance ratio is somewhat increased beyond the value calculated by the previous method and by an amount which can not be calculated

The resistance ratio for a circuit of wire of rectangular section may be treated by the same method as for a single strip. If portions of the circuit are in close proximity, the precautions mentioned for two strips near together (p. 303) should be borne in mind.

RESISTANCE OF COILS

Single-Layer Coil; Wire of Rectangular Cross Section.—The only case for which an exact formula is available is that of a single-layer winding of wire of rectangular cross section with an insulation of negligible thickness between the turns, the length of the winding being assumed to be very great compared with the mean radius, and the latter being assumed very great compared with the thickness of the wire.

If R = the resistance at high frequency
R_0 = the resistance to direct current
τ = the radial thickness of the wire
b = the axial thickness of the wire
ρ = the volume resistivity of the wire in microhm-cm
ρ_c = the volume resistivity of copper
μ = the permeability of the wire
D = the pitch of the winding,

then $\frac{R}{R_0}$ may be obtained directly from Table 20, having calculated first the quantity $\beta = 10\tau\sqrt{2}\,a$, in which $a = 0.1985\sqrt{\frac{\mu f}{\rho}}$. Values of a_c for copper are given in Table 19, and the value of a for any other material is obtained from a_c by the relation $a = a_c\sqrt{\mu\frac{\rho_c}{\rho}}$. For values of β greater than are included in Table 20 we have simply $\frac{R}{R_0} = \beta$.

In practice the ideal conditions presupposed above will not be realized. To reduce the value calculated for the idealized winding corrections need to be applied: (1) For the spacing of the wire, (2) for the round cross section of the wire, (3) for the curvature of the wire, (4) for the finite length of the coil.

Correction for Pitch of the Winding.—To take into account the fact that the pitch of the winding is not in general equal to the axial breadth of the wire an approximation is obtained if for β the argument

$$\beta' = \beta\sqrt{\frac{b}{D}} \text{ is substituted.}$$

For values of D greater than about $3b$ the values of $\frac{R}{R_0}$ thus obtained are too small.

Correction for the Round Cross Section of the Wire.—For coils of round wire only empirical expressions are known, and more experimental work is desirable.

To obtain an accuracy of perhaps 10 per cent in the resistance ratio the following procedure may be used:

Calculate first by (210) and Table 20, the resistance ratio $\frac{R'}{R_0'}$, supposing the coil to be wound with wire of square cross section of the same thickness as the actual diameter, taking into account the correction for the pitch of the winding. Then the resistance ratio $\frac{R}{R_0}$ for a winding of round wire will be found by the relation

$$\frac{R}{R_0} = 1 + 0.59\left[\frac{R' - R_0'}{R_0'}\right] \tag{212}$$

Effect of Thickness of the Wire.—Although formula (210) holds only for a coil whose diameter is very great in comparison with the thickness of the wire, the error resulting from non-fulfillment of this condition will, in practical cases, be small compared with the other corrections and may be neglected.

Correction for Finite Length of the Coil.—For short coils the resistance ratio is greater than for long coils of the same wire, pitch, and radius, due to the appreciable strength of the magnetic field close to the wires on the outside of the coil.

No formulas are available for calculating this effect, but experiment seems to show that for short coils of thick wire at radio frequencies the resistance ratio may be expressed by

$$\frac{R}{R_0} = \frac{A}{\sqrt{\lambda}} + \frac{B}{\lambda^2} \tag{213}$$

in which the first term represents the value as calculated by the formulas of the preceding section for long coils, while the constant of the second term has to be obtained by experiment. At long wave lengths the first term will predominate, but at very short wave lengths the second term may be equal or even larger than the first.

For round copper wires we may obtain the constant A by the relation $A = 15\ 500\ dR_0$.

Multiple-Layer Coils.—For this case no accurate formulas have been derived. Experiment shows that the resistance ratio is much greater for a multiple-layer coil than for a single-layer coil of the same wire. Furthermore, the capacity of such a coil has, as already pointed out, a large effect on the resistance of the coil. Consequently, it is usually impossible to calculate even an approximate value for the change of resistance with frequency. At very high frequencies losses in the dielectric between the wires may cause an appreciable increase in the effective resistance of the coil. This effect is proportional to f^3.

STRANDED WIRE

The use of conductors consisting of a number of fine wires to reduce the skin effect is common. The resistance ratio for a stranded conductor is, however, always considerably larger than the value calculated by Table 19, and Table 17, for a single one of the strands. Only when the strands are at impracticably large distances from one another is this condition even approximately realized.

Formulas have been proposed for calculating the resistance ratio of stranded conductors, but although they enable qualitatively correct conclusions to be drawn as to the effect of changing the frequency and some of the other variables, they do not give numerical values which agree at all closely with experiment. The cause for this lies, probably, to a large extent in the importance of small changes in the arrangement of the strands. The following general statements will serve as a rough guide as to what may be expected for the order of magnitude of the resistance ratio as an aid in design, but when a precise knowledge of the resistance ratio is required in any given case it should be measured.

Bare Strands in Contact.—The resistance ratio of n strands of bare wire placed parallel and making contact with one another is found by experiment to be the same as for a round solid wire which has the same area of cross section as the sum of the cross-sectional areas of the strands; that is, n times the cross section of a single strand. This will be essentially the case in conductors that are in contact and are poorly insulated, except that at high frequencies the additional loss of energy due to heating of the imperfect contacts by the passage of the current from one strand to another may raise the resistance still higher.

Insulated Strands.—As the distance between the strands is increased, the resistance ratio falls, rapidly at first, and then more slowly toward the limit which holds for a single isolated strand. A very moderate thickness of insulation between the strands will quite materially reduce the resistance ratio, provided conduction in the dielectric is negligible.

Spiraling or twisting the strands has the effect of increasing the resistance ratio slightly, the distance between the strands being unchanged.

Transposition of the strands so that each takes up successively all possible positions in the cross section—as for example, by thorough braiding—reduces the resistance ratio but not as low as the value for a single strand.

Twisting together conductors, each of which is made up of a number of strands twisted together, the resulting composite conductor being twisted together with other similar composite conductors, etc., is a common method for transposing the strands in the cross section. Such conductors do not have a resistance ratio very much different from a simple bundle of well-insulated strands.

The most efficient method of transposition is to combine the strands in a hollow tube of basket weave. Such a conductor is naturally more costly than other forms of stranded conductor.

Effect of Number of Strands.—With respect to the choice of the number of strands, experiment shows that the absolute rise of the resistance in ohms depends on the diameter of a single strand, but is independent of the number of strands. Since, however, the direct-current resistance of the conductor is smaller the greater the number of the strands, the resistance ratio is greater the greater the number of strands. Reducing the diameter of the strands reduces the resistance ratio, the number of strands remaining unchanged, but to obtain a given current-carrying capacity, or a small enough total resistance, the total cross section must not be lowered below a certain limit, so that, in general, reducing the diameter of the strands means an increase in the number of strands.

With enameled strands of about 0.07 mm bare diameter twisted together to form a composite conductor the order of magnitude of the resistance ratio may be estimated by the following procedure. Calculate by Table 19, and Table 17, the resistance ratio for a single strand at the desired frequency (this value of R/R_0 will lie very close to unity), and carry out the same calculation for the equivalent solid wire, whose diameter will of course be $d\sqrt{n}$, where n = the number of strands and d = the diameter of a single strand. Then the resistance ratio for the stranded conductor will, for moderate frequencies, lie about one-quarter to one-third of the way between these two values, being closer to the lower limit. This holds for straight wires up to higher frequencies than for solenoids. (See critical frequency mentioned in second paragraph below.) Not all so-called litzendraht is as good as this by any means. For a woven tube the resistance ratio may be as low as one-tenth of the way from the lower to the upper limits mentioned.

Coils of Stranded Wire.—In the case of solenoids wound with stranded conductor, the resistance ratio is always larger than for the straight conductor, and at high frequencies may be two to three times as great. It is appreciably greater for a very short coil than for a long solenoid.

For moderate frequencies the resistance ratio is less than for a similar coil of solid wire of the same cross section as just stated, but for every stranded-conductor coil there is a critical frequency above which the stranded conductor has the larger resistance ratio. This critical frequency lies higher the finer the strands and the smaller their number. For 100 strands of say 0.07 mm diameter this limit lies above the more usual radio frequencies.

This supposes that losses in the dielectric are not important, which is the case for single-layer coils with strands well insulated. In multiple-layer coils of stranded wire, dielectric losses are not negligible at high frequencies.

TABLES FOR RESISTANCE CALCULATIONS

TABLE 17.—Ratio of High-Frequency Resistance to the Direct-Current Resistance

[See formulas (207), (208), and (209)]

x	$\frac{R}{R_0}$	Difference	x	$\frac{R}{R_0}$	Difference	x	$\frac{R}{R_0}$	Difference
0	1.0000	0.0003	5.2	2.114	0.070	14.0	5.209	0.177
0.5	1.0003	.0004	5.4	2.184	.070	14.5	5.386	.176
.6	1.0007	.0005	5.6	2.254	.070	15.0	5.562	.353
.7	1.0012	.0009	5.8	2.324	.070			
.8	1.0021	.0013	6.0	2.394	.069	16.0	5.915	0.353
.9	1.0034	.0018	6.2	2.463	.070	17.0	6.268	.353
						18.0	6.621	.353
1.0	1.005	0.003	6.4	2.533	0.070	19.0	6.974	.354
1.1	1.008	.003	6.6	2.603	.070	20.0	7.328	.353
1.2	1.011	.004	6.8	2.673	.070			
1.3	1.015	.005	7.0	2.743	.070	21.0	7.681	0.353
1.4	1.020	.006	7.2	2.813	.071	22.0	8.034	.353
1.5	1.026	.007	7.4	2.884	.070	23.0	8.387	.354
						24.0	8.741	.353
1.6	1.033	0.000	7.6	2.954	0.070	25.0	9.094	.353
1.7	1.042	.010	7.8	3.024	.070			
1.8	1.052	.012	8.0	3.094	.071	26.0	9.44	0.70
1.9	1.064	.014	8.2	3.165	.070	28.0	10.15	.71
2.0	1.078	.033	8.4	3.235	.071	30.0	10.86	.71
						32.0	11.57	.70
2.2	1.111	0.041	8.6	3.306	0.071	34.0	12.27	.71
2.4	1.152	.049	8.8	3.376	.070	36.0	12.98	0.71
2.6	1.201	.056	9.0	3.446	.071	38.0	13.69	.71
2.8	1.256	.062	9.2	3.517	.070	40.0	14.40	.70
3.0	1.318	.067	9.4	3.587	.071	42.0	15.10	.71
						44.0	15.81	.71
3.2	1.385	0.071	9.6	3.658	0.070			
3.4	1.456	.073	9.8	3.728	.071	46.0	16.52	0.70
3.6	1.529	.074	10.0	3.799	.176	48.0	17.22	.71
3.8	1.603	.075	10.5	3.975	.176	50.0	17.93	3.54
4.0	1.678	.074	11.0	4.151	.176	60.0	21.47	3.53
						70.0	25.00	3.54
4.2	1.752	0.074	11.5	4.327	0.177			
4.4	1.826	.073	12.0	4.504	.176	80.0	28.54	3.53
4.6	1.899	.072	12.5	4.680	.176	90.0	32.07	3.54
4.8	1.971	.072	13.0	4.856	.177	100.0	35.61	....
5.0	2.043	.071	13.5	5.033	.176	∞	∞	

TABLE 18.—Maximum Diameter of Wires for High-Frequency Resistance Ratio of 1.01

Frequency ÷ 10^6	0.1	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	3.0
Wave length, meters	3000	1500	750	500	375	300	250	214.3	187.5	166.7	150	100
Material	Diameter in centimeters											
Copper	0.0356	0.0251	0.0177	0.0145	0.0125	0.0112	0.0102	0.0095	0.0089	0.0084	0.0079	0.0065
Silver	.0345	.0244	.0172	.0141	.0122	.0109	.0099	.0092	.0086	.0082	.0077	.0063
Gold	.0420	.0297	.0210	.0172	.0149	.0133	.0121	.0112	.0105	.0099	.0094	.0077
Platinum	.1120	.0793	.0560	.0457	.0396	.0354	.0323	.0300	.0280	.0264	.0250	.0205
Mercury	.264	.187	.132	.1080	.0936	.0836	.0763	.0706	.0661	.0623	.0591	.0483
Manganin	.1784	.1261	.0892	.0729	.0631	.0564	.0515	.0477	.0446	.0420	.0399	.0325
Constantan	.1892	.1337	.0946	.0772	.0664	.0598	.0546	.0506	.0473	.0446	.0423	.0345
German silver	.1942	.1372	.0970	.0792	.0692	.0614	.0560	.0518	.0485	.0458	.0434	.0354
Graphite	.765	.541	.383	.312	.271	.242	.221	.204	.191	.180	.171	.140
Carbon	1.60	1.13	.801	.654	.566	.506	.462	.428	.400	.377	.358	.292
Iron $\mu = 1000$	0.00263	0.00186	0.00131	0.00108	0.00094	0.00083	0.00076	.00070	0.00066	0.00062	0.00059	0.00048
$\mu = 500$	.00373	.00264	.00187	.00152	.00132	.00118	.00108	.00100	.00093	.00088	.00084	.00068
$\mu = 100$	.00838	.00590	.00418	.00340	.00295	.00264	.00241	.00223	.00209	.00197	.00186	.00152

TABLE 19.—Values of the Argument α_e for Copper Wire 0.1 cm Diameter and Resistivity 1.724 Microhm-cms $(a_c = \cdot 0107003\sqrt{f})$

f cycles per second	α_e	Difference	λ meters	f cycles per second	α_e	Difference	λ meters
100	0.1071	0.0443	....	50 000	2.395	0.229	6000
200	.1514	.0341	....	60 000	2.624	.210	5000
300	.1855	.0287	....	70 000	2.834	.195	4286
400	.2142	.0253	....	80 000	3.029	.184	3750
500	.2395	.0229	....	90 000	3.213	.174	3333
600	0.2624	0.0210	....	100 000	3.387	0.761	3000
700	.2834	.0195	....	150 000	4.148	.642	2000
800	.3029	.0184	....	200 000	4.790	.565	1500
900	.3213	.0174	....	250 000	5.355	.511	1200
1000	.3387	.1403	....	300 000	5.866	.318	1000
2000	0.4790	0.1076	....	333 333	6.184	0.380	900
3000	.5866	.0908	....	375 000	6.564	.452	800
4000	.6774	.0799	....	428 570	7.012	.561	700
5000	.7573	.0723	....	500 000	7.573	.723	600
				600 000	8.296	.664	500
6000	0.8296	0.0664	....				
7000	.8960	.0619	....	700 000	8.960	0.315	429
8000	.9579	.0581	....	750 000	9.275	.304	400
9000	1.0160	.055	....	800 000	9.579	.581	375
				900 000	10.16	.55	333
10 000	1.071	0.241	30 000	1 000 000	10.71	2.41	300
15 000	1.312	.202	20 000				
20 000	1.514	.341	15 000	1 500 000	13.12	5.43	200
30 000	1.855	.287	10 000	3 000 000	18.55	....	100
40 000	2.142	.253	7500				

TABLE 20.—Values of $\frac{R}{R_0}$ for Use with Formula (210)

β	$\frac{R}{R_0}$	Difference	β	$\frac{R}{R_0}$	Difference	β	$\frac{R}{R_0}$	Difference
0	1.000	....	1.0	1.086	0.037	2.5	2.477	0.111
0.1	1.000	....	1.1	1.123	.047	2.6	2.588	.109
.2	1.000	....	1.2	1.170	.059	2.7	2.697	.106
.3	1.001	....	1.3	1.229	.069	2.8	2.803	.104
.4	1.002	....	1.4	1.298	.080	2.9	2.907	.103
.5	1.006	0.002	1.5	1.378	.090	3.0	3.010	.101
0.55	1.008	.004	1.6	1.468	0.098	3.1	3.111	0.101
.60	1.012	.004	1.7	1.566	.106	3.2	3.212	099
.65	1.016	.005	1.8	1.672	.111	3.3	3.311	.099
.70	1.021	.007	1.9	1.783	.115	3.4	3.410	.099
.75	1.028	.008	2.0	1.898	.117	3.5	3.509	.099
0.80	1.036	0.009	2.1	2.015	0.117	3.6	3.608	0.098
.85	1.045	.011	2.2	2.132	.117	3.7	3.706	.098
.90	1.057	.013	2.3	2.248	.115	3.8	3.804	.098
.95	1.070	.016	2.4	2.364	.113	3.9	3.902	.098
1.00	1.086	....	2.5	2.477	.111	4.0	4.000	....

MISCELLANEOUS FORMULAS AND DATA

WAVE LENGTH AND FREQUENCY OF RESONANCE

$$\lambda_{cm} = 1.8838 \times 10^{11}\sqrt{LC} \text{ (cgs electromagnetic units)} \quad (214)$$

$$= 6.283 \quad \sqrt{L \text{ cgs electromagnetic} \quad C \text{ cgs electrostatic}} \quad (215)$$

$$\lambda_m = 0.05957 \quad \sqrt{L \text{ cgs electromagnetic} \quad C \text{ micromicrofarad}} \quad (216)$$

$$= 1.884 \quad \sqrt{L \text{ microhenry} \quad C \text{ micromicrofarad}} \quad (217)$$

$$= 1884 \quad \sqrt{L \text{ microhenry} \quad C \text{ microfarad}} \quad (218)$$

$$= 59\,570 \quad \sqrt{L \text{ millihenry} \quad C \text{ microfarad}} \quad (219)$$

$$= 1\,884\,000 \sqrt{L \text{ henry} \quad C \text{ microfarad}} \quad (220)$$

$$f = \frac{159.2}{\sqrt{L \text{ henry} \quad C \text{ microfarad}}} \quad (221)$$

$$= \frac{5033}{\sqrt{L \text{ millihenry} \quad C \text{ microfarad}}} \quad (222)$$

$$= \frac{159\,200}{\sqrt{L \text{ microhenry} \quad C \text{ microfarad}}} \quad (223)$$

$$\omega = \frac{1000}{\sqrt{L \text{ henry} \quad C \text{ microfarad}}} \quad (224)$$

$$= \frac{31620}{\sqrt{L \text{ millihenry} \quad C \text{ microfarad}}} \quad (225)$$

$$= \frac{1\,000\,000}{\sqrt{L \text{ microhenry} \quad C \text{ microfarad}}} \quad (226)$$

$$T = \frac{1}{f} = \frac{2\pi}{\omega} \quad (227)$$

$$\lambda_m = \frac{2.998 \times 10^8}{f} \quad (228)$$

$$= \frac{1.884 \times 10^9}{\omega} \quad (229)$$

When units are not specified, international electric units are to be understood. These are the ordinary units, based on the international ohm and ampere, the centimeter and the second. Full information is given on electric units in reference No. 152, Appendix 2

Current in Simple Series Circuit.—

$$I=\frac{E}{\sqrt{R^2+\left(\omega L-\frac{1}{\omega C}\right)^2}} \tag{230}$$

Phase Angle.—

$$\tan\theta=\frac{X}{R}=\frac{X_L-X_c}{R} \tag{231}$$

$$=\frac{\omega L-\frac{1}{\omega C}}{R}\text{ in simple series circuit.} \tag{232}$$

Sharpness of Resonance.—

$$\frac{\sqrt{\frac{I_r^2-I_1^2}{I_1^2}}}{\frac{\pm(C_r-C)}{C}}=\frac{1}{R\omega C_r}=\frac{\omega L}{R} \tag{233}$$

Current at Parallel Resonance.—

$$I=\frac{ER}{R^2+\omega^2L^2} \tag{234}$$

Coefficient of Coupling.—

$$k=\frac{X_m}{\sqrt{X_1X_2}} \tag{235}$$

$$=\frac{M}{\sqrt{L_1L_2}}\text{ for direct and inductive coupling} \tag{236}$$

$$=\frac{\sqrt{C_1C_2}}{C_m}\text{ for capacitive coupling.} \tag{237}$$

Power Input in Condenser—

$$P=0.5\times10^{-6}NCE_0^2\text{ watts} \tag{238}$$

for C in microfarads, E_0 in volts, and N = number of charges per second.

Power Loss in Condenser—

$$P = \omega C E^2 \sin \psi \tag{239}$$

Condenser Phase Difference—

$$\psi = r\omega C \tag{240}$$

for ψ in radians, r in ohms, C in farads.

$$\psi = 0.1079 \frac{rC}{\lambda} \text{ degrees} \tag{241}$$

for r in ohms, C in micromicrofarads, λ in meters.

$$\psi = 389. \frac{rC}{\lambda} \text{ seconds} \tag{242}$$

for r in ohms, C in micromicrofarads, λ in meters

$$r = \psi \times \frac{0.001}{C} \times \frac{\lambda}{1000} \times 0.154 \text{ ohms} \tag{243}$$

for ψ in minutes, C in microfarads, λ in meters.

Energy Associated with Inductance—

$$W = \frac{1}{2} L I^2 \tag{244}$$

Inductance of Coil Having Capacity:

$$L_a = \frac{L}{1 - \omega^2 CL} \tag{245}$$

for C in farads, L in the denominator in henries.

$$L_a = L\left(1 + 3.553 \frac{CL}{\lambda^2}\right) \text{ approximately} \tag{246}$$

for λ in meters, C in micromicrofarads, L in the parentheses in microhenries. This formula is accurate when the last term is small compared with unity.

Current Transformer—

$$\frac{I_1}{I_2} = \frac{n_2}{n_1}\left(1 + \frac{aR_2}{\omega L_2}\right) \tag{247}$$

Audibility—

$$\frac{I}{I_t} = \frac{s+t}{s} \tag{248}$$

Natural Oscillations of Horizontal Antenna.—

$$\lambda = \frac{1199}{m}\sqrt{C_0L_0},\ m = 1, 3, 5, \ldots \tag{249}$$

for λ in meters, C_0 = capacity in microfarads for uniform voltage, L_0 = inductance in microhenries for uniform current.

Approximate Wave Length of Resonance for Loaded Antenna.—

$$\lambda = 1884\sqrt{C_0\left(L + \frac{L_0}{3}\right)} \tag{250}$$

where L = inductance of loading coil in microhenries and other quantities are as in preceding formula.

Radiation Resistance of an Antenna.—

$$R = 1580\left(\frac{h}{\lambda}\right)^2 \text{ ohms} \tag{251}$$

where h = height from ground to center of capacity, and h and λ are in the same units, and λ is considerably greater than the fundamental wave length.

Electron Flow From Hot Filament.—

$$I_s = AT^{1/2}\epsilon^{-\frac{b}{T}} \tag{252}$$

where I_s = electron current in milliamperes per centimeter^2 of filament surface, T = absolute temperature, and A and b depend on metal of filament; for tungsten $A = 2.5 \times 10^{10}$, $b = 52500$.

Electron Current in 3-Electrode Tube.—

$$I_s = k\,(E_B + k_1 v_1)^{\frac{3}{2}} \tag{253}$$

where E_B = plate voltage, v_1 = grid voltage, k_1 = amplification constant.

Resistance Measurement by Resistance—Variation Method Using Undamped Emf.—

$$R = R_1\frac{I_1}{I - I_1} \tag{254}$$

Resistance Measurement by Resistance—Variation Method Using Impulse Excitation.—

$$R = R_1\frac{I_1^2}{I^2 - I_1^2} \tag{255}$$

Resistance Measurement by Reactance-Variation Method Using Undamped emf.—

$$R = X_1\sqrt{\frac{I_1^2}{I_r^2 - I_1^2}} \tag{256}$$

where X_1 = change of reactance between the two observations of current.

Natural Frequency of Simple Series Circuit.—

$$f=\frac{1}{2\pi}\sqrt{\frac{1}{CL}-\frac{R^2}{4L^2}} \qquad (257)$$

$$\omega=\frac{1}{\sqrt{CL}\sqrt{1+\left(\frac{\delta}{2\pi}\right)^2}} \qquad (258)$$

Number of Oscillations to Reduce Current to 1 Per Cent of Initial Value in Wave Train.—

$$n=\frac{4.6}{\delta} \qquad (259)$$

Logarithmic Decrement.—

$$\delta=\log_e\frac{I_1}{I_2}=\frac{a}{f} \qquad (260)$$

$$=\pi\frac{R}{\omega L}=\pi R\omega C=\pi R\sqrt{\frac{C}{L}}$$

$$=\frac{\pi}{\text{sharpness of resonance}}$$

$$=\pi\times\text{phase difference of condenser or coil, the}$$

resistance being in one or the other

$$=\frac{\text{average energy dissipated per cycle}}{2\times\text{average magnetic energy at the current maxima}}$$

$$\delta=0.00167\,\frac{R\lambda}{L} \qquad (261)$$

for R in ohms, λ in meters, L in microhenries.

$$\delta=5918\,\frac{RC}{\lambda} \qquad (262)$$

for R in ohms, λ in meters, C in microfarads.

$$\delta=3.1416\,R\sqrt{\frac{C}{L}} \qquad (263)$$

for R in ohms, C in microfarads, L in microhenries.

Current at resonance Produced by Slightly Damped emf Induced in a Circuit.—

$$I^2=\frac{N\,E_0^{\,2}}{16f^3L^2\delta'\delta\,(\delta'+\delta)} \qquad (264)$$

Decrement Measurement by Reactance—Variation Method.—

$$\delta'+\delta=\pi\frac{C_2-C_1}{C_2+C_1}\sqrt{\frac{I_1^{\,2}}{I_r^{\,2}-I_1^{\,2}}} \qquad (265)$$

POWER TRANSFORMERS.

Transformers may be regarded either as impedance or voltage matching devices, and when designing power transformers, it is more convenient to consider the voltage ratios.

Transformers for power supplies consist of two coils, or sets of coils, wound on an iron core to assist the coupling between them and thus improve their mutual inductance. Power from the A.C. mains is supplied to one coil or set of coils and the magnetic flux set up in the iron core and around the coil induces currents in the second set of coils, the voltages across these coils being either higher (step up) or lower (step down) than the voltage supplied.

The coil to which power is fed is known as the primary, those from which power is taken are known as secondaries, and in radio power transformers are of both step up and step down windings.

The size of each winding bears a very definite relationship to the power supplied to or drawn from it, the number of turns controlling the voltage, and the resistance, expressed as the diameter of the wire, controlling the current.

The number of turns varies inversely as the size of the core.

The core is built up of thin sheets of iron in the form known as a laminated core, and this is a method used in practically all A.C. apparatus. Clearly the rapidly varying magnetic flux will induce currents in the core as well as in the windings around it and if the core were one mass of metal with a very low resistance the current so induced would be exceedingly high. It is necessary, therefore to increase the electrical resistance of the core, which can only be done as described, by splitting it into thin sheets and insulating each sheet from the next. Eddy currents will still flow but the total loss of power so caused will be far less than it would otherwise have been.

Laminations are insulated in several ways—by chemical treatment of the metal surface, by varnish, by very thin cemented paper—and there are two main shapes of laminations, the E and I type and the T and U type, both sets giving a three-legged core (Fig. 9a).

When the laminations are being inserted into the finished coils on their former they must be alternated, that is an E must go in from the left with an I from the right, then an I from the left and an E from the right and so on, the laminations being brought into tight contact with no air gaps.

The cross sectional area of the core, Fig. 9b, is chosen from the formula given by "The Radio Designer's Handbook," Iliffe, where

$$A = \frac{\sqrt{W}}{5.58}$$

where W is the volt-amperes output, and A is the cross section area in square inches.

Example 1.

A transformer is to supply 300 volts at 100 m/as., 4 volts at 2 amps, and 4 volts at 4 amps.

The total output, therefore, for an ideal transformer is

$$300 \times \frac{100}{1{,}000} + (4 \times 2) + (4 \times 4)$$

$$= 30 + 8 + 16 = 54$$

Therefore, $A = \frac{\sqrt{54}}{5.58}$ or 1.3 square inches is the necessary core area.

The formula connecting the number of turns in a winding with a given voltage, size of core, frequency and flux density is

$$E = \frac{4.44 \times F \times H \times N \times A}{100{,}000{,}000}$$

Where E is the voltage supplied to or supplied by the winding, F is the mains frequency, H is the number of lines of magnetic flux per square inch in the iron, and A is the cross sectional area of the core.

If E is allowed to equal I then the calculation will give the number of turns per volt for any winding on that core.

It is supposed that often transformers will be re-wound using materials to hand, and in this case the characteristics of the iron will not be known. The best compromise in such conditions is to let H equal 60,000 lines per square inch, a figure at which many power transformers are run, although if winding space and other conditions permit, this may be reduced to 50,000 lines. A, it must be remembered, is built up of laminated sheets which have insulation on one side at least so that the actual magnetic area will be only 90% or so of the geometrical area. This measured area, then, should be reduced by 10% for the calculation. The shape of the core must be well proportioned, each outer limb having half the width of the middle limb on which all the windings are placed in layers, thus occupying the window space " a × b " of Fig. 9a. The general order of the windings is primary inside, nearest the limb, the H.T. secondary and the heater windings outside, of which there are usually at least two, one to supply the rectifier heater and one for the valve heaters of the receiver or apparatus.

The regulation of the transformer is very important—that is the virtue of its having only a small output voltage variation with varying current loads—and depends to a great extent on the iron of the core, the shape of the core and the filling of the window space with windings, there being no large gap between the last layers of wire and the outside limbs. The core must be large enough and the wire diameter fully adequate to handle the loads expected.

The main losses in a transformer are " iron " and " copper " losses; those watts lost due to eddy currents and the purely magnetizing effect on the core, and the watts lost due to the currents flowing in the resistances of the windings. Theoretical transformer design requires these losses to be equal when the transformer will be at its most efficient working level, but for the purposes of small transformer design, it will be sufficient to base all calculations on a theoretical efficiency of 80% instead of the 90% or so which, with care, will be obtained. These losses will be dissipated as heat and any transformer which heats up in working to anything but a small degree is inefficient and wasteful. Power is being lost, regulation will be poor and insulation will be subjected to the most undesirable strains. A good transformer will work for hours with a temperature rise which can scarcely be observed by touch.

The windings are usually on a former, Fig. 9c, a tube which will fit the core tightly with end cheeks to clear the window space, and through which the leads pass. Such a former can be made of stiff cardboard well shellaced or of thin paxolin. Cardboard is quite suitable for ordinary voltages ; the tube is first made to fit the core and the end cheeks are fitted, then the whole is well varnished and allowed to set hard. It will perhaps be best to follow the design and construction of a specimen transformer throughout.

Example 2.

A transformer is to be made with the specification :—Primary to be tapped to 210, 230, 250 volts, H.T. secondary to give 350-0-350 volts, 120 m/as, valve heater secondary to give 6.3 volts 3 amps. and Rectifier heater secondary to give 5 volts 2 amps.

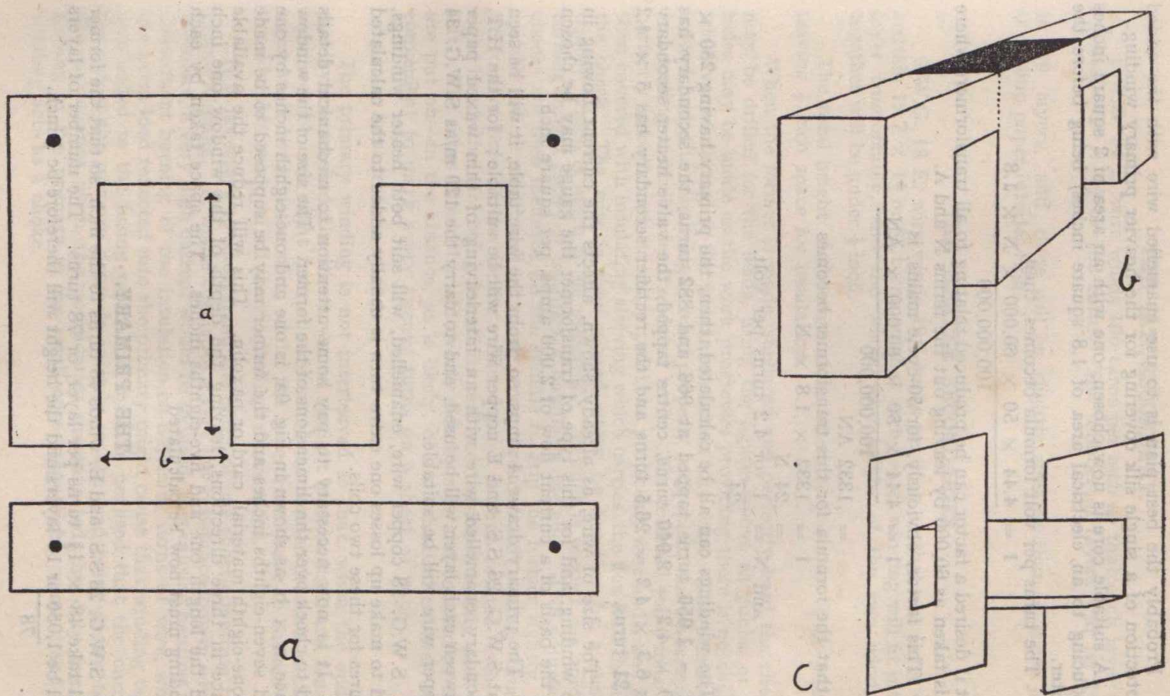
The watts ratings, therefore, are :—

350 × 120 m/as (only half the H.T. winding supplies current at one time) = ...	42 watts
6.3 × 3 = ...	18.9 „
5 × 2 = ...	10 „
Giving an *output* total wattage of ... ... or, say, 71 watts.	70.9 watts

The cross sectional area of the core should be at least $A = \frac{\sqrt{71}}{5.58}$ or 1.5 square inches, and assuming an efficiency of 80%, which should certainly be bettered in practice, the input wattage is therefore $71 \times \frac{100}{80}$ or 88.7 watts.

At a working voltage of 230, therefore (the usual mains voltage) the primary will take $\frac{88.7}{230}$ amps. or .4 amps. nearly, and the wire must be chosen to carry this current safely. The question of insulation enters here.

Commercial transformers, as inspection will show, are most often wound with enamelled wire, but conditions are different from those obtaining for home construction. The commercial transformer is machine wound so that the wire can be, and generally is slightly spaced between turns so that there is no rubbing of the enamel, whilst the wire tension can be more accurately controlled. For amateur construction enamelled wire can be used but on no account should it be wire taken from old coils or transformers. It must be new and every precaution must be taken to ensure the covering is not cracked, kinked or rubbed for a breakdown in insulation in any winding renders the whole transformer useless.



Nº 9. TRANSFORMER CORES AND FORMER.

Probably the best plan is to use enamelled wire with the added protection of a single silk covering for the heavier primary winding.

A suitable core is now chosen, one with an area of 2 square inches (reducing to an electrical area of 1.8 square inches) being before the writer.

The turns per volt formula becomes, then,

$$1 = \frac{4.44 \times 50 \times 60{,}000 \times N \times 1.8}{100{,}000{,}000}$$

but if desired a factor can be produced relating to all transformers where H is taken as 60,000 by leaving out the terms N and A.

This factor, obviously, for 50-cycle mains, is

$$1 = \frac{4.44 \times 50 \times 60{,}000 \times AN}{100{,}000{,}000}$$

$$= .1332\ AN$$

so that the formula for this transformer becomes

$$1 = .1332 \times 1.8 \times N$$

$$= .24\ N$$

$$\text{and } N = \frac{1}{.24} \text{ or } 4.2 \text{ turns per volt.}$$

The windings can all be calculated, then, the primary having 250 × 4.2 = **1,050** turns tapped at 966 and 882 turns, the secondary has 700 × 4.2 = **2,940** turns, centre tapped, the valve heater secondary has 6.3 × 4.2 = **26.5** turns and the rectifier secondary has 5 × 4.2 = **21** turns.

The size of wire, as already shown, affects the current flowing in the winding, and for this type of transformer the gauge may be chosen on the basis of a current flow of 2,000 amps. per square inch

The primary draws .4 amps. so, from the wire table, it will be seen that S.W.G. 26 S.S. and E copper wire will be suitable ; for the H.T. secondary enamelled wire with an interleaving of thin waxed paper between each layer will be used, and to carry the 120 m/as S.W.G. 34 copper wire will be suitable.

S.W.G. 18 copper wire, enamelled, will suit both heater windings, and to make up losses one extra turn is usually added to the calculated figures for these two coils.

It is now necessary to pay some attention to mechanical details and to check over the dimensions of the former. The size of the window space, a × b, as shown in Fig. 9a, is one and one-eighth inches by one and seven-eighths inches and the former may be supposed to be made of one-eighth material, card or paxolin. This will reduce the available space in three directions, leaving the depth of the window one inch and the length one and five-eighths inches. The space taken by each winding must now be calculated

THE PRIMARY.

S.W.G. 26 S.S. and E. winds 48 turns to the inch, so that the former will take 48 × $1\frac{5}{8}$ turns per layer, or 78 turns. The number of layers will be $\frac{1{,}050}{78}$ or 14 layers and the height will therefore be $\frac{1}{4}$ inch.

THE H.T. SECONDARY.

S.W.G. 34 E. wire winds 100 turns per inch so that each layer will contain $100 \times 1\frac{5}{8}$ or 162 turns. The number of layers will be $\frac{2,940}{162}$ or 19 layers, and these will be slightly greater than $\frac{1}{4}$ inch high including paper interleaving.

THE HEATER SECONDARIES.

S.W.G. 18 E. wire winds 19.7 turns per inch so that one layer will contain $19.7 \times 1\frac{5}{8}$ or 32 turns, so that each heater winding will fit into a layer comfortably, and the whole wire height of the two windings together will be under $\frac{1}{8}$ inch.

The total height of the wire alone, then, is $\frac{1}{3} + \frac{1}{5} + \frac{1}{8}$ or $\frac{2}{3}$ inch, leaving $\frac{1}{3}$ inch space for insulation.

When the former is made, shellaced and perfectly hard the cheeks may be drilled for the leads, using the figures above as guides or the holes may be made as the work progresses providing there is no chance whatever of damaging the wire insulation in any way. The primary is wound first, the wire being cleaned properly with spirit, not by scraping, and having a flexible lead soldered to it. The soldered joint must be perfectly smooth with no sharp points or projecting wire ends, and it is then covered with insulating sleeving which carries the flex lead through the cheek. The wire is then wound either by hand or by a simple winder, which is much to be preferred. All that is needed is a spindle turning in end plates or bearings, a handle at one end. Two adjustable cheeks are then mounted on the spindle to grip the former tightly, the spindle (which might well be a long screw-threaded rod) passing through the centre hole of the former. The former is then rotated with the right hand, the wire being fed off its reel and tensioned evenly with the left. The turns should be laid evenly side by side and counted as they are put on—in the absence, as is likely, of a mechanical counter, it is convenient to mark every twenty turns on a sheet of paper.

It is fatal to lose count !

The primary winding is not interleaved so that, when the end of one layer is reached, the wire is wound straight back on itself and tension must not be over tight for each corner of the former presents a sharp right angle bend to the wire, whilst the lower turns have to sustain the considerable strain of all those windings above them.

It is necessary to understand the effect of one short-circuiting turn in any winding. It would consist of a very low resistance loop in which, therefore, a very high current would be induced, this causing heating and consequent burning of the insulation on adjoining turns of wire, whilst the extra load reflected into the primary might cause that winding to be overloaded to the fusing point. It must be realised that the current flowing in the primary depends entirely on the load being drawn from the secondaries ;with the secondaries disconnected the only current flowing in the primary is the small core magnetizing current and the winding acts as a choke.

The taps for the various primary voltages can be taken out in the same manner as the taps on coils, by drawing out a loop of wire and returning the wire to the next turn without any breaks or joins, or a flex lead may be soldered to the winding at the correct turn and well insulated. Whenever possible taps should be arranged to fall at the end of a layer so that they may be passed straight through the former cheek. If, however, they have to pass over several turns the insulation must be perfect and on no account must uneveness of winding be allowed in the next layers. Any hump in the centre of the coil will be magnified in the later layers with a corresponding strain on wire and insulation.

When the primary is finished, and a flex lead soldered to the last turns, the winding must be insulated from the following coils. The best material is Empire Cloth interwoven with glass fibres and known under such names as Glassite, but plain Empire Cloth may be used. Every part of the primary must be covered, the insulation being carried up snugly to the former cheeks.

Many transformers have an electrostatic screen wound over the primary to prevent interference from the mains being induced into the secondaries. It consists simply of one layer of fine insulated wire—S.W.G. 34 emamelled, for example—one end of the wire being anchored internally and the other brought out through insulating sleeving. The end brought out is earthed to the receiver or other apparatus worked from the transformer. Naturally just as much attention must be paid to the insulation of the screen as of any other winding ; no load is taken from it as only one end has a connection but shorting turns would give rise to the same heavy overloads mentioned above.

If the screen is included, another layer of Empire Cloth is wound over it, giving a smooth, even base for the H.T. winding. Again a flex lead is soldered to the start of the coil and insulated, but in this winding a sheet of thin paper is interleaved between each layer of wire. Excellent paper for this purpose can be obtained by stripping down an old paper condenser of the Mansbridge type, any punctured parts of the paper being discarded. On each wire layer one turn of paper is wound, fitting tight up the cheeks, and the wire is wound back over it to form the next layer.

At the centre tap a flex lead is soldered to the wire and anchored firmly in the coil, the flex being taken through the cheek and the joint, as before, being perfectly smooth and insulated. When the H.T. winding is finished another layer of Empire Cloth or Glassite is laid over it and the valve heater winding made, the commencing lead through one cheek and the finishing lead through the other. A layer of Empire Cloth or Glassite separates it from the last winding, that for the rectifier heater which is put on in the same way.

Study of any power pack will show that the full H.T. voltage is established between the H.T. and rectifier heater windings and the insulation between them must be perfect. Any breakdown here will immediately ruin both transformer and rectifier valve.

When the former is wound it is given a last covering of cloth and the laminations are inserted into the centre aperture in order as already explained. The stampings must be inserted carefully for it may be possible to run a sharp edge or corner into and through the former material, cutting or scraping the primary winding.

The laminations must be clamped into a solid mass with wooden or metal clamps which can also be drilled to provide fixing holes for bolting the transformer to its chassis.

TESTING.

The first tests to be given the transformer are continuity and insulation checks, these being performed with a neon lamp worked from the A.C. mains. One mains lead is taken to the metal core of the transformer and the other, through the neon lamp, to each lead from the windings in turn. Any lighting of the lamp indicates a short circuit from a winding to the core which must be rectified. The next test is to check the insulation between the windings ; transfer the lead from the core to the common primary wire and test the screen and secondary leads in turn with the neon lamp, transferring the mains lead from the primary to each secondary in turn as the test progresses.

Again, any lighting of the lamp indicates a short circuit, but actually any short circuits so discovered would be due to very careless workmanship and are unlikely.

Finally, the continuity of each winding is checked with the neon lamp, connecting it across each coil in turn, not forgetting the tappings, when the lamp should light.

If a small megger set is available really valuable insulation tests can be made, but care must be used to choose a voltage below any break-down voltage calculated for the insulation used. However, as the peak voltage across the H.T. secondary of the transformer described would be almost 1,000 volts, the transformer should certainly show a resistance of many megohms at 2,000 volts between windings.

When the transformer has been checked for insulation and continuity, its voltage ratios can be checked. The primary is connected through the suitable tapping to the A.C. Mains, with all the secondary leads well separated so that no two can short-circuit together.

Never check secondaries by touching the leads together to produce a spark—results are spectacular but impose an unnatural strain on the primary and should the transformer have been wound to close limits the high currents flowing will probably fuse a winding.

Switch on with the primary only in circuit. After a slight thump or click there should be very little hum from the core, and any appreciable noise indicates loose laminations which must be tightened. Let the primary run alone for ten minutes and check for warming up. Any temperature rise indicates either a totally incorrect winding size or shorting turns in any one of the windings.

In either case connect an A.C. voltmeter across each secondary in turn, and note the voltages obtained from each. If they are all somewhat low and the transformer is heating up, it is likely that there are shorting turns in the primary. If one voltage is low and the transformer is heating up there are probably shorting turns in that secondary alone.

Any winding with shorting turns must be re-wound but if the work has been done properly and good wire used, there is very little reason for this fault to occur.

Check the voltage on the H.T. secondary from the centre tap to either end of the winding—there should be no difference in the readings, or at most one of only one or two volts. The heater winding voltages will be a little high but when the load is taken from them they will fall slightly to their correct value.

If the voltages are correct the transformer may be finished and coupled up, but a power test is advisable. For this, non-inductive resistors of adequate watts ratings must be used in the following manner.

The H.T. secondary supplies 350 volts at 120 m/as, or, disregarding the centre tap, 700 volts at 60 m/as. This is a wattage of 42, the resistance needed being $R = \frac{700 \times 1{,}000}{60}$ or 11,666 ohms, which might well be made up of lamps, whilst the L.T. windings can be tested on load using a resistor of 20 watts rating, 2.1 ohms for the valve heaters winding and one of 10 watts, 2.5 ohms for the rectifier winding, or, of course, the actual valve heaters to be used.

The test should run for an hour at least and the rise of temperature of the transformer tested—in commercial practice it might rise by 40 degrees C. but this should be bettered.

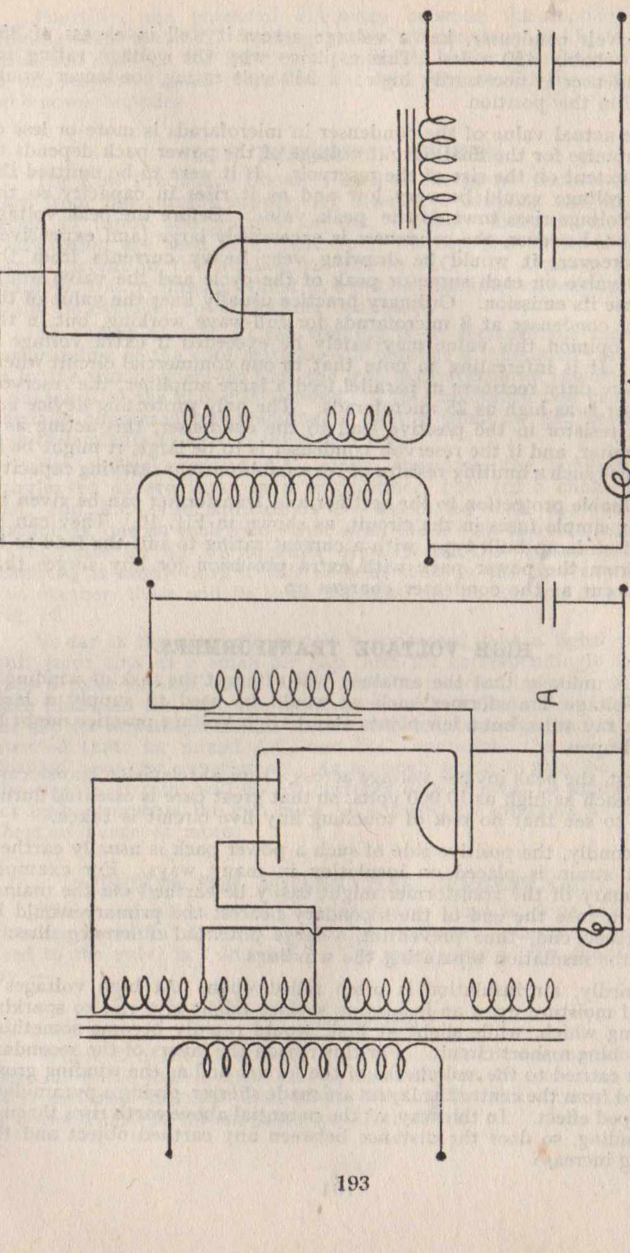
When the testing is completed the transformer can be finished. If the core is clamped satisfactorily and the transformer is to be permanently installed, nothing more need be done but if the transformer is to be used for experimental work the leads should not be used for direct connections but should be taken to terminals, mounted on paxolin in the form of a strip secured by two of the clamping bolts.

If the transformer can be mounted in an iron case or can, any stray fields which might give rise to hum can be suppressed. The old case of a choke or transformer could be used or even a heavy tin. In this case the leads should be brought out through insulating bushings or the terminal strip should be well insulated. The case or can should not be allowed to touch the winding at any point, both to assist in insulation and also to allow air to circulate freely for the purposes of ventilation.

In some cases the most tiresome and painstaking work, that of winding the H.T. secondary coil, can be avoided. The transformer can be made on a proportionately smaller core with primary and secondary windings to feed the valve and rectifier heaters, the H.T. being drawn straight from the mains by using the rectifier as a half-wave device (Fig. 10b). Provided that the rather lower voltage output is sufficient, this system can be very useful.

The operation of the power pack as a whole may here be considered, with reference to Fig. 10a, where the transformer just described is shown in its circuit. The H.T. secondary has been wound to give a R.M.S. voltage of 350, which means that the peak voltage will be 350 × 1.414 (peak value of a sinusoidal wave)

Thus the rectifier anodes will have peak voltages of 495 volts, the whole winding having a peak voltage across it of 990 volts, and even after the voltage drop due to the rectifier is allowed for, the condenser A,



a No 10. FULL AND HALF-WAVE RECTIFIER SYSTEMS. b the reservoir condenser, has a voltage across it well in excess of 350 volts—probably 450 volts. This explains why the voltage rating for this condenser is necessarily high ; a 350 volt rating condenser would soon fail in this position.

The actual value of the condenser in microfarads is more or less of a compromise for the final output voltage of the power pack depends to a great extent on the size of the reservoir. If it were to be omitted the output voltage would be very low and as it rises in capacity so the output voltage rises towards the peak value. Before the peak voltage is reached, however, the condenser is excessively large (and expensive), but, moreover, it would be drawing very heavy currents from the rectifier valve on each surge or peak of the cycle and the valve would soon loose its emission. Ordinary practice usually fixes the value of the reservoir condenser at 8 microfarads for full-wave working, but in the writer's opinion this value may safely be exceeded if extra voltage is needed. It is interesting to note that in one commercial circuit where two heavy duty rectifiers in parallel feed a large amplifier, the reservoir condenser is as high as 25 microfarads. The only protecting device is a 50 ohm resistor in the positive lead to the condenser, this acting as a surge limiter, and if the reservoir condenser is to be large, it might be as well to use such a limiting resistor of reasonable current carrying capacity.

Valuable protection to the rectifier and transformer can be given by inserting simple fuses in the circuit, as shown in Fig. 10. They can be of the flash lamp bulb type, with a current rating to suit the load to be taken from the power pack with extra provision for any surges that might occur as the condenser charges up.

HIGH VOLTAGE TRANSFORMERS.

It is unlikely that the amateur will attempt the task of winding a High Voltage Transformer such as would be used to supply a large cathode ray tube, but a few points about High Voltage practice might be touched upon.

First, the peak inverse voltage across a typical television transformer might reach as high as 10,000 volts, so that great care is essential during testing to see that no risk of touching any live circuit is taken.

Secondly, the positive side of such a power pack is usually earthed, so that strain is placed on insulation in many ways. For example, the primary of the transformer might easily be earthed via the mains ; in such a case the end of the secondary nearest the primary would be the earthed end, thus preventing a large potential difference directly across the insulation separating the windings.

Thirdly, air insulation is often relied upon. At high voltages a trace of moisture upon an insulating surface might give rise to sparking or arcing which, while slight at first, would rapidly become something approaching a short circuit. For this reason the layers of the secondary are not carried to the end cheeks of the former and as the winding grows outward from the centre the layers are made shorter, giving a pyramidical or stepped effect. In this way, as the potential above earth rises through the winding, so does the distance between any earthed object and the winding increase.

Fourthly, the potential difference between the rectifier heater winding and the H.T. winding makes it necessary to have perfect insulation between the windings, a separate heater transformer helping in this respect. Metal rectifiers give very good results for cathode ray tube power supplies.

LOW FREQUENCY CHOKES.

The Low Frequency Choke is used in the power pack to filter out hum from the current supply, for intervalve coupling and in various forms of input and output circuits. Slightly different methods of construction are used dependent upon whether the choke is to carry direct current in the winding as well as A.C. ; in a power pack, for example, D.C. is flowing whilst in a parallel fed intervalve coupling D.C. would be excluded by a blocking condenser.

The effect of D.C. in the winding is to decrease the incremental permeability of the core material—in practice a laminated core is used as in the transformer—so that the iron saturates more rapidly and the inductance of the choke is lowered. This inductance loss can only be partially countered by arranging to have a small air gap between the sets of laminations in the assembled core.

For chokes carrying A.C. alone, therefore, the laminations are interleaved as are those in a transformer, but, for a choke carrying D.C. and A.C., the laminations are assembled with the two sets of stampings, one on each side—that is all the E's on one side, and all the I's opposite (or all T's together opposite all U's, whichever type of stamping is used)—and it will be seen that, in the core assembled in this manner, there will be three air gaps, one at the end of each limb, Fig. 11.

So far as the magnetic circuit is concerned even a tightly clamped butt joint acts as a small air gap, and for correspondingly larger air gaps a piece of thin tissue paper may be inserted between the end of each limb and the opposite laminations. The calculation of the correct air gap for any single case is rather involved, however, and it is recommended that, for mixed A.C. and D.C. operation, the gap should be decided upon by experiment. As a rough guide it may be said that the close butt joint will do for currents of 5 or even 10 milliamps, but for higher currents the gap must be widened by inserting a " 5 thou " sheet of tissue or more.

CHOKES FOR ALTERNATING CURRENT ONLY.

These are chokes as used for intervalve coupling, tone control, bass boosting, resonant circuits and audio oscillators, wherever the current feed to the valve is " shunted." The inductance of the choke is given by :—

$$L = \frac{3.2 \times N^2 \times U \times A}{1 \times 100{,}000{,}000}$$

Where L is the inductance in henrys, N is the number of turns of wire, U is the incremental A.C. permeability of the iron core material, A is the cross sectional area of the winding limb in square inches and l is the length of the magnetic path in inches.

A safe figure to use for U is 1,000 unless greater information about the core material is available, and l is measured directly from the laminations. A well-shaped core has the two outer legs only half the width of the inner or winding leg, so that the magnetic path is split equally into two, and the length, l, to be measured is the centre line of ONE of these two paths as shown by the dotted line in Fig. 11.

Example 1.

A choke to possess an inductance of 100 henrys is to be wound on the core of Fig. 11, the dimensions being as shown.

Calculate the number of turns and the size of wire.

l is measured on the core along the path shown and is 6.2 inches.

The area of the winding limb is 8 inches × 1 inch, or .8 square inches, and as the permeability has been taken as a low figure, there is no real need for the 10% allowance to compensate for the thickness of the lamination insulation. The formula becomes, then :—

$$100 = \frac{3.2 \times N^2 \times 1{,}000 \times .8}{6.2 \times 100{,}000{,}000}$$

$$\text{or } N^2 = 24218750$$

$$\text{and } N = 4{,}920 \text{ turns nearly, say } 5{,}000 \text{ turns.}$$

The winding space is .6 inch × 1.3 inch and, allowing .1 inch each way for a former with end cheeks, this reduces to an area of .5 inch × 1.1 inch or .55 square inches, so wire must be used which will wind

$\frac{1}{.55}$ × 5,000 turns per square inch or 9,090 turns per square inch.

Reference to the wire tables shows that S.W.G. 34 enamelled copper wire winds 10,000 turns per square inch, which gives a little room for uneveness in winding.

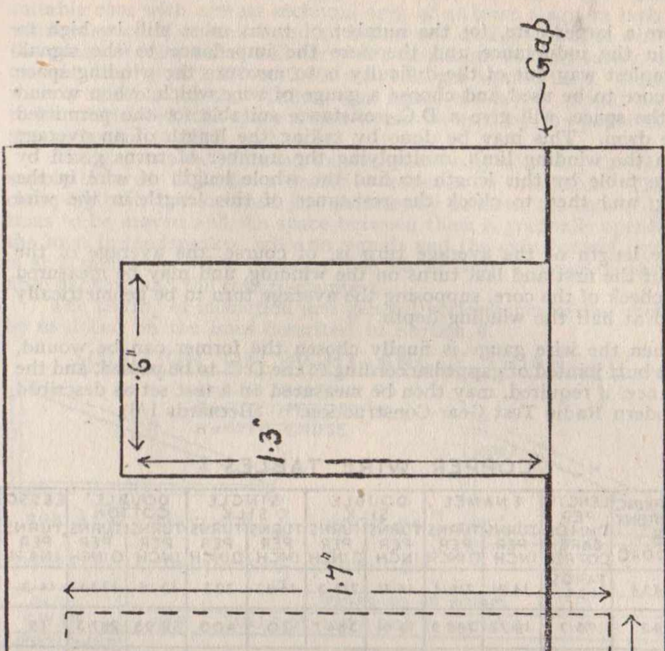
The choke is finished in the same way as a transformer, with a tightly clamped core and a tape or cloth binding to protect the wire. No provision has here been made for interleaving the windings with paper as it is unlikely that any really dangerous voltage would be set up in such a choke.

CHOKES FOR MIXED CURRENTS.

Where the choke is to carry D.C. as well as A.C. it will scarcely be possible to wind such a high inductance (should it be needed) on such a small core unless the D.C. component is practically negligible. In the first place the wire would need to be of a heavier gauge to carry the current as well as to reduce the D.C. resistance to as low a figure as possible.

For example, it may be necessary to use a choke as the anode load for a valve for the reason that a suitable resistance load reduces the anode voltage to too low a figure.

The choke will still present a high impedance to the A.C. signal but the D.C. resistance must be low or otherwise the whole purpose of the choke will be defeated. This means a thicker gauge of wire and



No. 11. CORE FOR L.F. CHOKE.

therefore a larger core, for the number of turns must still be high to maintain the inductance and therefore the impedance to the signal. The simplest way out of the difficulty is to measure the winding space of the core to be used and choose a gauge of wire which, when wound to fill the space, will give a D.C. resistance suitable for the permitted voltage drop. This may be done by taking the length of an average turn on the winding limb, multiplying the number of turns given by the wire table by this length to find the whole length of wire in the winding, and then to check the resistance of this length in the wire tables.

The length of the average turn is, of course, the average of the length of the first and last turns on the winding, and may be measured on the cheek of the core, supposing the average turn to be geometrically situated at half the winding depth.

When the wire gauge is finally chosen the former can be wound, the core butt jointed or gapped according to the D.C. to be passed, and the inductance, if required, may then be measured on a test set as described in " Modern Radio Test Gear Construction." (Bernards 1/6).

COPPER WIRE TABLES

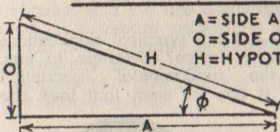
S.W.G No	WORKING CURRENT @ 2,000A□"	LENGTH PER OHM OF BARE COPPER	ENAMEL		DOUBLE SILK		SINGLE SILK		DOUBLE COTTON		E&S.S.C
			TURNS PER INCH	TURNS PER □ INCH	TURNS PER INCH	TURNS PER □ INCH	TURNS PER INCH	TURNS PER □ INCH	TURNS PER INCH	TURNS PER □ INCH	TURNS PER INCH
16	6·434	YARDS 13.4	14·81	219·4	14·71	216·3	14·93	223	13·16	173·1	14·2
18	3·62	75·3	19·72	388·9	19·61	384·7	20	400	16·95	287·3	19
20	2·036	42·4	25·97	674·4	25·64	657·3	26·32	692·8	21·28	452·7	24·7
22	1·232	25·6	33·33	1111	32·26	1041	33·33	1111	25·64	657·3	31·2
24	·76	15·8	42·37	1794	40	1600	42·55	1810	31·25	976·8	39·5
26	·508	10·6	51·55	2655	48·78	2379	51·81	2684	35·71	1275	48·1
28	·344	7·18	62·50	3906	57·8	3341	62·11	3858	40·32	1625	57·8
30	·24	5·03	74·63	5569	67·11	4564	72·99	5326	44·64	1992	67
32	·182	3·82	85·47	7308	75·19	5652	82·64	6830	48·08	2311	76·3
34	·132	2·77	100	10,000	85·47	7308	95·24	9070	52·08	2712	87·7
36	·090	1·89	120·5	14,520	99·01	9800	112·4	12,630	60·24	3629	102
38	·06	1·18	151·5	22,950	117·6	13,830	137	18,770	66·67	4446	125
40	·036	·755	188·7	35,620	137	18,770	163·9	25,870	72·46	5250	151

Smoothing chokes also may be wound in this way. Choose a suitable core with a cross sectional area of at least 1 square inch and a window space of at least 2 square inches and decide from the wire tables the gauge of wire which will carry the maximum current safely, using a current density of 1,500 or 2,000 amperes per square inch. Enamelled wire is suitable for the winding and again the layers should not need to be interleaved, the space which would be used by the paper being of greater value if filled with wire.

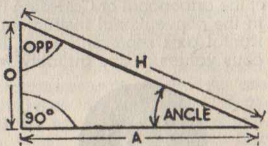
The gap can be adjusted experimentally by allowing the choke to supply filtered D.C. to a sensitive receiver or amplifier. The core clamping bolts are loosened just sufficiently to allow the sets of laminations to be moved and the space between them is gradually opened until the hum in loudspeaker, with no signals and the gain control right out, is at a minimum. The gap can then be set with a paper or very thin fibre packing and the core re-clamped.

The testing of insulation and general performance of the choke can be modelled on the lines described in Section 4.

SOLUTION OF RIGHT ANGLE TRIANGLES



A = SIDE ADJACENT TO ϕ
O = SIDE OPPOSITE TO ϕ
H = HYPOTENUSE



SINE $\phi = \frac{O}{H}$ TANGENT $\phi = \frac{O}{A}$ SECANT $\phi = \frac{H}{A}$

COSINE $\phi = \frac{A}{H}$ COTANGENT $\phi = \frac{A}{O}$ COSECANT $\phi = \frac{H}{O}$

PARTS GIVEN	PARTS TO BE FOUND				
	HYP	ADJ SIDE	OPP SIDE	ANGLE	OPP ANGLE
HYPOTENUSE AND ADJACENT	——	——	$\sqrt{HYP^2-ADJ^2}$	COSINE $= \frac{ADJ}{HYP}$	SINE $= \frac{ADJ}{HYP}$
HYPOTENUSE AND OPPOSITE	——	$\sqrt{HYP^2-OPP^2}$	——	SINE $= \frac{OPP}{HYP}$	COSINE $= \frac{OPP}{HYP}$
HYPOTENUSE AND ANGLE	——	HYP X COSINE	HYP X SINE	——	90°—ANGLE
ADJACENT AND OPPOSITE	$\sqrt{ADJ^2+OPP^2}$	——	——	TAN $= \frac{OPP}{ADJ}$	COTAN $= \frac{OPP}{ADJ}$
ADJACENT AND ANGLE	$\frac{ADJ}{COSINE}$	——	ADJ X TANGENT	——	90°—ANGLE
OPPOSITE AND ANGLE	$\frac{OPP}{SINE}$	OPP X COTAN	——	——	90°—ANGLE

B.A. TAPPING DRILLS

B.A. No	DRILL SIZE	B.A. No	DRILL SIZE	B.A. No	DRILL SIZE	B.A. No	DRILL SIZE
0	No 12	5	No 40	10	No 56	15	No 72
1	No 19	6	No 44	11	No 58	16	No 74
2	No 26	7	No 48	12	No 63	17	No 76
3	No 30	8	No 51	13	No 65	18	No 77
4	No 34	9	No 53	14	No 70	19	No 79

B.A. CLEARANCE DRILLS

B.A. No	DRILL SIZE	B.A. No	DRILL SIZE	B.A. No	DRILL SIZE
0	"C"	6	No 32	12	No 54
1	No 3	7	No 37	13	No 54
2	No 11	8	No 42	14	3/64"
3	No 19	9	No 46.	15	No 60
4	No 26	10	No 49		
5	No 29	11	No 51		

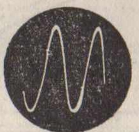
CATHODE-RAY OSCILLOGRAPHS

INTRODUCTION

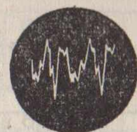
The cathode-ray oscillograph is one of the most versatile electronic instruments which has ever been developed as an aid to investigators of natural phenomena, and as a time saving accurate method for observing the characteristics of both electrical and mechanical machines. Fundamentally, the oscillograph provides a means of plotting a visual curve on a fluorescent indicating screen. The coordinates of the curve are usually of the orthogonal or Cartesian type, and, in the conventional instrument, the horizontal axis represents time. Instantaneous values of any quantity which can be converted into an electrical potential, whose amplitude will vary according to the variation of that quantity, are plotted along the vertical axis of the screen. Essentially, a cathode-ray oscillograph is an instrument with which the value of an unknown variable voltage may be plotted against a time reference. The indicating pointer or element is an electron beam having negligible inertia. Therefore, the instrument may be used to plot rapidly changing quantities which cannot be plotted with a mechanical system of indication. Another advantage of the electronic beam type of indicator element is that it cannot be damaged by the application of over-voltage on the deflection system. Furthermore, the indicator requires a negligible amount of power for operation. Thus, the source of the phenomenon under observation is not burdened, with a load which might disturb its operating characteristics.

Uses

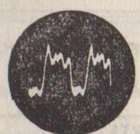
What are the practical applications of such a device? Needless to say, from the fundamental description above, it can be seen that they are manifold. A little thought will disclose hundreds of ideas for specialized applications. A few of the more general uses are for the study and testing of the operation of radio receivers, transmitters, welding circuits, transmission lines, electronic control devices, circuit breakers, ignition coils, relays, and other electrical devices. An oscillograph may also be used to advantage in the study of vibrations, properties of metals, and dynamic mechanical unbalance. Production testing applications even include fast and accurate adjustment of watches and musical instruments. Not to be overlooked are



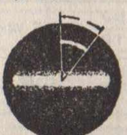
Sine waves of a tuning fork. A-440 cycles per second.



G-392 cycles per second as produced by a single reed of an accordian

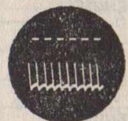


F-392.6 cycles per second as produced by the D string of a violin



Oscillogram of the operation of a two-way snap-switch, accurately timed in milliseconds

Oscillogram of the response of a given amplifier to a 100 kilocycle square-wave signal



Oscillogram showing the precise wave form of the DuMont Variable-Frequency Stimulator for brain surgery and research

Figure 1
Typical Oscillograms

uses in the field of internal combustion engines, where detonation studies and pressure-volume curves can be plotted.

The first domestic cathode-ray oscillograph was introduced in the United States in 1932 by the Allen B. Du Mont Laboratories. The limitations of these instruments compared to modern developments are quite severe. Nevertheless, what had previously been a laboratory curiosity evolved into a widely used instrument. The continual increase in use and interest led to rapid improvements and expanded production. Since the Du Mont Laboratories manufacture not only the equipment, but also the cathode-ray tubes used as the indicator, and the gas discharge tubes used in time-base generating circuits, it has been possible to supervise improvements in all three items simultaneously and thus produce a product of enviable quality.

DuMont Quality and Performance

A continuous research and development program assures the user of Du Mont equipment that it incorporates the latest innovations and improvements. Conservative design practice results in long life and dependable performance. All component parts are operated well below rated values, and mechanical design is such that the equipment will be rugged and convenient to operate. Painstaking methods are used in production to maintain a standard of quality which is unquestionable. Incoming test on capacitances, potentiometers, resistances, inductances, transformers, and vacuum tubes result in minimum failure of component parts. A rigorous mechanical and electrical inspection is maintained to make certain that Du Mont instruments will exceed the stated performance characteristics. Finally, a sample portion of the factory output is submitted to the Engineering Department for life and quality tests. Individual records are kept on each instrument as it is tested in production. These precautions and procedures are further evidence to support the statement that the name of Du Mont is synonymous with high quality and fine performance.

GENERAL DESCRIPTION

High Voltage Power Supply

A cathode-ray tube in itself is not a complete indicating device. In order to produce a spot on the fluorescent screen, the proper voltages must be applied to the various electrodes, as specified in the tube section of this reference manual. Fortunately, the power requirement is not severe. Although potentials of at least 1000 volts are required, the current drain is so small that bulky transformers and chokes are not necessary. The purposes of the different voltages applied to the tube electrodes are to focus, to accelerate and to position the electron beam so that a small, intense, yet visible spot is produced to trace the curve on the fluorescent screen. In addition, a source of heater power must be available to operate the indirectly heated cathode of the cathode-ray tube. Power supply details are discussed in a section which follows.

Amplifiers

The combination of the cathode-ray tube and power supply then is enough to form the indicator element. Unfortunately, the tube itself is a relatively insensitive device, and potentials in the order of several hundred volts are necessary for full scale deflection. Most applications involve input potentials of much lesser magnitudes and, therefore, an amplifier is necessary to supply the beam deflection voltages to the tube.

While the amplifier will permit the study of small voltages, it will also impose limitations on the character of signals that can be transmitted by the amplifier. With the unknown signal applied directly to the deflection plates, the maximum amplitude observable will be limited only by the full scale deflection of the beam, the maximum frequency which can be applied is limited by the transit time of the beam passing between the deflection plates, and also by the shunt capacitance between deflection plate terminals. Transit time effects generally restrict usefulness to below 200 megacycles in commercial tubes operated at accelerating potentials of about 1500 volts. Low capacitive reactance at higher frequencies may load down the signal source.

Applying a direct current voltage to the plates will deflect the beam proportionally to the magnitude of that voltage, and the beam will remain fixed in its deflected position until that d-c deflection voltage is removed. Therefore, there is no low frequency limitation when direct connection is used. In fact, it is the application of a direct current voltage, controllable in magnitude, that is used to position the beam in both horizontal and vertical directions in the complete oscillograph unit.

When an amplifier is interposed between signal source and deflection plates, the signal will be faithfully reproduced only if the limitations of the amplifier are not exceeded. These limitations include frequency discrimination both in the amplifier and input attenuator circuits, phase distortion and the maximum allowable direct current and peak input voltages. The minimum signal voltage is determined by the least amount of beam deflection which can be tolerated for effective study, and therefore by the gain of the deflection amplifier. The maximum voltage which can be applied is limited by the voltage rating of any input coupling capacitances and the voltage range of the input amplifier stage. Of course, a radio frequency signal will not be passed by an audio frequency amplifier, nor will a direct current signal be amplified by an alternating current amplifier. Attention must also be directed towards the gain or attenuation control, since the effects of the variable distributed capacitance depending on the setting of the rotor in a high resistance potentiometer can cause extreme phase and frequency distortion at the higher frequencies.

A very important consideration in choosing an oscillograph is the frequency response characteristic of the vertical axis amplifier. Many applications of an oscillograph require the observation of pulses, square waves and other non-sinusoidal waveforms. Therefore, not only must the sinusoidal response be uniform, but the transient response must permit undistorted amplification of irregular wave shapes.

This amplifier discussion thus far has been restricted largely to the vertical axis. Similarly, these considerations apply to the horizontal amplifier. For most applications, the signal applied to the horizontal deflecting plates provides for the movement of the spot at a uniform rate with respect to time. Such a signal provides the time-axis along which is plotted the unknown variable voltage. After the spot has traveled the width of the screen, it snaps back to its starting position and the process is repeated. Without going into a detailed discussion of the generator which supplies the horizontal voltage, it will suffice to say that the waveform of this time-axis deflecting voltage is usually of a saw-tooth nature, and therefore, is rich in harmonic content. Since this saw-tooth voltage is amplified by the horizontal amplifier, the frequency and phase characteristics of that amplifier should permit undistorted amplification of sinusoidal signals of frequencies extending both far above and below the saw-tooth recurrence rates. Frequently, the saw-tooth frequency range is from a few cycles per second to over 50,000 cycles per second, so that quite stringent requirements are

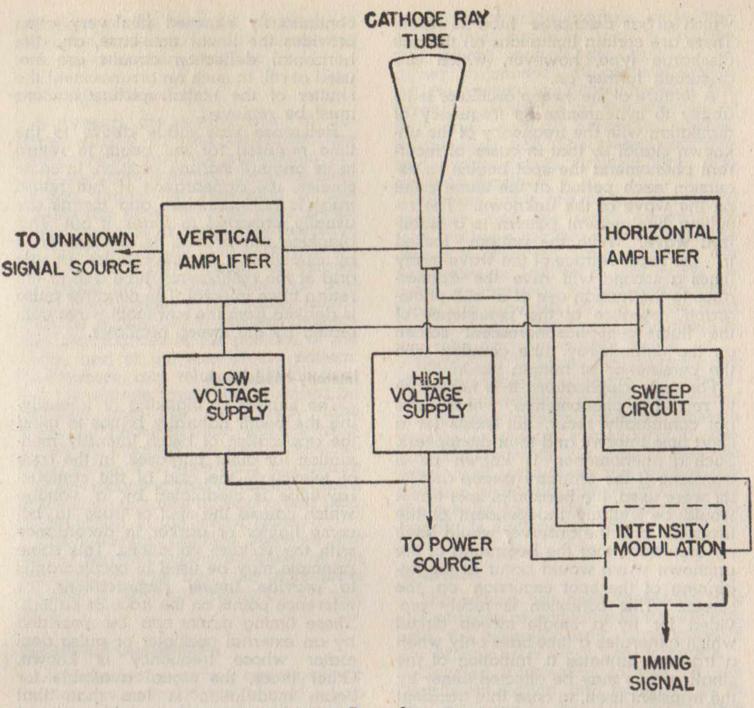


Figure 2
Block Diagram of Typical Oscillograph Circuit Groups

imposed on the frequency response characteristic of this amplifier.

It is also desirable for the horizontal and vertical amplifier to have identical phase characteristics to facilitate accurate study of the relationship between two different signals, each being applied to a separate axis. Such a connection will produce a pattern called a "Lissajou Figure". A detailed discussion of these figures is given in the application notes in the rear of this manual and may be found in many text books.

Linear Time-Base Generator

The linear time-base generator or sweep oscillator is the integral part of the oscillograph unit which generates the saw-tooth voltage producing the linear time-base referred to above. The time-base is not restricted to a linear function, but can also be a sinusoidal, circular or spiral function or any other shape that may be desirable for particular applications.

The saw-tooth wave is generally developed by a relaxation oscillator in which a gas discharge tube is used. There are certain limitations on the gas discharge type, however, which are discussed further on.

A feature of the sweep oscillator is its ability to synchronize its frequency of oscillation with the frequency of the unknown signal so that in cases of recurrent phenomena the spot begins its excursion each period at the same point on the wave of the unknown. The resulting luminescent pattern is a stabilized wave. With the pattern "locked in", the rapid retrace of the wave many times a second will give the appearance to the human eye of a "still photograph" because of the persistence of the fluorescent-phosphorescent screen on the cathode-ray tube coupled with the persistence of human vision.

For some applications it is necessary to record a phenomenon which does not continually recur, but exists for a short time interval and then disappears. Such a phenomenon is known as a transient. If the ordinary sweep oscillator were used, the horizontal spot travel would be entirely independent of the transient, and the observer would have no assurance that the beginning of the unknown wave would occur at the beginning of the spot excursion on the screen. This condition is nicely provided for by a single sweep circuit which generates a time-base only when a transient initiates it. Initiation of the single sweep may be effected either by the transient itself, in case that transient cannot be controlled at will by the observer, or by an independent voltage applied to the synchronizing terminal which can also control the initiation of the transient. The single sweep circuit is discussed in greater detail later.

For applications involving rotating machinery, it is often desirable to use a sinusoidal sweep, which can be obtained from either an external sinusoidal oscillator, or from a small generator mounted on the rotating shaft so that the frequency will correspond to the speed of the shaft.

Where photographic recording of transients is involved, the travel of the continuously exposed film very often provides the linear time-base, and the horizontal deflection circuits are not used at all. In such an arrangement the shutter of the motion picture camera must be removed.

Reference was made above to the time required for the beam to return to its original starting position. In some studies, the appearance of that return trace is objectionable, and means are usually provided to blank it out. This blanking out process is accomplished by applying a negative pulse at the grid of the cathode-ray tube during the return trace interval. The negative pulse is derived from the saw-tooth wave generated by the sweep oscillator.

Intensity Modulation

The subject of blanking or intensifying the beam naturally brings to mind the application of beam intensity modulation for other purposes. In the case of television, the grid of the cathode-ray tube is modulated by a voltage which causes the spot or trace to become lighter or darker in accordance with the voltage variations. This same principle may be used in oscillographs to provide timing demarcations, or reference points on the trace or pattern. These timing marks can be provided by an external oscillator or pulse generator whose frequency is known. Other times, the signal available for beam modulation is less than that needed for extinguishing the beam, and therefore, an amplifier is needed. This amplifier is commonly known as the Z-axis amplifier. A further use for this provision is to intensify the beam over portions of the trace where the writing rate of the spot is so great that the fluorescent screen is not sufficiently excited. Thus, the intensity is more uniform throughout the entire trace and photographic exposure is facilitated. Furthermore, the portion of the trace which is most interesting is often the least visible. This provision will prevent burning and damage to the fluorescent-phosphorescent screen caused by operation of the intensity control at maximum (i. e., zero bias) in an attempt to improve the total visibility.

Low Voltage Power Supply

In general, the requirements of the power supply for the amplifiers, the sweep circuit, and the positioning circuits are more exacting than the high voltage supply for operation of the cathode-ray tube. Not only must the filtered output be exceptionally free from a-c ripple to prevent hum from appearing on the trace because of voltage variations on the amplifiers, but also small irregularities in the power source must be eliminated to prevent momentary disturbances of the position of the beam, and of the size of the pattern. Furthermore, any magnetic fields from the transformer and chokes must be shielded from the cathode-ray tube since the beam position will be influenced by magnetic as well as electrostatic fields. It is interesting to observe that the magnetic field of the earth itself is sufficient to cause at least a half inch of deflection in the larger tubes.

Good design practice requires the use of separate power supplies for the cathode-ray tube and the associated circuits to prevent interaction of controls.

Mechanical Considerations

Any piece of electronic equipment, no matter how complicated, should be so designed that it is rugged and compact, and yet the various components should be readily accessible. Layout of the various components in Du Mont Oscillographs is planned to eliminate cross coupling difficulties and to provide short direct leads in high impedance and high frequency portions of the assembly. In addition, controls are located on the front panel in such a fashion that related controls are grouped together. In general, all controls involving the vertical or Y-axis amplifier are arranged vertically on the left side of the panel; and all horizontal controls on the right side. The sweep oscillator and synchronizing controls are also grouped together.

All steel parts are plated to prevent corrosion, and the usual practice of lock washer assembly with all machine screws is observed. Rivet fasteners are eliminated on all parts that might require replacement. Recent oscillograph types are provided with a sturdy front cover to protect the face of the cathode-ray tube and the control knobs.

Nearly all DuMont oscillographs are of the portable type. Electronic apparatus which consists of a number of rather complicated circuits requires extreme caution in design, particularly in mechanical respects. No possibilities are overlooked, and even the weight distribution of the units is planned so that the weight load when carried by the handle is well balanced.

Conclusion

This section has been presented with the purpose of acquainting the layman with the operation and construction of Du Mont Cathode-ray Oscillographs.

Detailed information follows in the instrument section, and further material can be found in the cathode-ray tube section. From time to time application briefs, which may be assembled in the rear of this reference manual, will be forwarded. These sheets are intended to familiarize the user of cathode-ray equipment with the varied applications of Du Mont instruments.

OSCILLOGRAPH DESIGN CONSIDERATIONS

POWER SUPPLIES

Requirements of power supplies for cathode-ray oscillographs are more stringent than for the majority of electronic applications. Since power supply ripple voltages might show up as spurious deflection or cause modulation of beam intensity, good filtering is essential.

Transformer

The cathode-ray tube is extremely sensitive to electric and magnetic fields, therefore it is essential that the power transformer have a low external magnetic field and in some cases it must be equipped with a magnetic shield. The transformer should be located as remotely as possible from the cathode-ray tube and must be oriented so that its external field has the least effect of spurious deflection. Furthermore, the transformer, being the heaviest single component, should be located in a position such that the oscillograph will have an even weight distribution to facilitate its handling. Usually, a compromise must be made between these two factors. In general, the power transformer (and power supply) should be located near the rear of the instrument.

Since the majority of cathode-ray oscillographs are portable, it is essential to keep the size and weight of the transformer at a minimum consistent with good design practice. In no case, however, should a sacrifice be made in transformer ratings in order to obtain small size and weight. The insulation must be acceptable for at least the sum of the maximum positive and negative voltages.

The power supply transformer should have a lamination stack designed for at least the minimum operating frequency and preferably for a lower frequency in order to keep external magnetic fields at a minimum. A high turns-per-volt ratio is desirable even though it tends to increase the physical size of the transformer

Primary

The primary windings should be completely surrounded by a grounded electrostatic shield to prevent capacitive coupling to the high voltage winding.

A safety switch of the momentary close type, connected in series with one side of the primary to the power line, is usually mounted on the rear of the chassis. Such a mounting is used so that the switch is closed only when the chassis is completely within its cabinet. This protection is important since dangerously high voltages are employed.

Secondary

The exact voltages and currents required of the secondary windings of the power transformer will, of course, depend upon the subsequent oscillograph circuit. In all cases, the cathode-ray tube filament winding must be a separate winding and must be insulated from ground for at least the full accelerating potential. It is customary to insulate the windings from the core for at least twice the rated operating voltage plus 1000 volts. The cathode-ray tube heater winding also must be surrounded by a grounded electrostatic shield to eliminate capacitive coupling of this winding to other windings, which would cause distortion of the pattern by intensity modulation of the beam at power-line frequency. It is, likewise, desirable to shield the heater windings for the power supply regulator tubes, and these windings should be separate from the amplifier windings.

Amplifier voltages are usually obtained from a center-tapped secondary winding, such as those found in conventional radio receiver transformers. Secondary voltages in the order of 400 r.m.s. volts on either side of the center tap, and current values from 20 to 200 milliamperes, depending upon the d-c load requirements, are common.

High voltage for the cathode-ray tube is usually obtained from an extension of one side of the secondary winding. Voltages from 800 to 1500 volts r.m.s. either side of center tap are the usual supply voltages for 3 and 5 inch oscillographs. Current requirements are small, being in the order of 2 or 3 milliamperes.

Figure 3 shows the schematic diagram of a typical oscillograph transformer.

Low Voltage Supplies

The oscillograph may have several low-voltage supplies for the amplifier and other circuits. All of them may often be derived from the same transformer winding. The supply will usually have positive and negative sections, either or both of which may be regulated or unregulated.

The voltage and current requirements for the deflection amplifier circuits are determined by the deflection factor of the cathode-ray for the accelerating potential at which the tube will be operated, the type of amplifier circuits, the frequency response range, and other factors which may depend upon particular operating conditions.

When balanced deflection circuits are used, as is true in the more recent designs, the spurious deflections resulting from line-voltage changes and from residual hum tend to be cancelled out. A further advantage in the use of balanced deflection circuits is that the deflection-amplifier supply voltage need be only half that for an unbalanced amplifier having the same signal-voltage output.

Filtering and Regulation

The power supplies for any low-level stages of the deflection amplifier usually must have better filtering, stability, and regulation, not only because any spurious signals introduced into these stages are amplified by the final amplifier, but also because such stages are usually unbalanced, or single-ended. In general, the percentage of ripple content should not exceed 0.5% of the d-c supply voltage. Final deflection amplifiers, which sometimes require high voltages, seldom need a regulated supply. Furthermore, it is common practice to supply from a common source, several circuits within the oscillograph performing different functions. The tendency toward coupling through the com-

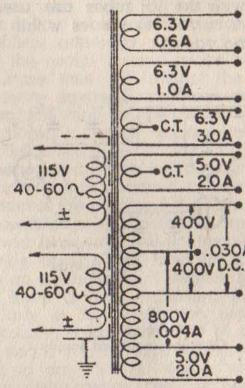


Figure 3
Typical power transformer for use in a cathode-ray oscillograph

mon impedance of the power supply must be lessened by reducing that impedance. Reduction of this impedance is accomplished effectively by the use of voltage regulating devices.

The two types of voltage regulators in general use in oscillographic circuits are the gas-tube regulator and the electronic degenerative regulator.

Gas-tube regulators make use of the fact that, within their operating range, the voltage between electrodes is constant for large variations in electrode current. Some neon tubes and the VR series of cold-cathode discharge tubes are examples of this type of voltage regulator. The VR tubes will maintain constant voltage within the range of electrode currents from 5 to 30 milliamperes.

An additional rectifier may be connected as indicated in Figure 4. To provide a half wave low-voltage negative supply from the same winding used for the positive supply, a simple resistance-capacitance filter following the rectifier will often suffice. Figure 4 also shows the complete circuit using VR tubes to produce positive and negative regulated voltages. The resistances in series with the VR tubes are used to limit the current to values within their operating range.

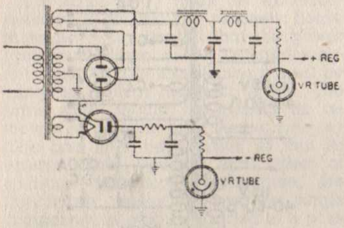


Figure 4
Gas-tube regulated supply

The degenerative- regulator makes use of a high-vacuum tube connected between the power supply and the load and operated as a variable resistance in such a manner as to give a constant voltage across the load dspite changes in line voltage or load current. A complete circuit of such a regulator is given in Figure 5.

HIGH VOLTAGE SUPPLIES

In almost all oscillographs the accelerating electrode is operated at ground potential and the cathode at a negative potential. This potential may range from 1000 volts to 6000 volts or more. In oscillographs equipped with intensifier-type cathode-ray tubes, the total accelerating potential is divided, so that part of it is applied between the cathode and the accelerating electrode, and the remainder between the accelerating electrode and the intensifier. The potential between the accelerating electrode and the intensifier should not exceed 50% of the total accelerating potential.

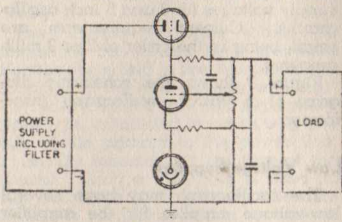


Figure 5
Degenerative regulator circuit

Therefore, with the accelerating electrode at ground potential, the cathode will be negative and the intensifier positive. This somewhat simplifies the filter and transformer requirements for any individual electrode with respect to ground, although the total voltage is still the same. Insulation for the transformer must be based on the total accelerating potential.

The average potential of the deflection plates should be at or near the accelerating electrode potential to prevent acceleration of the beam by the deflection plates with resultant defocusing and change in deflection sensitivity. Simpler deflection plate coupling schemes may be used when the accelerating electrode is operated at ground potential since the hazard and complication of high voltages are eliminated.

While the voltages necessary to operate the cathode-ray tube are high, the currents required are small. Half-wave rectification and resistance-capacitance filtering is ample. Insufficient filtering, however, may cause spurious intensity modulation of the beam or modulation of deflection sensivity in accordance with the residual power supply ripple. When circuits are provided for intensity modulation, better filtering of the high-voltage supply is necessary than for oscillographs in which this provision is not made.

The functions of the various amplifiers used in a cathode-ray oscillograph impose rigid requirements upon their design. Cathode-ray tube deflection elements necessarily operate at high signal potentials. Therefore, to provide an instrument suitable for wide application, it is necessary to provide amplification of the signals it is desired to study. These amplifiers should preferably be incorporated within the instrument itself. Although it is customary to refer to the voltage or power gain of an amplifier as a measure of its performance, actually, for oscillographic applications, these terms do not have any particular significance since a given amplifier will produce entirely different results with different cathode-ray tubes, and even with the same cathode-ray tube if the accelerating potential is changed. Also, most conventional amplifier ratings refer to electrical quantities only, whereas the indication on a cathode-ray tube is strictly visual. For this reason it is desirable to incorporate two new terms in stating amplifier performance. One is the sensitivity of the amplifier at its input terminals in terms of the visual effect produced by a certain electrical cause. The other term, involving the frequency response, will be discussed later.

Deflection Sensitivity and Deflection Factor

It is convenient to express the gain of a given amplifier by use of the term "Deflection Sensitivity," which is the ratio of the lineal deflection produced on the cathode-ray tube screen to the r.m.s. or the direct current voltage required at the input terminals to produce this deflection. Deflection Sensitivity, therefore, gives a convenient figure for comparison of various types of oscillographs irrespective of type of cathode-ray tube used or the accelerating potential at which it is operated. An increasingly desirable term used for the sake of convenience is the term "Deflection Factor," which is the reciprocal of the "sensitivity" ratio.

In general, the useful range of a cathode-ray oscillograph extends from zero frequency to several hundred megacycles, provided sufficient voltage is available to allow a reasonable deflection with direct connection to the cathode-ray tube deflection plates. The amplifiers generally provided will extend the useful voltage range while at the same time will restrict the useful frequency range. Since these two considerations tend to operate in opposite directions, a factor taking both into account is useful in determining the performance of a particular amplifier. Such a factor is that obtained by taking the product of the gain and the band width. Consequently, it follows that an amplifier with high gain will not usually have a wide band width, and an amplifier with an extended high frequency range will have a high deflection factor or similarly a low deflection sensitivity. Obviously, a large number of amplifying stages can be used to increase the gain to any desired value, providing noise disturbances can be kept to a satisfactory minimum. For a device which provides a visual indication, however, the requirements for stability are stringent. Unless sufficient stability is provided, accurate photographic records of cathode-ray tube indications are not practical. As a result, the design of any oscillographic amplifier is necessarily a compromise.

Square Wave Response

Since a cathode-ray oscillograph is primarily a test instrument, it should give a true representation of the signal under observation. In order to investigate the characteristics of an amplifier, it is common practice to apply a square-wave signal, as shown in Figure 6, to the input circuit. The steep front of such a wave gives an indication of the high-frequency or "transient" response, and the flat top of the wave is an indication of the low frequency characteristics of the amplifier, where the terms "high" and "low" frequency are relative to the fundamental frequency of the square wave.

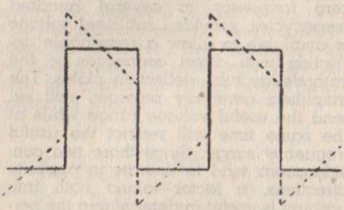


Figure 6.
A square wave signal, solid line: sawtooth distortion, broken line.

Low Frequency Distortion

If a low frequency square wave signal is applied to the amplifier circuit shown in Figure 7 between point A and ground, and if the time constant of the grid circuit, C_1R_1 is too small, the signal at point B and therefore at the output between point C and ground, will appear as shown by the dotted line in Figure 6. This sawtooth distortion is caused by the charging and discharging of the capacitance C_1 through resistance R_1 during the flat top periods. This type of low-frequency distortion may obviously be reduced or eliminated by making the values of C_1 and R_1 sufficiently large so that the time constant of this part of the circuit becomes very large. For very good low-frequency response, i.e. with this type of distortion eliminated, the physical size of the capacitance required becomes unreasonable since the grid resistance must be limited in value by the grid current characteristics of the vacuum tube. It is also desirable to keep the time constant of this part of the circuit as small as possible since it will determine the actual time required for the amplifier to recover from the effects of a large transient pulse. One method of obtaining good low-frequency response while still limiting the size of C_1 and R_1 is to employ plate circuit compensation as shown in Figure 8. By the addition of the resistance-capacitance circuit R_2 C_2 in the plate circuit of the amplifier as shown in Figure 8A, a voltage appears at point D having a form as shown in Figure 8B. When this potential is added to that shown by the dotted line in Figure 6, the resultant is the original square wave, which appears at point C in Figure 8A. This compensation must be carefully balanced to provide the proper amount of compensation to correct for the amplifier characteristics without introducing additional distortion.

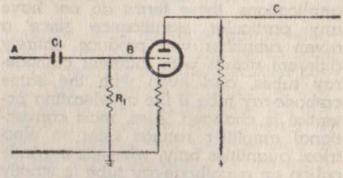


Figure 7
Denoting time constant of input coupling circuit

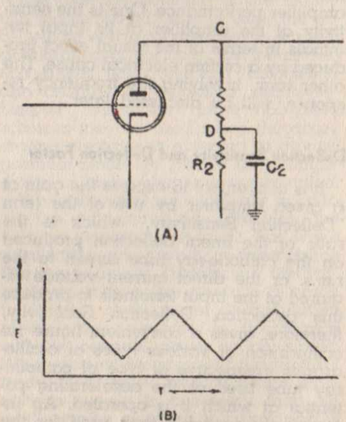


Figure 8
Low frequency plate circuit compensation

Stray Circuit Capacitances

The presence of stray circuit capacitance and the interelectrode capacitances of the vacuum tubes in the amplifier may be represented by the dotted shunt capacitance Co shown in Figure 9. These stray circuit capacitances have the effect of decreasing the plate load impedance as the signal frequency is increased. High frequencies are therefore attenuated and the frequency response curve will appear as shown by curve A of Figure 10.

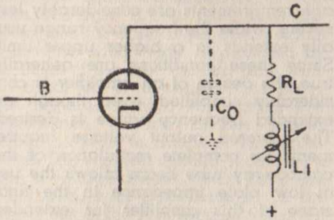


Figure 9
Indicating stray capacitance

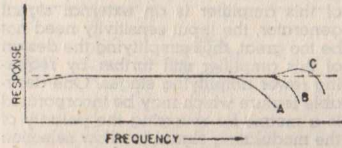


Figure 10
Showing response characteristics

High Frequency Compensation

By the insertion of a series inductance Ll in the plate circuit of the amplifier, as shown in Figure 9, a reactance increasing with frequency is added to the vacuum tube plate load to increase its impedance at high frequencies and, to, consequently, maintain the amplifier gain at these frequencies. If this inductance should be increased in value above the optimum, a response curve similar to curve C of Figure 10 will be obtained. This rising characteristic is obtained by resonance between the added inductance Ll and the stray circuit capacitance Co. This type of characteristic will accentuate the response to signal components over a limited frequency range, thus tending to distort the signal under observation. The effect is shown in Figure 11, illustrating a tendency toward oscillation at the start of each half cycle of the square wave. The inductive compensation employed should be so proportioned that the maximum increase in high-frequency response is obtained without introducing additional distortion of the signal. An example of proper compensation is shown by curve B of Figure 10, and a typical example of good wave response corresponding to this type of characteristic is illustrated by Figure 12, for a square wave of 100,000 square-wave cycles per second. It will be noted that usable deflections may be obtained at frequencies higher than the high-frequency rating of the amplifiers, provided that the amplifier characteristics are taken into consideration and the resulting pattern properly interpreted.

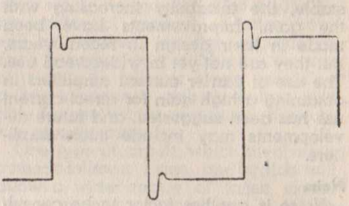


Figure 11
Overpeaked square wave characteristic

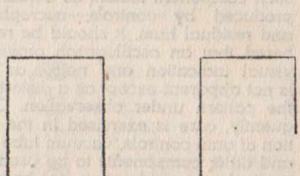


Figure 12
Proper square wave response

D-C Signals

The resistance-capacitance coupled amplifiers ordinarily employed in cathode-ray oscillographs will not pass direct current signals because of the inability of a capacitance to pass direct current. Signals which are composed of an alternating component superimposed upon a direct current are therefore established upon a new reference axis corresponding to the average level of the alternating component. Since means are already available for the measurement of the direct current component of the signal by meters and direct connection to deflection plates, automatically removing the d-c component results in being able to obtain full-scale deflection, or more, of the alternating component, thereby facilitating fine detail study of the pattern.

Although nearly all oscillographs do not include direct current amplifiers, special instruments have been made with them. This problem has proved difficult to solve since direct current amplifiers are in general, rather unstable, the instability increasing with the gain. Improvements have been made in their design in recent years, but they are not yet in widespread use. The use of carrier current amplifiers in obtaining a high gain for direct current use has been suggested, and future developments may include such amplifiers.

Noise

Noise is another factor to be considered in amplifier design. Noise includes such component factors as actual noise produced by controls, microphonics, and residual hum. It should be remembered that an oscillograph provides a visual indication and noise, as such, is not apparent except as a distortion of the pattern under observation. Consequently, care is exercised in the selection of gain controls, vacuum tube types and other components to be used. This particular consideration is becoming more important since the state of the art is indicating a trend toward higher accelerating potentials and more sensitive instrument amplifiers to extend the range of usefulness.

Z-Axis Amplifiers

Separate amplifiers are usually provided for Z-axis or intensity modulation of the cathode-ray beam. The considerations of the design of these amplifiers are, in general, different from those employed for deflection. The output voltage requirements are considerably less severe, while the frequency range usually extends to a higher upper limit. Since these conditions are generally true, the design of an amplifier is considerably simplified, even though an extended frequency range is desired. The lowered output voltage requirements for complete modulation of the cathode-ray tube beam allows the use of low plate impedance in the final stage of this amplifier for extended high-frequency response. Since, in general, the source of signal for operation of this amplifier is an external signal generator, the input sensitivity need not be too great, thus simplifying the design of this amplifier still further by requiring fewer amplifying stages. One desirable feature which may be incorporated is a means for reversing the polarity of the modulating signal to allow selection at will of either a reduction or an increase in the intensity of the beam.

Uses

One of the principal uses of the Z-axis amplifier is to provide a means for impressing a timing signal upon the pattern. The timing signal for this purpose is supplied desirably in the form of sharp pulses of short duration and necessarily higher frequency or rate than the signal under observation in order to increase the accuracy with which the time interval between certain events can be determined and in order to prevent elimination of large sections of the trace. Although the linear time-base provided is very nearly linear in time, it cannot be depended upon for highly accurate determinations. Therefore, use of the modulation amplifier for timing purposes is recommended.

In some cases this amplifier handles the signal used for elimination of the return trace or flyback of the time-base to prevent confusion of the pattern.

Attenuators

Since the oscillograph is a measuring instrument, the power drawn from the circuit under test should be a minimum. The input circuits must have provision also for attenuation of the signal to a value which may be handled by the input of the first vacuum tube without distortion or overload. This provision requires a high impedance, low capacitance, voltage divider placed across the input terminals of the oscillograph. The simplest method of obtaining such a voltage divider would be to use a high-resistance potentiometer in the grid circuit of the first vacuum tube. The use of such an attenuator however, is

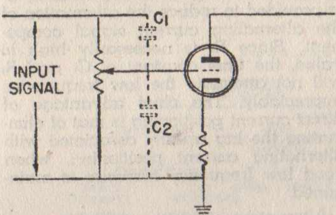


Figure 13
Showing equivalent of distributed capacitance

subject to certain limitations, mainly extreme frequency discrimination at intermediate settings. As shown in Figure 13, the distributed capacitances C_1 and C_2 produce a voltage division at the higher frequencies. This voltage division is essentially constant and independent of the setting of the potentiometer arm. Thus, as the posititon of the potentiometer arm is changed, the relative voltage division across the sections of the potentiometer and capacitances will differ, producing serious frequency discrimination. Although this frequency discrimination may be reduced by using a low-resistance potentiometer, the loading upon the circuit under test will be excessive. A solution of the difficulty is to provide an input attenua-

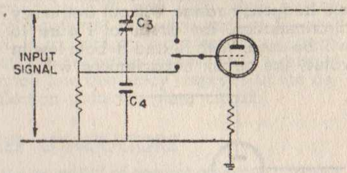


Figure 14
Stepped attenuator

tor with fixed steps and adjustable capacitance elements as illustrated in Figure 14. This scheme will permit individual adjustment for each attenuation ratio, maintaining uniform voltage division over a wide frequency range. Obviously, this cannot be used as the only attenuator, since to cover a wide voltage range and still maintain useful attenuation ratios, a large number of steps would be required. Consequently, an additional method of attenuation will be required for fine adjustment. Such a method is available by the use of a cathode follower stage, providing a low impedance cathode output suitable for use with a continuous attenuator, or gain control.

One type of circuit, which involves a cathode-follower stage, and which will allow a wider range of input signal than conventional amplifiers is shown in Figure 15. This circuit will, however,

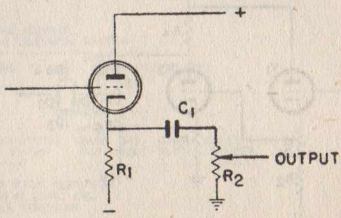


Figure 15
Cathode follower circuit

have a definite frequency limitation, but it is a definite improvement over other previous systems. For the widest possible frequency range without frequency discrimination, the circuit of Figure 16 will be used. With R_1 and R_2 both low in value, the circuit capacitances will be

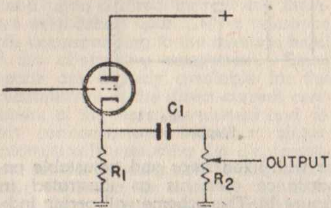


Figure 16
Improved cathode follower circuit

ineffectual even in the megacycle region. C_1 is used as a blocking capacitance in both cases to remove the direct current from the control R_2. Both of these circuits when used in conjunction with the fixed-step attenuator permit an extremely wide range of voltage input without frequency discrimination.

Positioning Circuits

The cathode-follower circuit illustrated in Figure 15 may also be used for obtaining a means of providing a positioning voltage for cases where the deflection amplifier is directly connected to the deflecting plates of the tube. Such a circuit is illustrated in Figure 17, as well as a method for connecting the amplifier to the deflection plates, and still operating the deflection plates at or near ground potential

Since the cathode of V_1 operates at a positive potential with respect to ground, and since the return for R_2 is to a negative supply, some point on R_1 can be made a point of zero potential. Consequently, a direct current voltage is available when applied to the grid of V_2 to cause the direct current plate voltage of V_2 to vary, and therefore, to cause direct current positioning. The resistor R_4 comprises the plate load for the deflection amplifier V_2, while R_5 and R_6 returned to a high negative potential provide direct current voltage division to cause point P to be at zero potential with respect to ground. Capacitance C_1 is provided to reduce the attenuation of the alternating current signal component. Since R_5 is necessarily high in value, the time constant of C_1 and R_5 will not attenuate the low frequencies appreciably. The chief advantage of direct current positioning is that of eliminating the lag usually associated with alternating current positioning, when good low frequency response is maintained.

Alternating current positioning, as illustrated in Figure 18, is used for applications where the lag is not serious, or when direct current connection is not desirable.

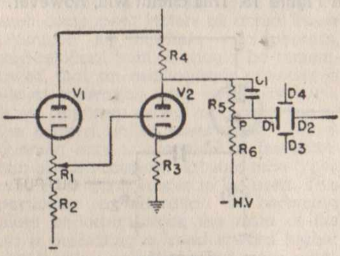


Figure 17
Illustrating a d-c positioning scheme

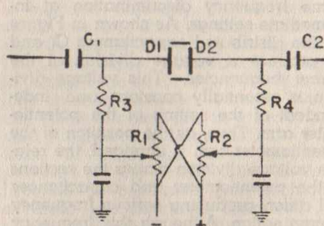


Figure 18
Alternating current positioning circuit

The above mentioned lag or "electrical backlash" is caused by the time required for the capacitance C_1 and C_2 to establish a steady direct current potential at plates D_1 and D_2 after position control potentiometers R_1 and R_2 have been adjusted to some new value. This time is necessitated by the large time constants C_1R_3 and C_2R_4. High values of resistance are necessary at R_3 and R_4 to maintain a high input impedance at the deflection plates and to insure good low frequency response in the deflection plate coupling circuit.

TIME-BASES OR SWEEP GENERATORS

Since practically every pattern on the screen of the cathode-ray tube is a plot of some variable quantity with respect to time, the motion of the luminescent spot with respect to time is of utmost importance. The most common deflection system consists of two sets of parallel deflection plates arranged at right angles to each other. By making the potential of one set of plates in some manner proportional to time, and that of the other set proportional to the prenomenon to be studied, a plot can be obtained in the usual Cartesian coordinate form. The deflection of the spot by a potential proportional to time would trace out a linear time-base. Many other types of time-bases are used in which

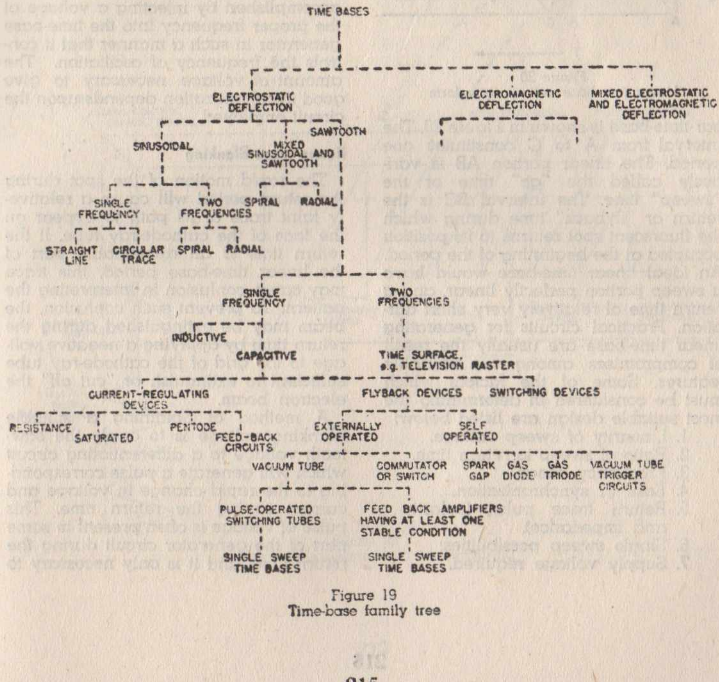


Figure 19
Time-base family tree

the deflecting potential is proportional to some function of time. Examples of these are the sinusoidal and circular time-bases. Figure 19, after Puckle, shows an entire family tree of time-bases. All of the types shown will not be discussed here, but each type has particular advantages for some specialized investigation.

Linear Time-Bases

The linear-time-base is adaptable to wide varieties of uses. A plot of a voltage wave which would produce a linear time-base is shown in Figure 20. The interval from A to C constitutes one period. The linear portion AB is variously called the "go" time or the "sweep" time. The interval BC is the return or "flyback" time during which the fluorscent spot returns to its position occupied at the beginning of the period. An ideal linear time-base would have a sweep portion perfectly linear, and a return time of relatively very short duration. Practical circuits for generating linear time-base are usually the result of compromises among the desirable features. Some of the factors which must be considered in determining the most suitable design are listed below:

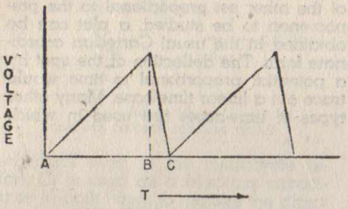


Figure 20
Linear time-base voltage waveform

1. Linearity of sweep voltage.
2. Ratio of sweep to return time.
3. Frequency range.
4. Ease of synchronization.
5. Return trace pulse, (polarity and impedance).
6. Single sweep possibilities.
7. Supply voltage required.
8. Output level and impedance.
9. Number and type of tubes required.
10. Number of variable circuit components necessary to give usable results over required range of frequencies.

The order of the listing does not necessarily indicate the relative importance of the factor involved. The use to which the time-base is put will determine the weight each factor must be given.

Synchronization

In order that a stationary pattern will appear on the cathode-ray tube screen, the time-base must have the same period as the variable quantity to be plotted or some sub-multiple of that period. The adjustment of the time-base to this condition is called synchronization. Synchronization can be accomplished by injecting a voltage of the proper frequency into the time-base generator in such a manner that it controls the frequency of oscillation. The amount of voltage necessary to give good synchronization depends upon the circuit employed.

Return Trace Blanking

The rapid motion of the spot during the return period will cause a relatively faint trace of its path to appear on the face of the cathode-ray tube. If the return time is an appreciable part of the linear time-base period, this trace may cause confusion in interpreting the pattern. To prevent such confusion, the beam may be extinguished during the return time by applying a negative voltage to the grid of the cathode-ray tube sufficient to extinguish or "cut off" the electron beam.

A method of obtaining a suitable blanking voltage is to apply the saw-tooth voltage to a differentiating circuit which will generate a pulse corresponding to the rapid change in voltage and current during the return time. This pulse of voltage is often present in some part of the generator circuit during the return time, and it is only necessary to adjust its amplitude and polarity and apply it to the cathode-ray tube grid to get satisfactory return trace blanking.

Single Sweep

When transient phenomena are to be observed, it is desirable to have occur only a single linear sweep which lasts for the duration of the transient, and which is initiated by the beginning of the transient or some related disturbance occurring just before the start of the transient. If it is wished to observe the very beginning of the transient, the latter method is recommended since a finite time is required to start the sweep after the initiating pulse occurs.

The description of a method of obtaining single sweeps from gas-triode linear time-base generators appears below under the section on gas-triode generators.

Gas Triodes

The most common method of obtaining a saw-tooth wave is to allow a capacitance to charge from a high voltage source through a resistance. Only a relatively small portion of the charging curve of the R-C network is used.

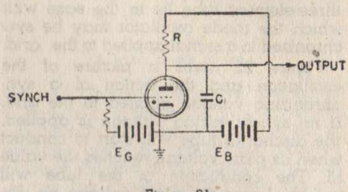


Figure 21
Basic gas triode sweep oscillator circuit

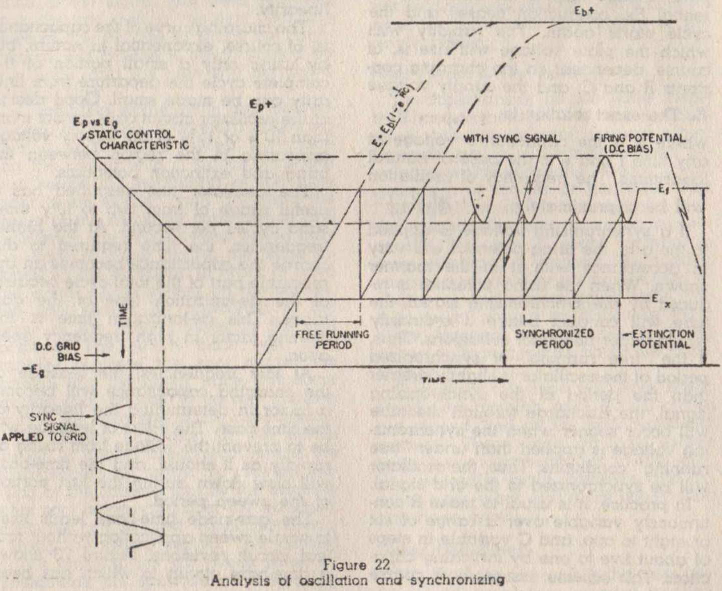


Figure 22
Analysis of oscillation and synchronizing

With the capacitance connected from plate to cathode of a gas diode or triode, that capacitance is allowed to charge only to a relatively low potential determined by the breakdown potential of the discharge tube. Figure 21 shows the basic circuit of the oscillator just described. The discharge tube could be a gas diode, but the advantages of the three-element tube lie in the ease with which the triode oscillator may be synchronized to a signal applied to the grid.

Figure 22 gives a picture of the oscillation and the action of a synchronizing voltage applied to the grid. If no synchronizing voltage is applied, the discharge tube will start to conduct when its plate voltage reaches the value Ef. The conduction of the tube will quickly lower the plate voltage by discharging the capacitance. When the plate voltage falls to the extinction potential Ex, conduction ceases and the cycle starts again. The rapidity with which the plate voltage will rise is, of course, dependent on the charging constants R and C, and the supply voltage E_b. The exact relation is $E = E_b\left(1 - e^{-\frac{t}{RC}}\right)$

where E is the capacitance voltage at any time t and e is the base of natural logarithms. The frequency of oscillation will be approximately: $f = \frac{E_b}{RC}\left(\frac{1}{E_f - E_x}\right)$

If a synchronizing voltage is applied to the grid, the firing potential will vary in accordance with it in the manner shown. When the firing potential is reduced by the synchronizing signal, the tube will conduct before it ordinarily would under no signal conditions. Thus, if the "free running" or synchronized period of the oscillator is slightly greater than the period of the synchronizing signal, the discharge through the tube will occur sooner when the synchronizing voltage is applied than under "free running" conditions. Thus, the oscillator will be synchronized to the grid signal.

In practice, it is usual to make R continuously variable over a range of six or eight to one, and C variable in steps of about five to one by switching capacitors. This scheme assures both coarse and fine adjustment of the sweep frequency and provides for the overlapping of the adjacent ranges.

The source of the signal to which the linear time-base is to be synchronized may usually be selected by a synchronizing selector switch. Either an external, power line frequency, or Y-axis signal is usually used.

The Y-axis signal used for synchronizing should be picked off at some point in the Y-amplifier system where it will be of sufficient amplitude to provide good synchronizing. A continuous variable control for the adjustment of the amount of synchronizing voltage which reaches the gas-triode grid is desirable. Only the minimum amount of synchronizing voltage necessary to give good synchronization should ever be used, since excess synchronizing voltage at the gas-triode grid will introduce non-linearity.

The charging curve of the capacitance is, of course, exponential in nature, but by using only a small portion of the complete cycle the departure from linearity can be made small. Good design of the oscillator circuit calls for not more than 10% or 15% of the supply voltage appearing in the region between the firing and extinction potentials.

The oscillator just described has a useful range of from two to fifty thousand cycles per second. At the higher frequencies, the time required to discharge the capacitance becomes an appreciable part of the total cycle because of the de-ionization time of the gas-triode. This de-ionization time is the limiting factor in high frequency operation.

At low frequencies, the leakage of the charging capacitance will become a factor in determining the linearity of the time-base. The effect of leakage will be to prevent the voltage from rising as rapidly as it should, and the time-base will slow down during the last portion of the sweep period.

The gas-triode time-base lends itself to single sweep application without radical circuit revisions. Figure 23 shows a time-base circuit to which has been added a diode with its plate connected to a gas-triode plate, and its cathode to a source of variable potential. If the cathode of the diode is set to a voltage below that at which the gas triode will fire, conduction through the diode will take place when the plate voltage tends to rise above this value of cathode potential. Thus, the "clipping" action of the diode will allow the plate voltage of the gas triode to be adjusted to a value just below that at which the tube fires. If a positive signal is then introduced on the grid of the gas triode, the firing potential may be lowered below that value set by the diode, and the tube will conduct. When the extinction potential is reached, the tube ceases conducting and the capacitance starts to charge again through the series resistance. If the signal has been removed from the grid during this next charging interval, the voltage to which the capacitance will charge is again limited by the diode, and the tube will not fire a second time

A complete single cycle has thus occurred, consisting of a return trace and then a single linear sweep. By initiating the sweep with a signal occurring just before the beginning of the transient to be studied, and adjusting the value of the charging capacitance and resistance, the single sweep period may be made to occur during the same interval as the transient. In order to have the entire single sweep on the screen, the spot should be positioned to the edge of the screen while in the rest position. The return trace will then rapidly displace the spot across the screen, and the linear trace will occur as the spot returns to its rest position during the charging of the capacitance.

For fullest utilization of the single sweep, a photographic recording of the trace should be made. To prevent fogging of the camera film by the luminescent spot before and after the transient, a shutter can be used which opens only during the sweep period. This method is not practical for fast sweep rates. By positioning the spot just off the screen for its rest position, the fogging may be

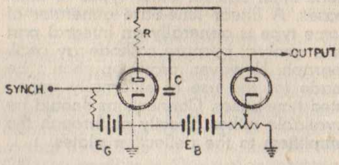


Figure 23
A basic single sweep

reduced. The most effective method is to have the beam in the "on" condition only during the sweep time, and off at all other times. By providing a positive pulse at the grid of the cathode-ray tube during the sweep period, this switching arrangement may be accomplished. Methods of obtaining such a pulse will not be discussed, as they would depend upon the particular application of the single sweep.

High Vacuum Sweep Circuits

The limitations of the gas-triode linear-time-base generator are not encountered with circuits using vacuum tubes. Several types of circuits have been developed which utilize the "trigger" characteristics of triodes or pentodes. This "triggering action" is a result of a sudden change in plate or screen current caused by only a slight change in some other circuit constant. The sudden change in current or voltage is used to charge or discharge a capacitance. The subsequent charge or discharge takes place through a resistance and the sweep voltage appears across the capacitance.

Circuits of this type will give linear time-bases as high as 1,000,000 cycles per second, and as low as 2 cycles per second. These high vacuum sweep types have disadvantages in that they are generally more complex and require more tubes and more power than gas-triode types.

Other Time-Bases

While the linear type is the most useful of all time-bases, special applications often call for other types of time-bases. A linear time-base generator of some type is generally an integral part of a general purpose cathode-ray oscillograph. However, provision should be made for the use of externally generated time-bases. Connections should be available either directly or through the amplifiers to the deflection plates.

Sinusoidal

By applying a sinusoidal voltage to the timing axis, deflection proportional to the sine function of an angular variable may be obtained. Near the center of the trace, i.e., when the voltage wave is near zero, the velocity of the spot is nearly linear. By making the total deflection large, this center portion may be used as a linear time-base. If the phase of the sinusoidal voltage is shifted through 180°, a phenomena occurring during any part of the wave period may be centered on the screen for observation.

Another time-base involving sinusoidal waves is produced by applying one of two sinusoidal potentials which are 90° out of phase to each set of deflection plates. If the amplitudes are equal and no harmonics are present, a circular trace will result. The quantity under investigation may then be applied either to the deflection plates to produce rectilinear deflection, or to the accelerating electrode to produce radial deflection, or to the modulating electrode to produce blanking.

Spiral and Radial

Combinations of linear and sinusoidal voltages may be used to generate spiral or radial time-bases by applying a circular time-base to the deflection plates and a linear voltage to the second anode.

An advantage of the circular and spiral time-base is that for a given size tube, the length and duration of the time-base of the graph plotted is greatly increased over that obtainable with the more generally used linear-time-base. The circular time-base is also suited for applications involving a phenomenon which is a function of an angular quantity such as in rotary motion studies.

The reader is hereby advised that pages 200 to 220 inclusive of this book deal with Cathode Ray Oscilloscope assembly, while pages 221 to 229 refer principally to the actual Cathode Ray circuits.

Introduction

In recent years the cathode-ray tube —providing, as it does, a two dimensional indicating device free from inertia effects and capable of plotting one quantity as a function of another—has become one of the most important instruments available for electrical observations, measurements, and indications. As used in the cathode-ray oscillograph it provides the engineer and technician with an instrument whose usefulness is immeasurable. Its use makes possible instantaneous observations of the variations of related phenomena with respect to one another, and hours, days, even weeks of painstaking point by point investigation are often eliminated. Used at first almost entirely for oscillographic work, the cathode-ray tube later became the medium for reproduction of television pictures, and even more recently it has been applied to a myriad of special indicating applications.

The cathode-ray tube is not as new a device as might be supposed from the rapid increase in its use in recent years. In fact, the first device in which an electron stream in a sealed tube was focused on a fluorescent screen to produce a movable fluorescent spot was built by Braun in 1897. The introduction of the hot cathode in 1905, the application of gas focusing (now generally abandoned), improvements in cathode design, the use of a negative grid, general improvement in the "electron gun," improvements in the fluorescent screen, and the development of suitable auxiliary circuits gradually brought the cathode-ray tube to its present usefulness as a multi-purpose device.

The Modern Cathode-ray Tube

An outline drawing of a modern high-vacuum cathode-ray tube is shown in Figure 1. A heater element (7) mounted within a cathode sleeve (8) operates to heat the oxide coating on the end of this sleeve and cause electron emission. The electric field produced by the control electrode or grid (10), and the focusing electrode (11) acts to draw the electrons emitted from the cathode into a narrow beam having a small minimum cross-section in the vicinity of the grid.

From this point the electron beam diverges until it passes through the region between the focusing electrode (11) and the accelerating electrode (13) where the electric field set up by these electrodes causes the beam to converge so that it reaches the fluorescent screen (24) in a small spot. This action is analogous to the action of optical lenses on light, and it may be said that the minimum beam cross-section in the vicinity of the grid is focused onto the screen by the electron lens formed by the field between the focusing electrode and the accelerating electrode.

The control electrode is ordinarily operated at a negative potential with respect to the cathode and the beam current (and therefore the brightness of the spot) is varied by varying this bias potential. This potential difference is in the order of 100 volts maximum. The focusing electrode usually operates at a lower voltage than the accelerating electrode, and it is by variation of this focusing electrode voltage, in the vicinity of 500 volts for 2000 volts accelerating potential, that the spot is properly focused on the screen. The entire beam forming structure is known as the "electron gun."

After leaving the gun the electron beam passes between the plates of the deflection-plate pair (16) and then between the plates of the pair (17). A potential difference applied between the plates of the pair (16) produces an electric field which deflects the electron beam in a direction perpendicular to the plane of those plates. Similarly a potential applied between the plates of pair (17) results in deflection of the beam in a direction perpendicular to the direction of deflection produced by plate pair (16). Thus it is possible to control the position of the spot on the screen by two potentials applied to the two sets of deflection plates.

It will be noted that in this cathode-ray tube, focusing and deflection of the

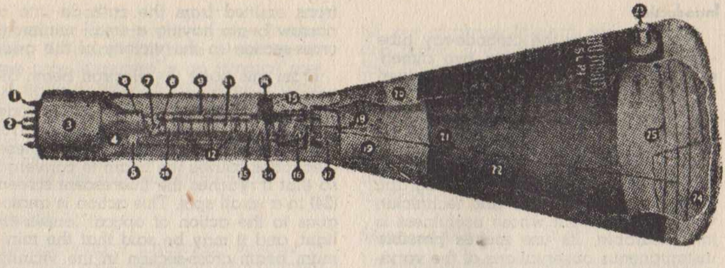


Fig. 1—A typical high-vacuum, hot-cathode, low-voltage, electron-lens focus, cathode-ray tube. The parts shown are as follows:

1—Base Pins
2—Alignment Key
3—Base Collar
4—Stem
5—Getter
6—Press
7—Heater Leads (Heater inserted inside the cathode tubing)
8—Cathode Support Collar (Cathode inserted inside the grid tubing)
9—Ceramic Supports (two supports diametrically opposed)
10—Control Electrode
11—Focusing Electrode
12—Support Collar
13—Accelerating Electrode
14—Mount Suppports
15—Mica Deflection Plate Support Rings
16—Deflection Plate Pair D_3-D_4
17—Deflection Plate Pair D_1-D_2
18—Spring Contact (Makes contact with static shield)
19—Static Shield
20—Glass Envelope
21—Electron Beam
22—Intensifier Electrode
23—Intensifier Terminal
24—Fluorescent Screen Material
25—Pattern traced by beam

beam are both accomplished by electrostatic fields. It is also possible to use electromagnetic fields for either focusing or deflection or both. However, the convenience of electrostatic focusing and deflection, and the advantages of electrostatic deflection, especially for operation over wide frequency ranges, have made it almost universal except in a few special applications.

The intensifier electrode (22), a Du Mont development, is operated at a higher voltage than the accelerating electrode. This intensifier electrode serves to further accelerate the beam subsequent to deflection. The sensitivity of the beam to electrostatic deflection varies inversely with the potential applied to the accelerating electrode, which potential, measured from cathode, determines the velocity of electrons in the deflection-plate region. However, the brilliance of the trace caused by the electron beam increases with increase in accelerating potential. A compromise must therefore be made between brilliance and deflection sensitivity. With the intensifier-type cathode-ray tube, the necessity for compromise is greatly reduced, since the beam may be deflected at a low accelerating electrode potential and then further accelerated after deflection by a higher potential applied to the intensifier electrode.

Considerations Involved in the Choice and Use of Cathode-ray Tubes

In choosing a cathode-ray tube for any particular application, points which should be considered are the type of screen to be used, the operating potentials which can be supplied conveniently or economically, the spot size and intensity required, the deflection sensitivity required, and the importance of deflection-plate or grid capacitances.

Some of these factors are interdependent, and compromises must usually be made

Screens

Standard Du Mont cathode-ray tubes are available with four types of screens, referred to as type P1, P2, P4, and P5, which satisfy the requirements of most applications. The type P1 screen produces a green trace of medium persistence and is well suited for general-purpose visual oscillographic work. It is quite efficient, and bright traces can be obtained with comparatively low accelerating voltages. The spectral distribution of the light produced is in the region of high sensitivity of the human eye, resulting in good contrast when the tube is illuminated by external daylight or incandescent lighting.

The type P2 screen produces a green trace with a long persistence characteristic and is useful for visual observations of transient signals and of very low frequency recurrent signals. With this type of screen a pattern can be observed for a period ranging from a fraction of a second to 50 or 100 seconds after it has been produced, depending upon the writing rate of the spot, the accelerating potential, and the level of the surrounding light. Because of the many factors affecting the useful persistence time, it is difficult to give quantitative data. However, it has been found empirically that, at a writing rate of 150 inches per second, a persistence time of approximately 5 seconds may be obtained from a cathode-ray tube operating at an accelerating potential of 2500 volts. It is essential that a high accelerating potential be used with long-persistence screens, and it is for this reason that tubes having a maximum overall accelerating potential rating of less than 2500 volts are not manufactured with the type P2 screen.

The type P4 screen is generally used for television applications in which a white trace is desired. It has been found that where a screen must be observed for long periods of time, this type of screen will cause less eye fatigue than the other screen types.

The type P5 short persistence blue screen is particularly suited for applications involving photographic film recording. The high actinic value of its radiation is desirable for best film exposure density and the short persistence characteristic is essential to prevent fogging of a moving film recorder and time base. Photographic recording methods are discussed in a section which follows.

Operating Potentials, Spot Size, Intensity, Deflection Sensitivity

In most applications high deflection sensitivity, high intensity, small spot size, and minimum operating potentials are desirable. Since there are several conflicting factors involved, compromise is usually necessary. In general, intensity and spot size must be considered together. With a given tube the spot size and brilliance improve with increasing accelerating voltage, but the deflection sensitivity decreases. Furthermore, high accelerating voltages are in themselves undesirable from the standpoint of economy and simplicity in equipment. The particular application will, therefore, determine the tube to be used and the conditions of its operation. Where maximum intensity and minimum spot size are most important, high accelerating voltages are indicated. Where maximum deflection sensitivity is the most important requirement, lower accelerating potentials should be used. For applications where a maximum deflection sensitivity and a maximum brilliance are required, intensifier-type cathode-ray tubes should be used, since a high final accelerating potential can be used with a minimum of effect on the deflection sensitivity. The intensifier-type cathode-ray tube also simplifies the power supply problem for a given overall accelerating potential by reducing the maximum voltage for which the power supply must be insulated from ground.

Deflection-Plate Capacitances

For applications where high frequencies must be supplied to the deflection plates, minimum deflection-plate lead lengths and capacitances are essential. For such applications, special high-frequency cathode-ray tubes are made in which the leads are brought from the deflection plates directly to terminal caps on the neck of the cathode-ray tube opposite the plates. In this way the total effective capacitance between two plates of a deflection-plate pair can be lowered to two or three micro-micro-farads.

Special Considerations Involved In Photographic Work

Photography of cathode-ray tube patterns has been mentioned briefly in connection with fluorescent screens, but there are further special considerations involved when cathode-ray tube patterns are to be photographed.

Photography of the stationary patterns produced on the cathode-ray tube screen by recurrent signals may be effected very easily since the camera shutter may be left open as long as is necessary to obtain the required negative density. In such cases the brilliance of the trace is comparatively unimportant, since the camera shutter need only be left open for a comparatively long period when the brilliance is low. With some types of signals (such as square waves) where the writing rate over various portions of the cycle changes greatly with resultant large variations in brightness over different parts of the pattern, it may become necessary to overexpose the brighter parts of the pattern in order to obtain satisfactory recording of the less intense portions.

It is in the photography of transient patterns, however, that the most careful attention must be paid to writing rates and film requirements. There are two methods applicable to photographic recording of non-recurrent transient signals; a moving film method and a stationary film method. In the moving film method the spot on the cathode-ray tube is deflected by the signal along one axis only, and the time axis is provided by the motion of the film in a direction perpendicular to the deflection of the spot. In the stationary film method, the time-base is provided by a single linear sweep of the spot by one set of deflection plates, the signal being applied to the other set. The single sweep must be initiated simultaneously with or just prior to the start of the transient to be studied. The camera shutter must be opened before the occurrence of the transient and closed after the transient has occurred.

The moving film method may put restrictions upon the allowable persistence time of the fluorescent screen, depending upon the speed of movement of the film, which in turn is determined by the signal to be recorded. It has the advantage of being capable of providing a time base of practically unlimited length, however, and in some cases simplifies the electrical arrangements. Regardless of which method is used, the writing speed of the spot will have a fundamental bearing upon the negative density produced with a given set of electrical and optical conditions; and, in fact, there will be a limit to the writing speed which can be recorded satisfactorily under such conditions.

It has been determined empirically that writing rates of 1500 inches per second can be photographed satisfactorily using a type P1 screen, an accelerating potential of 1000 volts, a lens opening of f4.5, a magnification of 0.50, and an emulsion having a Weston speed rating of approximately 24. The practicability of photographing transient traces of higher writing rates may be determined from the above data and the following facts. The writing rate can be increased in approximately inverse proportion to the square of the f rating of the lens. It can be further increased approximately in proportion to the square of the accelerating potential. Further increase can be effected by the use of faster film and by the use of the type P5 fluorescent screen. In fact, this screen is recommended for equipment which is to be used primarily for photographic purposes. Satisfactory photographic recording of writing rates of 20,000 inches per second is not at all uncommon, and rates as high as 100,000 inches per second have been recorded with excellent results.

Circuits especially devised for transient studies have been incorporated into existing commercial oscillographic equipment.

A table of films recommended for use with the various types of fluorescent screens follows:

SCREEN	TYPE P1 (medium-persistence green radiation)	TYPE P2 (long-persistence blue-green radiation)	TYPE P5 (short-persistence blue radiation)
ROLL FILM	1. Verichrome 2. Super-XX 3. Panatomic-X	1. Verichrome 2. Regular N.C. 3. Panatomic-X	1. Verichrome 2. Regular N.C. 3. Panatomic-X
PLATES	1. Eastman Super Panchro Press 2. Eastman Ortho-Press 3. Eastman 50	1. Eastman Super Panchro Press 2. Eastman Ortho-Press 3. Eastman 50	1. Eastman 40 2. Eastman Ortho-Press 3. Eastman Universal
FILM PACKS	1. Verichrome 2. Super-XX 3. Panatomic-X	1. Verichrome 2. Panatomic-X	1. Verichrome 2. Panatomic-X
35-mm. ROLL FILM	1. Super-XX Pan. 2. Plus-X 3. Panatomic-X	1. Super-XX Pan. 2. Plus-X 3. Safety Positive Film	1. Ortho Negative Film 2. Super-XX Pan. 3. Safety Positive Film

The following materials are suggested for photography of black-and-white screens:

TYPE P4

Tri-X Pan.
Super Panchro Press
Super Ortho Press
Super-XX
Ortho-X

Operating Notes

Cathode-ray tube power supplies must usually provide between 1000 and 5000 volts d.c. at from one to three miliamperes. In oscillographic applications, usual practice is to operate the accelerating electrode (second anode) at ground potential, in order that the deflection plates may be substantially at ground potential and thus facilitate their coupling to deflecting signal circuits and reduce the hazard in making connections directly to the deflection plates. When this method of operation is used, it is necessary to insulate the transformer winding supplying heater power to the cathode-ray tube for the full accelerating voltage, since the heater and cathode are operated at a negative potential with respect to ground equal to this voltage.

A voltage divider is ordinarily used to provide the required voltages for the control electrode (grid) and focusing electrode (first anode). The negative grid voltage is provided by a rheostat or potentiometer at the negative end of the voltage divider, and sufficient range should be provided to permit variation of grid bias from zero to a value at least equal to the maximum cut-off voltage for the tube at the accelerating voltage at which it is to be operated. The focusing voltage potentiometer should be capable of providing a range of voltage to the focusing electrode corresponding to the range over which the voltage required for focus is permitted to vary by the specification for the particular tube type involved.

In order to reduce defocusing of the spot to a minimum, positioning and signal voltages should be balanced whenever possible; that is, equal positive and negative voltages should be applied to the two plates of a deflection-plate pair.

The intensifier should ordinarily be operated at a potential 30% to 100% above the accelerating electrode potential. When lower values of intensifier voltage are to be used, the intensifier can be connected to a 300 or 400 volt plate supply if such a supply is readily available. If not, or if a higher intensifier potential is desired, a separate rectifier with a simple resistance-capacitance filter, operating from the same transformer winding as the accelerating voltage supply, is easily provided.

A typical power supply, with positioning circuits and deflection-plate input circuits, is shown in Figure 2. Such a supply will provide adequate voltages for operating intensifier-type cathode-ray tubes, such as the Type 5LP series. A supply for cathode-ray tubes not provided with an intensifier electrode is shown in Figure 3.

In a transformer designed for operating cathode-ray tube circuits, both the cathode-ray tube heater winding and the primary winding should be completely surrounded with grounded electrostatic shields. These shields are necessary to prevent electrostatic coupling to the heater winding which might cause intensity modulation and to prevent electrostatic coupling from the high voltage winding to the other windings. It is advisable to ground the chassis of cathode-ray equipment to prevent any possibility of the chassis attaining a high potential with respect to ground. The potentials at which cathode-ray tubes operate are dangerous, and precaution should be taken to prevent contact with them.

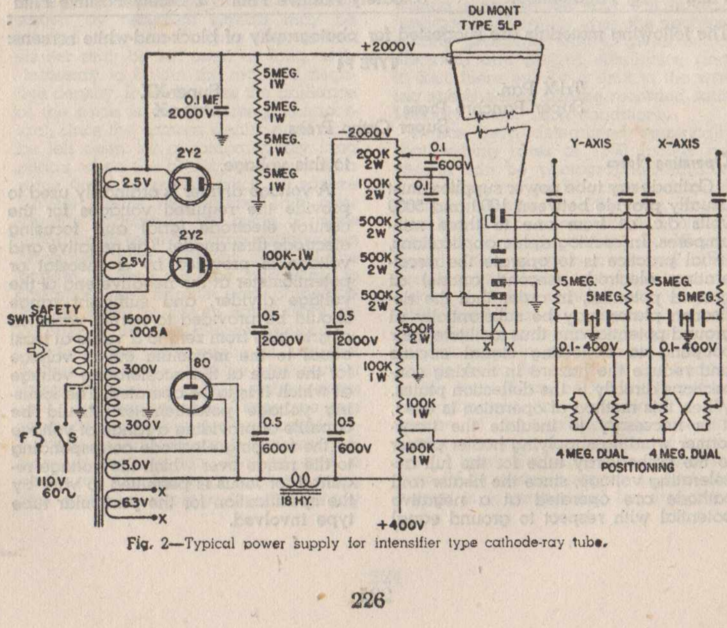


Fig. 2—Typical power supply for intensifier type cathode-ray tube.

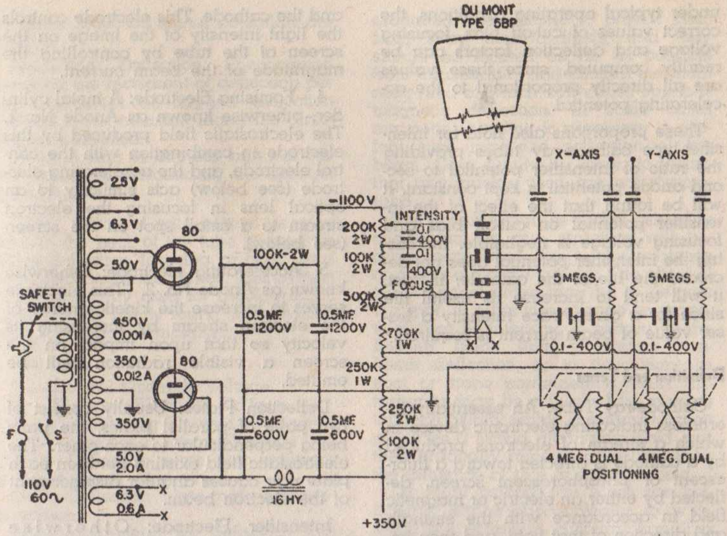


Fig. 3—Typical power supply for cathode-ray tube (no intensifier).

Discussion of Tube Characteristic Sheets

On the following pages will be found descriptions and characteristics of the various Du Mont cathode-ray tubes. These bulletins are arranged to give the essential data on each type in the manner which the industry has found most useful and complete.

Values of capacitance are average values, and are given for the modulating electrode and the deflection plate electrodes in various combinations which are deemed sufficient for design purposes. The tolerances given the various ratings under typical operation are those adopted by the Radio Manufacturers Association as standard throughout the industry. Particular notice of these tolerances should be given in designing the associated operating equipment with which the cathode-ray tube is to be used.

The units of deflection factor and deflection sensitivity have been chosen so that all types of tubes, regardless of accelerating potentials used, are referred to a common level for comparison. That level is one kilovolt. If the tube is to be operated at an accelerating potential other than one kilovolt, as it usually is, the deflection factor value should be multiplied by the value in kilovolts of the operating potential to obtain the actual operating deflection factor. The sensitivity value should be divided by the same ratio. In intensifier-type tubes this value is given for the condition of the intensifier operating at the same potential as the second anode. In addition, the effect of the intensifier is indicated by the values of deflection factor and sensitivity under typical operating conditions.

In the event that the exact accelerating potential actually used is not given under typical operating conditions, the correct values of cut-off bias, focusing voltage and deflection factors can be readily computed, since these values are all directly proportional to the accelerating potential.

These proportions also hold for intensifier-type cathode-ray tubes providing the ratio of intensifier potential to second anode potential is kept constant. It will be found that the effect of the intensifier potential on cut-off bias and focusing voltage is negligible. Increasing the intensifier potential does not decrease the life of the cathode; in fact, it will tend to increase its useful life since for a given trace intensity a lesser value of beam current is required.

Definition and Terms

Cathode-ray Tube: An essentially inertialess indicating electronic device in which a stream of electrons produced by a cathode is directed toward a fluorescent or phosphorescent screen, deflected by either an electric or magnetic field in accordance with the strength and direction of that field, and then impinged on the screen to produce a visible spot of light. The deflection may be static or dynamic.

Gun Structure: A metal assembly within the tube in which the electron stream is produced, controlled, focused, and accelerated. This assembly usually consists of:

1. Heater: A spiral coil of resistance wire which is heated by the current flow through it. The heat produced serves to raise the temperature of the cathode.

2. Cathode: A metal sleeve, surrounding the heater, the end of which is coated with a material which copiously emits electrons when heated to a high temperature.

3. Control Electrode: A metal structure adjacent to the cathode which controls the potential relationship between this electrode, sometimes called the grid, and the cathode. This electrode controls the light intensity of the image on the screen of the tube by controlling the magnitude of the beam current.

4. Focusing Electrode: A metal cylinder, otherwise known as Anode No. 1. The electrostatic field produced by this electrode in combination with the control electrode, and the accelerating electrode (see below) acts similarly to an optical lens in focusing the electron stream to a small spot on the screen (see below).

5. Accelerating electrode: Otherwise known as Anode No. 2. This electrode serves to increase the kinetic energy of the electron stream by increasing its velocity so that upon impact on the screen a visible radiation will be emitted.

Deflection Plates: Usually consist of two pairs of parallel plates, the pairs being perpendicular to each other. The electrostatic field existing between each plate pair causes angular displacement of the electron beam.

Intensifier Electrode: Otherwise known as Anode No. 3. Imparts additional kinetic energy to the electron stream after deflection. This post-acceleration results in an increase in light intensity without a large decrease in deflection sensitivity (see text).

Screen: A fluorescent-phosphorescent chemical coating on the face of the glass blank which converts kinetic energy of the electron stream into visible radiation.

Trace: The line or combination of lines produced by the rapid movement of the spot. Such effect is due to the persistence characteristic of the human eye and of the screen.

Astigmatism: Focus condition in which the spot is not round thus causing different trace widths depending upon the direction of the trace.

Symmetrical Deflection: Deflection by an electric field produced by a pair of deflection plates to which equal and opposite deflection signal potentials are applied.

Non-Linear Deflection: Phenomenon in which the increment of deflection per unit increment of applied deflection voltage is not constant along the direction of deflection.

Halo: A ring or circular band of visible radiation surrounding the spot on the screen.

Yoke: A coil of wire placed near or around the neck of the tube to produce either deflection, focusing, or both. Used with electromagnetic types. This system is not ordinarily used for oscillographic applications, but is found in television and in special equipment.

Symbols:

E_{c1}—Control Electrode Voltage

E_{b1}—Focusing Electrode Voltage

E_{b2}—Accelerating Electrode Voltage

E_{b3}—Intensifier Electrode Voltage

D_3D_4—Deflection plate pair adjacent to accelerating electrode.

D_1D_2—Deflection plate pair adjacent to screen

Volts/kv.in.—term for deflection factor with E_{b2}=1000 volts

mm. kv./d.c. volt—term for deflection sensitivity with E_{b2}=1000 volts

Installation Notes

Du Mont cathode-ray tubes may be operated in any position. It is sometimes necessary that they be inclosed in a grounded metal shield to protect them from stray electric fields, and they should be located as far as possible from transformers and chokes, the magnetic field of which can cause spurious magnetic deflection. In some cases magnetic shielding is necessary to prefent such magnetic deflection of the beam. Care should be taken to insure that any shields used are not magnetized.

It is possible that the nickel assembly composing the gun structure will become magnetized due to the existence of a strong magnetic field. The effect of such magnetization may be to defocus the spot, or otherwise change its shape, to reduce its intensity, to distort the deflecting fields thus producing non-linear deflection, or to deposition the spot or trace permanently. This disturbance may be remedied by placing the tube axially within a solenoid which produces a strong alternating field and then gradually removing the tube from the influence of that alternating field.

Du Mont cathode-ray tubes are sufficiently strong mechanically to withstand the shocks of ordinary handling and temperature changes. Especially in the case of the larger tubes, however, the glass bulb is under considerable stress from atmospheric pressure. Consequently, hard bumps and extreme temperature changes should be avoided. Care should be taken to avoid scratching the bulb since such scratches will greatly weaken the glass.

APPLICATION NOTE
Number 1

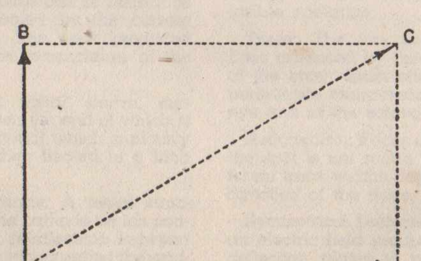
FREQUENCY AND PHASE DETERMINATIONS WITH THE CATHODE-RAY OSCILLOGRAPH

One of the simplest and most accurate methods of making frequency and phase comparisons is with the cathode-ray oscillograph or cathode-ray tube with suitable power supply. Such studies involve the observation of a pattern produced on the screen known as a "Lissajou Figure" which is produced by applying a varying voltage on each pair of deflection plates. This "Lissajou Figure" is the result of the spot of the cathode-ray tube being deflected along the X- and Y-axes simultaneously. While the deflection forces act in perpendicular directions, their vector sum produces a movement or displacement in a third direction depending on the instantaneous magnitude of each deflecting voltage.

Phase Measurements

If forces OA and OB in Figure 1 vary independently in magnitude but in a certain fixed manner which is periodic, the location of point C, which is the spot on the screen of the tube, will be caused to move in a fixed pattern.

Now, assume that two alternating voltages of identical frequency, phase, and amplitude characteristics are applied to the two pairs of deflection plates. The resultant pattern may then be determined graphically. In Figure 2 the numbers correspond to identical times on the waves of the two deflection voltages. The resultant figure is determined by projecting these points until they intersect.



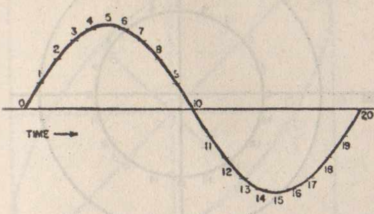


Figure 2

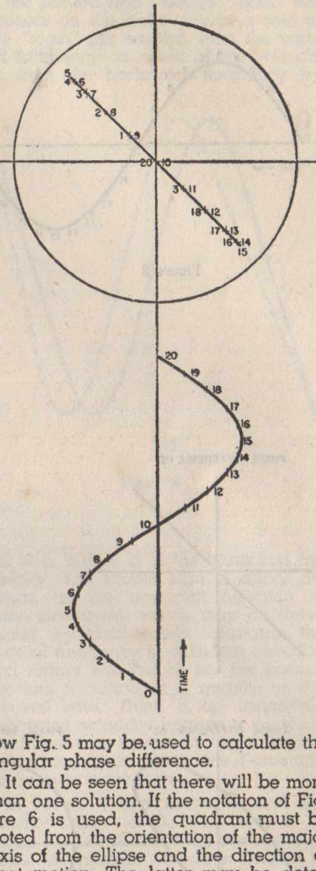
Figure 2 illustrates the case of a sinusoidal wave shape.

Now, if one of the sinusoidal deflection voltages shown in Figure 2 is applied to its deflection plate pair with a 90° phase retardation with respect to the other sinusoidal deflection voltage so that as voltage X is at its peak when voltage Y is at zero, the resultant pattern is more interesting. If the two voltages have equal amplitudes, the pattern observed will be a perfect circle; if unequal, an ellipse. This is shown in Fig. 3.

If the complete cycle is divided into 360 degrees, then in this arbitrary discussion, the peaks of the sine-wave X will occur at the 90 degree and 270 degree positions; while the peaks of the sine wave Y will correspond to the 0 degree and 180 degree positions on the time axis of voltage X. The angular difference between the two waves then is 90° with wave X leading wave Y. This relationship may be also viewed as wave Y lagging X by 270°.

This graphical construction may also be carried through for other degrees of phase differences. Typical resultant patterns are shown in Fig. 4 on the following page.

This phenomenon may be used for accurate measurements of phase differences at frequencies from a few cycles per second to several megacycles per second. In the case of sine wave shapes the formula appearing below Fig. 5 may be used to calculate the angular phase difference.



It can be seen that there will be more than one solution. If the notation of Figure 6 is used, the quadrant must be noted from the orientation of the major axis of the ellipse and the direction of spot motion. The latter may be determined by shifting the phase of one of the voltages in a known direction and observing the effect on the pattern. This formula must be used with care if the signals are applied to amplifiers preceding the deflection plate pairs of the

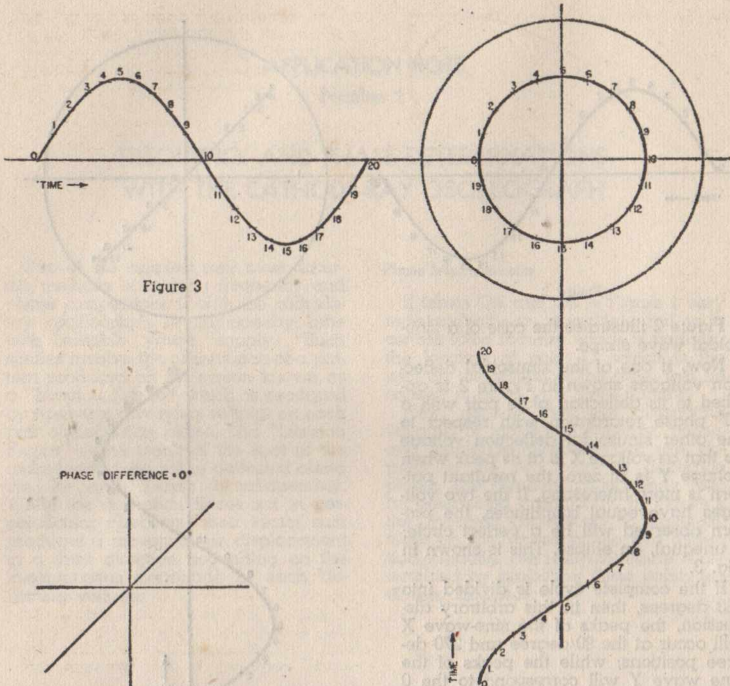


Figure 3

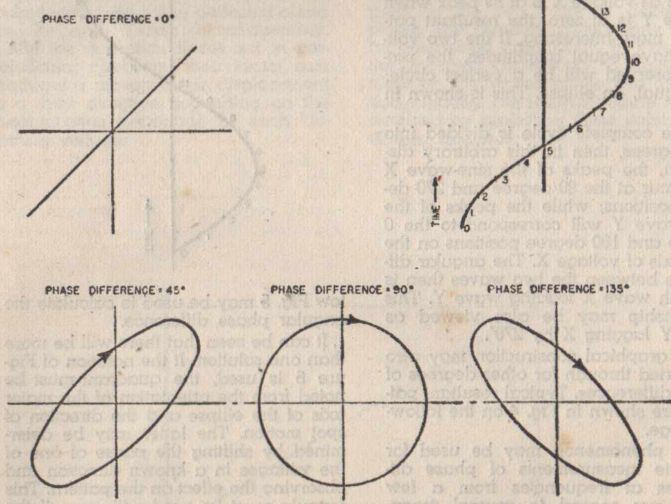


Figure 4

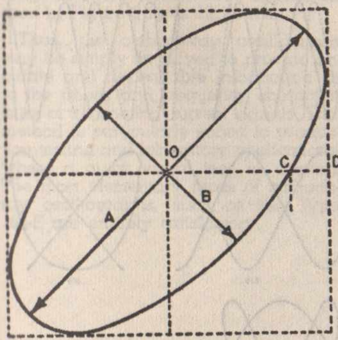


Figure 5

$\frac{OC}{OD} = \sin\beta$ or $\frac{AB}{4V_1 V_2} = \sin\beta$

where β = phase difference in angular degrees.

where V_1 = zero to peak value of horizontal voltage.

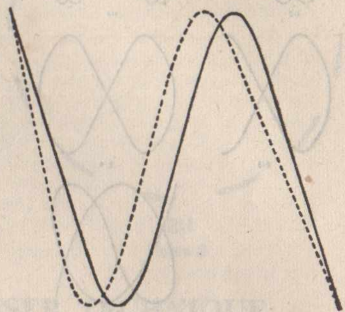
where V_2 = zero to peak value of vertical voltage.

cathrode-ray tube. In this case it is necessary that the phase distortion characteristics of the amplifiers are either identical at the frequency of the applied signals, or that any differences are properly taken into account in solving the formula above.

Frequency Determinations

If a signal is applied to the vertical plates with a frequency which is exactly an integral number of times the frequency of a similar signal applied to the horizontal plates, a stationary pattern such as that seen in Figure 6 would be observed. This pattern is for the case of the vertical frequency being three times the horizontal frequency.

If the frequency factor is not exactly an integer the pattern will appear to rotate. If the speed of rotation is such that one "tooth" appears on the left side of the pattern and another "tooth" disappears on the right side at a rate of one "tooth" per second, then the vertical frequency as noted above will differ from the horizontal frequency by



3:1

Figure 6

$3fx \pm 1$. Where fx is the horizontal frequency. The proper sign to apply depends on the apparent direction of trace movement, which may be determined by deliberately changing the vertical frequency in a known direction and noting whether or not the pattern appears to rotate at a greater or decreased rate. Then, if an accurately calibrated standard frequency source is used for X-axis deflection, any unknown signal may be applied to the Y-axis and its frequency measured.

In Figure 7 are shown typical frequency ratios for X- with respect to Y-axis frequencies. For the complex patterns, the number of points tangent to the horizontal sides of an imaginary rectangle just enclosing the pattern, compared to the number of tangent points on the vertical sides results in the ratio of the vertical frequency to the horizontal frequency.

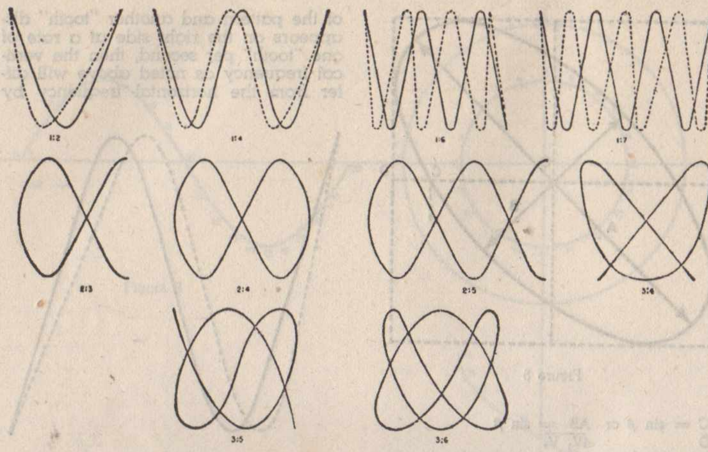
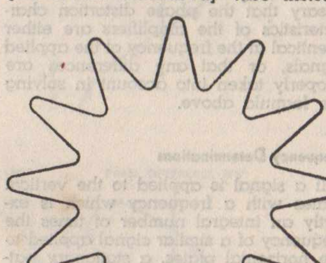


Figure 7

Another simple method of computing the vertical to horizontal frequency ratio is to count the number of peaks, along the top horizontal edge of an enclosing rectangle and divide by the maximum number of intersections in the figure along any vertical line. As the frequency ratios become more complex, the pattern will also become complex and will not lend itself to rapid visual analysis.

When the frequency ratio is large, another scheme for determining the exact frequency ratio by inspection is to use the gear-wheel pattern arrangement shown in Figure 8. This type of pattern is produced by causing the low frequency to provide a circular sweep through a phase splitting network, and then by causing the high frequency to modulate the 2nd anode of the cathode-ray tube. For the pattern shown the 12:1 ratio of the high to low frequency is determined by the number of teeth.

Another method is to modulate the grid of the cathode-ray tube instead

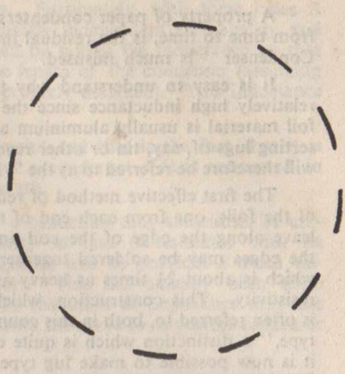


12:1

Figure 8

of the 2nd anode. With such an arrangement the pattern will appear as seen in Figure 9 for a 12:1 ratio.

Thus, the cathode-ray oscillograph may be simply employed to provide accurate and dependable information as to the phase and frequency characteristics of alternating current signals. This method is particularly suited to production testing and laboratory applications, where a quick visual test is desired. The most elementary types of cathode-ray oscillographs, such as the Type 164-E are entirely satisfactory.



12:1

Figure 9

MODERN CONDENSER TECHNIQUE

by

J. H. Cozens, B.Sc., (Hons.), A.M.I.E.E.

OF

TELEGRAPH CONDENSER CO. LTD.

The Paper Dielectric Condenser

General Description.

Little need be said about the physical form of this type of condenser, which is quite well known. The electrodes consist of metal foils (usually Aluminium but sometimes Tin or Copper) interleaved with paper and rolled into compact form. The paper is specially dried and impregnated in wax or oil. The smaller units are usually housed in tubes of cardboard, bakelised paper or sometimes metal, while the larger units are normally housed in metal boxes.

A good quality paper condenser in a hermetically sealed container will have an insulation resistance of the order of 1,000 to 10,000 megohms for a capacity of 1μF and the power factor will usually be of the order of 0.003. The most frequently met capacities range from 0.001 to 10μF but, of course, capacities up to several hundreds of microfarads are sometimes made for special purposes. Typical uses are for coupling and decoupling in A.F. amplifiers (and sometimes in R.F. circuits) and smoothing of H.T. supplies particularly where heavy ripple currents have to be carried.

Non-inductive Condensers.

A property of paper condensers which appears to cause some confusion from time to time, is the residual inductance, and the term " Non-inductive Condenser " is much misused.

It is easy to understand why the early condensers of this type had a relatively high inductance since the foils form a coil of many turns. The foil material is usually aluminium and contact is made with the foil by inserting lugs of, say, tin or other readily solderable metal. This construction will therefore be referred to as the " lug type."

The first effective method of reducing the inductance was the projection of the foils, one from each end of the roll, so that current could enter and leave along the edge of the coil and thus avoid a circular path. So that the edges may be soldered together, this usually means the use of tin foil which is about 2½ times as heavy as aluminium and has about 4 times the resistivity. This construction, which will be called " extended foil type," is often referred to, both in this country and America, as the " non-inductive type," a distinction which is quite erroneous to-day since by careful design it is now possible to make lug type condensers with inductance no greater than that of the extended foil type.

This point may be illustrated by the following measurements made at a test frequency of 50 mc.

Condenser Type	*Inductance*	*Series Resistance*
Lug type	0.020μH.	0.52 ohm.
Extended Foil type ..	0.014μH.	0.38 ohm.

This test suggests that the lug type has a slightly higher inductance, but the difference is negligible. However, further recent improvements in design have enabled even this difference to be eliminated and some cases have been known of R.F. circuits in which the lug type has given the better performance.

The constructional difference between the lug and extended foil types is indicated in Figs. 1*a* and 1*b*, which show diagrammatically portions of the unrolled condensers.

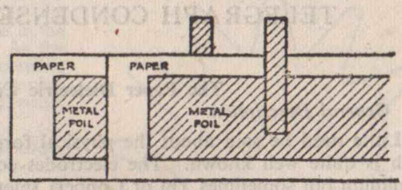


Fig. 1a.—Lug type.

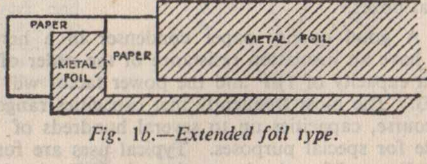


Fig. 1b.—Extended foil type.

The advantage of the extended foil type lies in its lower equivalent series resistance and greater current carrying capacity, but from the foregoing it can be seen that it has no exclusive right to the name " non-inductive." In fact, no condenser can be truly non-inductive, and it would be preferable to use the term " low-inductance condenser," for both the types described above, adding " lug type " or " extended foil type " where necessary, to distinguish between them.

In circuit design, the only paper condensers whose inductance is likely to be of importance, are the tubulars. Fortunately, with these types it is found that the inductance is very nearly independent of capacity and a useful approximation may be obtained by taking the inductance as that of a straight 20 S.W.G. copper wire the length of the condenser (assuming of course that the condenser has been properly designed). This inductance should lie between 0.02 and 0.05 μH.

This brings out a very important point and that is the fact that it is useless worrying about the inductance of a condenser if it is connected in circuit with wires several times its own length.

A knowledge of the inductance of a condenser may sometimes be usefully employed by choosing the capacity so that it resonates with its own inductance at some particular frequency and so provides a much enhanced by-pass effect at that frequency. This has actually been done in certain radio interference filters. The reduction of impedance near the resonant frequency is shown compared with the curve for a perfect condenser in Fig. 2.

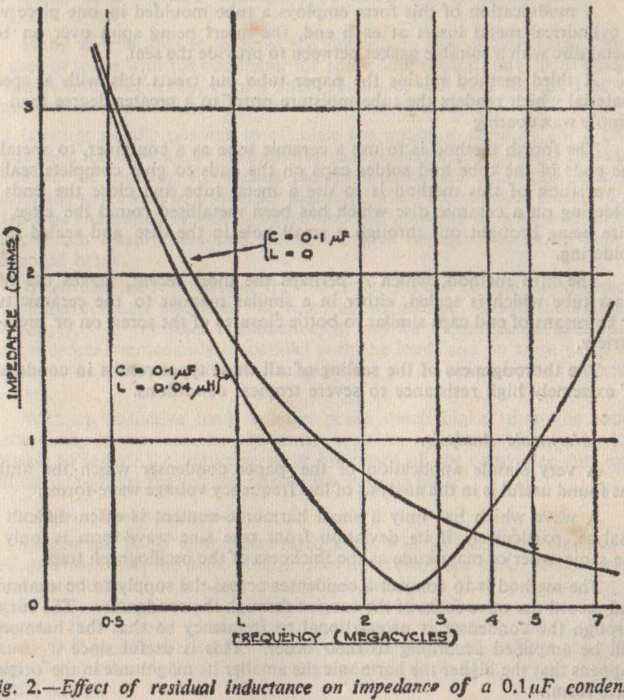


Fig. 2.—Effect of residual inductance on impedance of a 0.1μ*F condenser.*

Sealing of Tubular Condensers.

The greatest enemy of the paper condenser is moisture, and not only must this be removed as thoroughly as possible during manufacture but the finished product must be protected against the ingress of moisture during service or storage.

The hermetic sealing of the larger condensers housed in metal boxes does not present a great deal of difficulty, but the smallness of the tubular condenser complicates the problem somewhat.

The majority of the tubular condensers are contained in impregnated paper tubes and the commonest method of protecting them against moisture is to give them a good coating of suitable wax. Condensers thus treated can give very good performance under conditions of high humidity. Recently, however, there has arisen a demand for tubular condensers to withstand extremely severe tropical conditions, and new methods of sealing have consequently been developed.

One such method involves the use of a bakelite moulded tube having a moulded-in terminal at each end. The tube is made in two halves which are cemented and clamped together after insertion of the condenser unit, and connecting wires are brought out through the hollow terminal stems which are subsequently sealed by soldering.

A modification of this form employs a tube moulded in one piece with a cylindrical metal insert at each end, the insert being spun over on to a metal disc with a suitable gasket between to provide the seal.

A third method retains the paper tube but treats this with a special material which renders the tube moisture proof to a greater degree than the simple wax coating

The fourth method is to use a ceramic tube as a container, to metallise the ends of the tube and solder caps on the ends to give complete sealing. A variation of this method is to use a metal tube and close the ends by soldering on a ceramic disc which has been metallised round the edge, the wire being brought out through a small hole in the disc and sealed in by soldering.

The fifth method, which is perhaps the most recent, makes use of a glass tube which is sealed, either in a similar manner to the ceramic tube or by means of end caps similar to bottle closures of the screw on or press-on variety.

The thoroughness of the sealing of all these types results in condensers of extremely high resistance to severe tropical conditions.

Harmonic Analysis.

A very simple application of the paper condenser which the author has found useful is in the analysis of low frequency voltage wave-forms.

A wave which has only a small harmonic content is often difficult to analyse, particularly if its deviation from true sine wave-form is only of the same order of magnitude as the thickness of the oscillograph trace.

The method is to connect a condenser across the supply to be examined and record the wave-form of the current through the condenser. The current through the condenser is proportional to frequency so that the harmonics will be amplified according to their order. This is useful since it usually happens that the higher the harmonic the smaller its magnitude in the original wave-form.

The analysis is therefore carried out on the current wave-form, where the harmonics are amplified, and then the second harmonic is divided by 2, the third by 3, the fourth by 4 and so on to obtain the analysis of the original voltage wave. Fig. 3a shows the apparent absence of harmonics in a particular voltage wave, while the corresponding condenser current wave (Fig. 3b), shows the harmonics clearly.

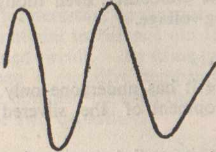


Fig. 3a.

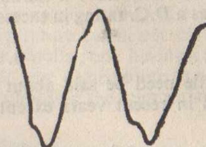


Fig. 3b.

Spark Suppression.

A use which has grown up very rapidly of late is the suppression of sparking at the contacts of D.C. switches, usually thermostatically operated. As an example of what can be done in this direction, a certain thermostat whose contacts were rated for 15 A. A.C. but only 0.1 A. D.C. could, after the fitting of a suitable condenser, be rated for 15 A. on either A.C. or D.C.

Many people appear to have the impression that a resistance should be used in series with the condenser for spark suppression, but this is seldom advisable and, frequently, even a small resistance will ruin the effect of the condenser when currents of 1 A. or more are being handled.

It is not usually possible to calculate the optimum capacity for a given circuit, and the capacity is best found by trial and error, Generally speaking, the larger the capacity, the smaller the spark as the contacts break, but the greater the spark due to condenser discharge when the contacts close. Provided that the switch is well designed and has contacts of adequate area, a capacity can usually be found which will give negligible sparking both at make and break.

When the load is resistive the condenser should be connected directly across the contacts and need be rated at no greater voltage than that of the supply. If the load is inductive, it may be found better to connect the condenser permanently in parallel with the load, and in some cases one in each position may be the best arrangement. This point should be decided by trial.

With an inductive load, voltage peaks much higher than the supply voltage may occur and the condenser must be rated accordingly. It is possible to reduce the inductive surge by means of the condenser, but more will be said about that in the section on electrolytics.

Paper Condensers used on A.C.

In general, paper condensers rated up to 450 V. D.C. may be used on A.C. provided that the peak voltage does not exceed the D.C. voltage rating of the condenser. It does not follow, however, that a condenser of higher D.C. voltage rating is suitable for A.C. operation at equivalent peak voltage. It is a good general rule not to apply more than 300 V. R.M.S. to any D.C. condenser, whatever its voltage rating, without first consulting the makers, since A.C. rating in excess of 300 V. R.M.S. usually calls for special design.

It might appear, at first sight, unnecessary to emphasise this point, but the Author has known many instances where its incomplete understanding has led to trouble. For example, if a condenser is charged and discharged rapidly, as may occur in a time base circuit, it is often forgotten that this is equivalent to applying a steady D.C. potential with a superposed alternating potential, and if the charging voltage is high enough, the A.C. component may have a harmful effect on the condenser, even though the latter has a D.C. rating in excess of the charging voltage.

3. Mica Condensers

Little need be said about this type, since it has undergone only slight changes in recent years except for the development of the silvered mica types.

The general form of mica condenser is quite well known and consists of alternate layers of mica and metallic foil electrodes held together by some form of clamp.

The chief characteristic of this type of condenser is its low power factor, usually of the order of 0.0003 to 0.0005, which remains sensibly constant with varying frequency and renders the condenser particularly suitable for use in R.F. circuits where low loss is required.

In the silvered mica condenser the electrode takes the form of a silver film deposited by a special technique on the mica. Since this film adheres closely to the mica and excludes any possibility of air pockets or relative motion of electrode and dielectric, a high degree of stability is attained.

4. Ceramic Condensers

General.

In this type of condenser a ceramic body, having in the simplest case the form of a disc, is given a metallic coating (usually silver) on the opposite parallel faces to provide the electrodes, the ceramic material forming the dielectric.

A discussion of this class of condenser becomes largely a discussion on the electrical properties of the various ceramic materials and might well form the subject of a separate paper. In this instance only the outstanding general properties which typify this class will be mentioned.

Properties and Types of Materials.

Perhaps the most interesting property of these ceramic bodies is their low power factor at radio frequencies and the fact that the power factor improves with increasing frequency, making them especially suitable for short wave working.

The ceramic materials fall into two main classes. The first class have a base of soapstone, are white in appearance, have permittivity of the order of 6 and give condensers with a positive temperature coefficient of capacity of the order of 10^{-4} per degree C. Frequentite, Frequelex and Calit are examples of this class. The second class have a base of Titanium Dioxide (Rutile) and are light brown or buff in colour. They have a phenomenal permittivity of the order of 80 and produce condensers with a negative capacity temperature coefficient, of 6 to 8×10^{-4} per degree C. Examples of this class of material are Faradex, Permalex and Condensa. Condensers made with the Rutile type of body usually have a high power factor at audio frequencies, but the improvement with increase of frequency is sufficient to make the power factor satisfactory at radio frequencies. However, recent research has shown that it is possible to make a ceramic body of high permittivity and negative capacity temperature coefficient which has a good power factor throughout the frequency range from very low audio frequencies upwards.

Compensated Temperature Coefficient.

An interesting application is the use of the negative temperature coefficient material to balance out the positive temperature coefficient of the coil in a tuned circuit. By using two condensers in parallel, one having a positive and one a negative temperature coefficient, any temperature coefficient can be obtained between the two extremes by choosing the appropriate ratio for the two capacities.

5. Electrolytic Condensers

General.

The outstanding feature of this type of condenser is the large capacity which can be obtained in a given volume, particularly when the applied voltage is low.

With a paper dielectric condenser the size for a given capacity depends upon the voltage rating, but the 200 V. condenser is usually the smallest obtainable since the dielectric of the 200 V. condenser is the thinnest paper normally available. No further reduction in size is possible therefore, even though the working voltage may be much below 200.

In the case of the electrolytic condenser the reduction in size with decreasing voltage rating can be carried right down to about 3 volts, so that for very low working voltages enormous capacities can be obtained in a small space. As an example, a condenser of capacity of 20,000μF for 3 volt working can be made in a box 3 in. $\times$4 in. $\times 2\frac{1}{2}$ in., and the construction of a condenser of capacity 1 Farad, once thought quite fantastic, now becomes quite a simple matter. It is interesting to reflect that if we consider the sun as a spherical conductor, its radius being 432,000 miles, it will have a capacity of only 0.08 Farad, and an electrolytic condenser of this capacity could be contained in a box measuring 5 in. cube.

Nature of the Dielectric.

The nature of the dielectric merits some discussion since, although it has been well treated in various publications, an appreciation of certain points is essential to a useful understanding of some of the properties of these condensers.

About the middle of the nineteenth century it was discovered that an electrolytic cell could behave as a condenser, and eventually it was observed that with certain electrode materials the capacity varied greatly with the applied voltage, while with other materials, notably aluminium, the variation of capacity with voltage was quite small. Accordingly two classes of electrolytic condenser are recognised, (*a*) the polarisation type, using, for example, platinum electrodes, and (*b*) the oxide film type with electrodes of, say, aluminium.

The differences between these two types will be referred to later. It is the oxide film type which has undergone such rapid development during the past 15 years.

If a piece of aluminium is made the anode of an electrolytic cell containing a solution of ammonium borate and the cell is connected, in series with a resistance, to a D.C. supply, a current will flow, limited initially only by the resistance. This current will gradually diminish and at the same time the voltage across the cell will rise, the rate of change of current and voltage decreasing with time so that each will gradually settle down to a steady value.

On removing the aluminium from the cell it will now be found to have a coating of aluminium oxide produced by the oxygen liberated by electrolysis, and it is this oxide which forms the dielectric of the electrolytic condenser. The oxide film is transparent, but it can usually be detected by visual inspection owing to the interference colours which it produces. Sometimes the thicker films appear to have a greyish tint. This process, which produces the oxide film on the aluminium, is known as "forming" or "anodising."

The interference colours are an indication of the extrême thinness of the film and it is interesting to attempt to estimate the film thickness by observation of these colours.

For a given anode surface area the capacity obtained is found by experiment to be inversely proportional to the voltage used in the formation process, from which it follows that the thickness of the film is proportional to the forming voltage. Now from the theory of physical optics it may be deduced that a film of transparent material will appear coloured if the thickness of the film is given by the relation.

$$t = \frac{n\lambda}{2\sqrt{\mu^2 - \sin^2\theta}} \text{ or } t = \frac{(2n+1)\lambda}{4\sqrt{\mu^2 - \sin^2\theta}}$$

according as the light does or does not suffer a reversal of phase on reflection at the inner surface, where

t = thickness of film
μ = refractive index of film
θ = the angle of incidence
λ = the wavelength of the light removed by interference
n = a small integer.

Thus, taking the shortest wavelength of visible light to be 4,000 Å, $\mu = 1.5$, which seems to be a reasonable approximation, and $\theta = 0$ i.e. normal incidence, the thinnest film which should show colours would have a thickness of 1,333 Å or 666 Å.

The thickness of the film for a given formation voltage varies somewhat with the electrolyte used and the details of the process, but for one particular process the 100 volt foil is the lowest voltage foil which shows any colours except for very large angles of incidence. With this foil formed at 100 volts, a surface area of 17.6 cm². is required to give a capacity of 1 μF whence the permittivity k of the film may be calculated from the formula $k = \frac{4\pi tC.}{A}$
If the thickness is 1,333Å, this gives $k = 8.6$ while $t = 666$Å gives $k = 4.3$. The observed value of k for pure dry aluminium oxide is about 7.8 which suggests that the first formula mentioned above for thickness is the correct one to use and the thickness of film on the 100 volt foil is approximately 1,300Å thick. Even the thickest film therefore, formed at about 600 volts will have a thickness only of the order of the wavelength of red light.

Bearing in mind the fact that the capacity of a parallel plate condenser is inversely proportional to the thickness of the dielectric between the plates, it will now be readily understood how the electrolytic condenser can have such a large capacity.

It is interesting to note that aluminium has a very great chemical affinity for oxygen and that on exposure to air, the metal rapidly grows a very thin transparent film of oxide so that it is practically impossible to obtain aluminium without at least a thin film on its surface, a fact which has sometimes been the cause of high resistance contact on an aluminium chassis. This film is generally found to have a thickness of the order of 50Å. and Professor Mott has shown by the use of quantum mechanics that this is the maximum thickness which could develop at normal temperatures without the addition of energy to the electrons of the metal. Thus it is possible to use aluminium in its normal state to form a condenser which will operate at very small potentials but of course the oxide is not in its best form and the practice is not recommended.

A further interesting point about Professor Mott's work is that he has reached the conclusion that the film builds up, not by oxygen penetrating the oxide layer and combining with aluminium at the bottom of the layer, but by the movement of metallic ions through the oxide layer to combine with oxygen at the surface,

Etched Anodes.

An important development which resulted in an even greater capacity per unit volume of condenser was the roughening of the anode to increase its surface area. If the electrodes of a paper dielectric condenser were roughened, no advantage would be gained since the thickness of the dielectric would be large compared with the undulations on the electrode surface, and further, the contour of the second electrode could not be made to follow that of the first so that, if anything, a loss of capacity would result because the mean distance between the electrodes would be increased. This is illustrated in Fig. 4 (*a*) in which the thickness of foil and paper is exaggerated for the sake of clarity.

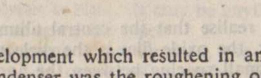


Fig. 4a.—Section of paper dielectric condenser with one electrode etched.

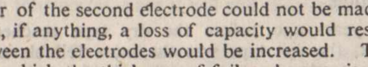


Fig. 4b.—Section of electrolytic condenser with one electrode etched.

In the case of the electrolytic condenser the dielectric is so thin that it readily follows the contour of the anode and since the true cathode is the electrolyte this also is able to conform to the irregularities of the anode surface as shown diagrammatically in Fig. 4 (*b*). In this way the capacity may be increased by as much as 10 times, though in practice the gain is usually adjusted to between 2 and 5 times.

The roughening may be performed by mechanical means, which can seldom be made to give an increase of more than 2 : 1, or by etching which can be made to give much larger increases. Generally speaking, the higher the voltage to which a foil is formed the more difficult it is to get a high gain because the thicker oxide film tends to level out the surface of the anode.

Practical Forms.

The electrolytic condenser may be classified into " wet " or " aqueous " types and " dry" types. A third class, the "semi-dry" type is sometimes referred to but this is so similar in construction to the dry type that no separate discussion is needed here.

The wet type consists generally of a rigid aluminium anode, upon which an oxide layer has been formed, rigidly mounted in a cylindrical metal container (usually aluminium) filled with electrolyte. This type is obsolescent but is briefly described here as a step in the understanding of the electrolytic condenser.

It is important to realise that the central aluminium electrode is the anode of the condenser, the oxide film is the dielectric and the solution is the cathode, the very small spacing between the anode and cathode being responsible for the large capacity obtained. The metallic container is frequently referred to as the cathode and this is convenient but not strictly correct since it is really only a means of making contact with the true cathode i.e. the solution.

A few years ago, before the dry type reached its present stage of development, the wet type was the more reliable and was recommended in preference to the dry, but now that the dry type can be made as reliable as the wet the latter is falling into disuse. This is not surprising since, while the wet type must be mounted upright in operation, the dry type can be mounted in any position and further has better electrical characteristics.

The general form of the dry electrolytic unit is very similar to that of a paper dielectric condenser. Two aluminium foils, one with an oxide film and one without, are interleaved with paper or other suitable material and rolled up into a compact cylindrical form. The paper or other separator is saturated with electrolyte the consistency of which may be anything from that of a viscous liquid to a hard fudge-like cream, depending on the technique of the manufacturer. This electrolyte usually contains ammonia in combination with boric acid and some form of polyhydric alcohol such as glycerol or ethylene glycol.

The oxide film is put on to the positive foil by passing it continuously through an electrolytic bath of which it forms the positive pole. The bath itself usually forms the negative pole and the applied voltage is rather more (say 20%) than the voltage at which the condenser will be rated. The other foil, usually called the negative foil, is untreated and serves to make intimate contact with the electrolyte and so minimise the effective series resistance of the condenser.

One end of each foil is folded back to form a lug projecting at right angles to the length of the foil and these lugs provide means of making connection from the condenser unit to the terminals.

The finished unit must be assembled in a container and hermetically sealed because the electrolyte is usually hygroscopic and increase of moisture content would be detrimental. The container is preferably of aluminium but may be of inert non-metallic material such as bakelite. Sometimes tin plate is used for the container but then the unit is usually wrapped in some way to prevent the electrolyte making contact with the case.

Properties.

The principal properties of the electrolytic condenser are as follows.

(*a*) *Capacity.* This is very large for a given bulk and does not vary greatly with applied voltage.

In the polarisation type of cell consisting, say, of a pair of platinum plates in dilute sulphuric acid, the dielectric appears to be a layer of gas on the electrode surface and the capacity obtained depends on the applied voltage and increases very rapidly with increasing voltage.

With the oxide film type however, this effect does not occur, the change of capacity with applied voltage being small, and usually there is a slight decrease in capacity with increasing voltage.

(*b*) *Power Factor.* Compared with other classes of condenser, the power factor of electrolytics is high. It may be anything from 2% to 30% at 50 c.p.s. depending on the type.

As a useful rough approximation, the electrolytic condenser may be considered to consist of a perfect capacity in series with a fixed resistance. Thus the power factor will be roughly proportional to frequency for low audio frequencies and will tend to unity at high frequencies. This does not necessarily mean that the condenser is useless at high frequencies, since it will still discriminate between A.C. and D.C.

(*c*) *Insulation Resistance.* This is low compared with other types and is usually between 5 and 50 megohm-microfarads. For this reason leakage current is usually specified rather than resistance. Leakage increases with, and at a slightly greater rate than, applied voltage, until the rated voltage is exceeded, after which the leakage current increases very rapidly.

(*d*) *Temperature Coefficient.* Increase of temperature brings about an increase of capacity and leakage current and a decrease in power factor. The latter property is useful in helping to prevent excessive temperature rise due to ripple currents.

The temperature coefficients of capacity and power factor are not unduly great at normal room temperatures but begin to increase rather rapidly when the temperature drops below about $-20°C$. However, new types are in the course of development which will operate satisfactorily at very much lower temperatures.

Applications.

Some of the applications of electrolytic condensers will now be discussed.

Reservoir Condensers.

Probably a greater number of electrolytic condensers have been used for smoothing the H.T. supply to radio receiver circuits than for any other purpose. The condensers used in the H.T. supply circuits are usually 4, 8, 16 or $32\mu F$. and may be considered under two headings, viz. Reservoirs and Smoothers.

The reservoir condenser performs two functions. One is to increase the mean voltage output of the rectifier and the other is to confer some measure of smoothing on the output. The voltage across the reservoir condenser is a fluctuating one and may be considered as a steady D.C. component, plus an A.C. component usually known as the ripple voltage. The fundamental frequency of this ripple voltage is equal to that of the supply for half-wave rectifiers and voltage summation circuits and twice that of the supply for current summation and bridge circuits.

Now when an alternating potential E exists across a condenser of capacity C farads, a current flows through the condenser of magnitude $E\omega C$ where ω is 2π times the frequency, and thus an appreciable alternating current flows through the reservoir condenser. In normal commercial radio circuits, this ripple current may be anything from 50 to 150 mA R.M.S., and its value should be carefully considered when choosing the reservoir condenser to ensure that it does not exceed the maker's rating.

The power factor of the condenser may be taken as that fraction of the total alternating current through the condenser which is in phase with the applied voltage and so causes the generation of heat in the condenser. For a reservoir condenser, therefore, it is desirable that the power factor should be as small as possible since in most cases the generation of heat is the factor which limits the amount of ripple which the condenser can safely carry.

The ripple current through the reservoir is approximately proportiona to the D.C. output current so that for small current outputs it may be neglected. The best procedure is of course to measure the ripple current to ensure that the rating is not exceeded, but, as a guide to a preliminary choice, the condenser will most probably be safe from the ripple aspect if the following conditions are not exceeded.

Capacity μF.	D.C. Output.			
	Plain Anode		Etched Anode	
	Half-wave	Full-wave	Half-wave	Full-wave
4	30 mA.	60 mA.	20 mA.	40 mA.
8	45 mA.	85 mA.	30 mA.	60 mA.
16	60 mA.	120 mA.	40 mA.	80 mA.
32	90 mA.	170 mA.	60 mA.	120 mA.

The column headed "Half-wave" includes the voltage doubler, which is essentially two half-wave rectifiers in series, and the "Full-wave" column refers to the usual current summation circuit and to bridge rectifiers.

It is emphasised that the above figures are not meant as hard and fast ratings, since these will naturally vary from one type to another, but are intended as a guide where ripple currents cannot readily be measured or the ripple rating of the condenser is unknown.

As a further guide, if the circuit is run for half an hour or so delivering full load and no appreciable temperature rise in the reservoir condenser can be observed, then the ripple current is not likely to be excessive.

One other point has to be observed in choosing the reservoir condenser and that is that it must be rated to withstand the maximum peak voltage which will be applied to it, and this will often be considerably more than the D.C. output. In actual fact it will be the output voltage plus the voltage drop in the smoothing choke plus the peak of the ripple voltage. The condenser may thus easily have to withstand 50. or 100 volts in excess of the output voltage.

Smoothing Condensers.

It has been stated above, that for the reservoir condenser a low power factor is required, and it is often suggested that low power factor is the chief criterion of a good condenser. This, however, is not true since low power factor may be obtained in manufacture at the expense of breakdown voltage, leakage current and condenser life. It does not follow, therefore, that of two condensers, the one with the lower power factor is the better condenser. In fact, the higher power factor condenser may be the better of the two in all respects, including smoothing efficiency as will be shown later.

In a smoothing condenser, power factor is of little importance provided that it does not exceed 30%, and even values higher than this may sometimes be used without loss of smoothing efficiency.

It is commonly assumed that in a filter circuit such as Fig. 5, the output ripple voltage is proportional to the condenser impedance. This is not strictly true, but let it be taken as true for the moment. Then the curve of Fig. 6 showing variation of impedance with power factor for a condenser of fixed capacity, will show that power factors up to 30% may be neglected and further indicates that a power factor of even 50% means an increase of only 15½% in the impedance and hence an increase of only 1·25 dB. in hum level.

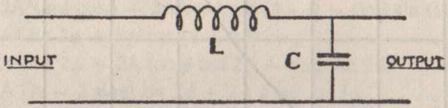


Fig. 5.—Simple smoothing circuit.

Now consider two condensers, A and B, and suppose A has capacity 8.0μF and power factor 2%, while B has capacity 8.1μF and power factor 15%. A would probably be the most popular choice for a smoothing circuit, but, in actual fact, its impedance is equal to that of B, and furthermore, as will be shown later, B will provide even better smoothing than A. Also it is possible that A would have a higher leakage and a shorter life than B. It must be remembered, too, that the manufacturer's capacity tolerance is never less than 10% (it is usually −10%+50%) and this would swamp any variation in impedance due to power factor.

It thus appears that, provided a designer has the slightest margin in hand on his smoothing capacity, he need not worry unduly about the power factor of the condenser, and it might even be suggested that he should specify a minimum value for power factor because, for maximum smoothing efficiency, there is an optimum value of condenser power factor which is not zero as is popularly supposed.

It is instructive to consider in greater detail the effect of power factor on smoothing, and the simple smoothing filter having a series choke and shunt condenser as shown in Fig. 5 is taken as a basis for this investigation.

To simplify the calculation it will be assumed that the load impedance is large compared with that of the condenser and does not appreciably affect the impedance measured between the condenser terminals.

The symbols used are as follows—

X_C = Condenser reactance — X_L = Choke reactance

Z_C = Condenser impedance — Z_L = Choke impedance

ϕ = Condenser phase angle — θ = Choke phase angle

R_C = Effective series resistance of condenser — R_L = Effective series resistance of choke

Z = Impedance of choke and condenser in series

S = Smoothing ratio = ratio of input ripple voltage to output ripple voltage.

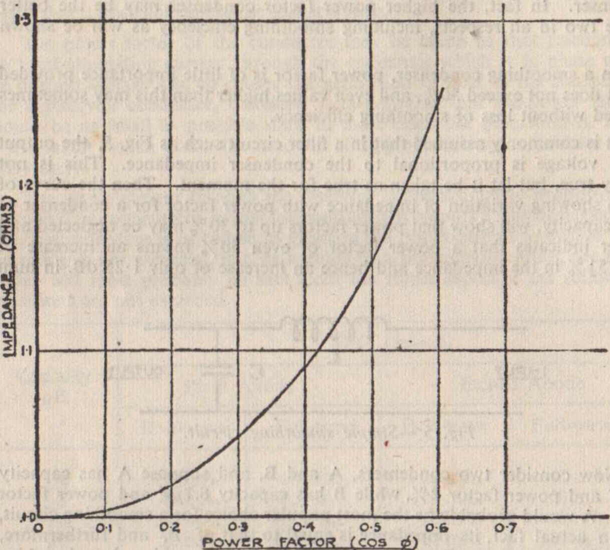


Fig. 6.—Relation between impedance and power factor for condenser of unit reactance.

From the vector diagram Fig. 7

$$Z^2 = Z_C^2 + Z_L^2 - 2Z_CZ_L \cos[\pi - (\theta + \phi)] \ldots\ldots (1)$$

$$\text{Whence } \left(\frac{Z}{Z_C}\right)^2 = 1 + \left(\frac{Z_L}{Z_C}\right)^2 + 2\left(\frac{Z_L}{Z_C}\right)\cos(\theta + \phi) \ldots\ldots (2)$$

Now suppose that the condenser has constant impedance but its power factor may vary. Then $\left(\frac{Z_L}{Z_C}\right)$ will be a constant, say k, and the smoothing ratio S which is equal to $\frac{Z}{Z_C}$ will be given by the relation.

$$S^2 = 1 + k^2 + 2k\cos(\theta + \phi)$$

which means that S will increase continuously as $(\theta + \phi)$ decreases, reaching a maximum value when $\phi = 0$ since θ is fixed and ϕ cannot be negative.

Hence of two condensers of equal impedance that with the higher power factor will give the higher smoothing ratio.

Now consider the effect of varying the power factor of a condenser of fixed capacity. In this case X_C is constant while Z_C and ϕ are varied.

From the vector diagram, $Z_C = \frac{X_C}{\sin\phi}$ and substituting this value in the R.H.S. of equation (2) gives

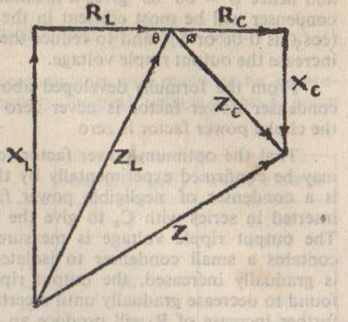


Fig. 7.—Vector diagram for circuit of Fig. 5.

$$\left(\frac{Z}{Z_C}\right)^2 = 1 + \left(\frac{Z_L}{X_C}\right)^2 \sin^2\phi + 2\left(\frac{Z_L}{X_C}\right) \sin\phi \cos(\theta + \phi)$$

$$\text{i.e. } S^2 = 1 + A^2\sin^2\phi + 2A \sin\phi \cos(\theta + \phi) \quad \ldots\ldots\ldots (3)$$

Where $A = \frac{Z_L}{X_C}$ which is a constant.

To find the condition that S may be a maximum, differentiate equation (3) thus —

$$\begin{aligned}
\frac{d(S^2)}{d\phi} &= 2A^2\sin\phi\cos\phi + 2A[\cos\phi\cos(\theta+\phi) - \sin\phi\sin(\theta+\phi)] \\
&= A^2\sin 2\phi + 2A\cos(\theta + 2\phi) \quad \ldots\ldots\ldots (4) \\
&= A^2\sin 2\phi + 2A(\cos\theta\cos 2\phi - \sin\theta\sin 2\phi) \\
&= A(A - 2\sin\theta)\sin 2\phi + 2A\cos\theta\cos 2\phi \quad \ldots\ldots\ldots (5)
\end{aligned}$$

When S is a maximum S^2 is also a maximum and $\frac{d(S^2)}{d\phi} = 0$.

i.e. $(2\sin\theta - A)\sin 2\phi = 2\cos\theta\cos 2\phi$

$$\tan 2\phi = \frac{2\cos\theta}{2\sin\theta - A} \quad \ldots\ldots\ldots (6)$$

To proceed further it is necessary to assign values to A and θ and in order to work an example A will be made 10 and $\theta = 60°$.

$$\text{Then } \tan 2\phi = \frac{2\cos 60°}{2\sin 60° - 10} = -0{\cdot}1209$$

and $\phi = -3° \, 27'$ or $86° \, 33'$

The negative angle is obviously inadmissible and the positive angle will give either a maximum or a minimum value for S. To test this, differentiate equation (4) giving

$$\begin{aligned}
\frac{d^2(S^2)}{d\phi^2} &= 2A^2\cos 2\phi - 4A\sin(\theta + 2\phi) \\
&= 2A[A\cos 2\phi - 2\sin(\theta + 2\phi)] \quad \ldots\ldots\ldots (7)
\end{aligned}$$

Substituting $\phi = 86° \, 33'$ gives

$$\begin{aligned}
\frac{d^2(S^2)}{d\phi^2} &= 20[10\cos 173° \, 6' - 2\sin 233° \, 6'] \\
&= -166{\cdot}58
\end{aligned}$$

and hence $\phi = 86° 33'$ gives a maximum value for S, which means that the condenser will be most efficient in the smoothing circuit if its power factor ($\cos\phi$) is 0·06 or 6% and to reduce the power factor below this figure would increase the output ripple voltage.

From the formulæ developed above it becomes clear that the optimum condenser power factor is never zero except in the impossible case when the choke power factor is zero

That the optimum power factor for a smoothing condenser is not zero may be confirmed experimentally by the simple circuit of Fig. 8, where C_2 is a condenser of negligible power factor and R is a variable resistance inserted in series with C_2 to give the effect of increasing its power factor. The output ripple voltage is measured on the A.C. voltmeter V which contains a small condenser to isolate it from D.C. If R, initially zero, is gradually increased, the output ripple voltage measured by V will be found to decrease gradually until a certain value of R is reached, after which further increase of R will produce an increase in the reading on V. The optimum value of R found in this way is usually rather higher than that indicated by the theory outlined above and further investigations on this point are being carried out

It is interesting to note that if the series choke of the filter circuit be replaced by a pure resistance, as it might be for a high impedance load circuit, a similar set of conditions will be found to obtain, the appropriate formulæ being derived by putting $\theta = 0$ in equations (1) to (6).

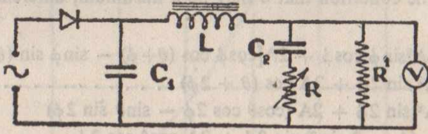


Fig. 8.—Circuit for demonstration of optimum power factor for smoothing condenser

Surge Absorbing Condensers.

The electrolytic condenser can be very usefully employed for preventing dangerous voltage rise occurring when a highly inductive circuit carrying a direct current is broken.

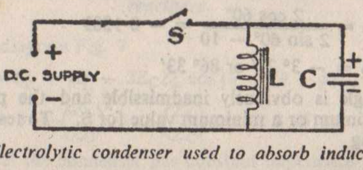


Fig. 9.—Electrolytic condenser used to absorb inductive surge.

The condenser is connected as shown in Fig. 9 and acts more as an asymmetric conductor than a condenser although the capacity does help. While a steady current flows through L, the current through C is very small but when the switch S is opened and the main current interrupted, the induced e.m.f. in L is in such a direction that a current flows through the condenser in its reverse (i.e. low resistance) direction and the energy stored in L is dissipated.

In an actual case the following measurements were made on an electromagnet energised from a 300V. D.C. supply, the peak voltage across L being measured at the instant S was opened.

Type of Condenser	Capacity (μF)	Peak Voltage
Paper	1	2,550
Paper	2	2,000
Paper	4	1,700
Paper	10	1,100
Electrolytic (reversible)	8	500
Electrolytic (polarised)	8	150

Welding Condensers.

An interesting application of electrolytic condensers is in spot welding. For this type of work a condenser of many thousands of microfarads is charged and then discharged through the primary of a specially designed welding transformer.

This method of spot welding has two great advantages over other methods. Firstly, it enables the energy used in each weld, and hence the quality of the weld, to be controlled with great accuracy and secondly, it almost completely eliminates the fluctuations of mains voltage which result from the very heavy transient currents taken by the standard type of spot welder.

The latter advantage results from the fact that the condenser welder draws its energy relatively slowly from the mains as the condenser charges up, the stored energy in the condenser being released in a relatively short time to make the welds, whereas the standard type of welder takes its short bursts of energy straight from the mains as required, resulting in the well known voltage fluctuations.

Testing.

In view of the uses to which electrolytic condensers are put, the relatively large changes which occur with change of temperature and the wide manufacturing tolerances, it is but very rarely that accurate measurements of the characteristics of these condensers are required. In fact, very precise determinations are generally confined to the manufacturers' laboratories and for this reason the few hints on testing which follow are intended, not for the condenser specialist but for the general worker who may want to make rough measurements without purchasing special apparatus.

Measurement of Capacity

The simplest method of measuring capacity is by a measurement of impedance. The condenser is connected in series with an ammeter or milliameter, according to its suspected capacity, and a small alternating voltage applied as shown in Fig. 10. The current which flows through the condenser is given by $I = E\omega C$ whence $C = \frac{I}{\omega E}$ farads. The filament winding of a mains transformer is a useful voltage source and its nominal voltage may be used for calculation purposes but it is better to connect a high impedance voltmeter across the condenser to measure the true voltage. An

Avometer may well be used for this purpose and some models have a scale already calibrated in microfarads.

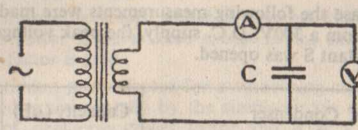


Fig. 10.—*Capacity measurement by impedance method.*

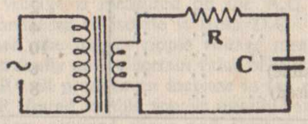


Fig. 11.—*Capacity measurement by comparison of P.D. across C and R.*

A variation of this method is to use a series resistance of known value as shown in Fig. 11 and to measure the voltages E_R and E_C across resistance and condenser respectively. Capacity is then given by $C = \frac{E_R}{\omega R E_C}$ farads.

Perhaps the best modification, if many tests are contemplated, is to use the circuit of Fig. 10 and calibrate the ammeter by means of condensers of known capacity. Some resistance in series with the meter is desirable to prevent the latter being damaged by short-circuits.

No account of power factor is taken in the above methods and this is seen to be justified for rough measurements by the discussion in 5.6.2 above.

It will be noted that no provision is made for a polarisation voltage and, despite the oft repeated advice to the contrary, no polarisation is necessary. The accuracy does not warrant it, and the condenser will certainly not be harmed by application of a small alternating voltage for the short period required to make a test.

In many instances a capacity bridge will be available, and this, too, may be used without the simultaneous application of a polarisation voltage.

With either of the above methods it is good practice to apply to the condenser a D.C. polarising voltage equal to, or a little less than, the rated voltage, just prior to the capacity test, but this is a much simpler procedure than applying the D.C. and A.C. together. The period between the removal of the condenser from the D.C. circuit and the capacity test should not be more than about 5 minutes.

Measurement of Power Factor.

A bridge method is desirable for the measurement of the power factor of an electrolytic condenser and a very satisfactory circuit is the series resistance modification of the De Sauty Bridge (see "Alternating Current Bridge Methods," B. Hague, Pitman).

Since the power factor to be measured is high, a good quality paper condenser can be used as a standard.

The test frequency should be 50 c.p.s. and the filament winding on a mains transformer is a convenient source. As in the case of the measurement of capacity, it is not necessary to apply a polarising voltage during the actual measurement, but it is desirable to do so for a few minutes immediately before making the measurement.

Measurement of Leakage Current.

For this test the condenser should be connected, in series with a resistance and milliammeter, to a D.C. source the voltage of which is approximately equal to, but not greater than, the voltage rating of the condenser. The value of the resistance should be chosen to pass a current of 100 to 200 mA. when the condenser is short circuited.

When the circuit is first completed, the current will rise momentarily almost to the short circuit value and will then decay, rapidly at first and then at a gradually decreasing rate, till it finally settles down to a steady value. A multi-range milliammeter with switch for selecting ranges is useful so that it can be set to a high range to protect it from damage due to condenser charging current and then switched to a more sensitive range as the current decays.

The leakage current will normally fall to a value corresponding to an insulation resistance of about 10 megohm-microfarads in 1 to 5 minutes, but may take longer than this if the condenser has been out of use for a very long period.

COMMONLY USED LETTERS OF THE GREEK ALPHABET

Letter	Name
α	*Alpha*
β	*Beta*
γ	*Gamma*
Δ, δ	*Delta*
θ	*Theta*
λ	*Lambda*
μ	*Mu*
π	*Pi*
ρ	*Rho*
Φ, φ	*Phi*
Ω, ω	*Omega*

CONVERSION TABLES.

To change	Into	Multiply by	To obtain converse multiply by
Cubic Centimetres	Cubic Inches	0.06102	16.39
Calories	Kilogrammetres	427.0	0.00234
Dynes	Grammes weight	0.001019	980.39
Cubic Yards	Cubic Metres	0.7646	1.308
Cubic Inches	Litres	0.0164	61.0
B.Th.U.	Watt-hours	0.2931	3.41
Atmospheres	Lb./sq. in.	14.70	0.068
B.Th.U.	Calories	0.252	3.97
B.Th.U.	Foot Pounds	777.4	0.001285
Centimetres	Inches	0.3937	2.54
Cubic Feet	Cubic Metres	0.0283	35.31
Dynes	Poundals	0.000072	13825.52
Feet	Metres	0.305	3.281
Ergs	Foot-lb.	7.373×10^{-8}	1.36×10^{7}
Foot-lb.	Kilogrammetres	0.1384	7.23
Feet/sec.	Miles/hr.	0.68182	1.467
Feet/min.	Miles/hr.	0.01137	88.0
Feet/sec.	Metres/min.	18.288	0.0547
Grains	Grammes	0.0648	15.432
Gallons	Litres	4.546	0.2205
Foot-lb./sec.	Horse-power	0.0018	55.0
Feet/min.	Metres/sec.	0.00508	196.8
Horse-power	B.Th.U./min.	42.41	0.0236
Grammes/c.c.	Lb./cu. in.	0.03613	27.68
Gallons	Cubic Feet	0.161	6.211
Grammes	Ounces	0.03527	28.35
Grammes/sq. m.	Ounces/sq. yd.	0.0295	33.9
Inches	Millimetres	25.4	0.03937
Horse-power	Kilogrammetres/sec.	76.04	0.01315
Horse-power	Watts	746.0	0.00134
Joules	Watt-seconds	1.0	1.0
Inches	Feet	0.0833	12.0
Imperial Gallons	U.S. Gallons	1.205	0.830
Kilocalories/Kilogramme	B.Th.U./lb.	1.80	0.55
Joules	Ergs	10^{7}	10^{-7}
Inches of Mercury	Lb./sq. in.	0.4902	2.04
Inches	Metres	0.0254	39.37
Inches	Yards	0.0277	36.0
Kilocalories	B.Th.U.	3968.0	0.000251
Kg./P.S.	Lb./h.p.	2.235	0.4475
K.Cal./cm.^{2}/cm./hr.C°	B.Th.U./in./hr./F°	5.598	0.180
Kilogrammes	Lb.	2.205	0.454
Metres	Yards	1.094	0.914
Kilowatt Hours	Joules	36×10^{5}	27×10^{-7}
Kilogrammes/sq. cm.	Lb./sq. in.	14.22	0.0703
Kilogrammes	Tons	0.000891	1016.2
Kilometres	Miles	0.621	1.609
Poundals	Lb. weight	0.03107	32.15
Knots	m.p.h.	1.151	0.868
Kilowatts	Horse-power	1.3406	0.746
Litres	Pints	1.76	0.568
Metres/sec.	m.p.h.	2.24	0.447
Square Metres	Square Yards	1.197	0.8361
Square Centimetres	Square Inches	0.155	6.4516
Tonnes	Tons	0.9842	1.016

LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	·0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	·0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	·0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
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14	·1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
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18	·2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	·2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	·3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	·3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	·3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	·3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	·3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	·3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	·4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
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28	·4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	·4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	·4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	·4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	·5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	·5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	·5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	·5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	·5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	·5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
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44	·6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	·6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	·6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	·6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	·6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	·6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	·6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	·7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	·7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	·7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	·7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
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56	·7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	·7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	·7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	·7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	·7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	·7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	·7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	·7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
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70	·8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	·8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	·8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	·8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	·8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	·8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	·8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	·8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	·8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	·8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	·9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	·9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	·9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	·9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	·9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	·9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	·9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	·9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	·9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	·9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	·9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	·9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	·9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	·9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	·9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	·9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	·9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	·9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	·9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	·9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2334	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

POWERS AND ROOTS

n	n^2	$\sqrt{n}$	n^3	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\sqrt{10n}$
1	1	1	1	1	2·154	4·642	3·162
2	4	1·414	8	1·260	2·714	5·848	4·472
3	9	1·732	27	1·442	3·107	6·694	5·477
4	16	2	64	1·587	3·420	7·368	6·325
5	25	2·236	125	1·710	3·684	7·937	7·071
6	36	2·449	216	1·817	3·915	8·434	7·746
7	49	2·646	343	1·913	4·121	8·879	8·367
8	64	2·828	512	2·000	4·309	9·283	8·944
9	81	3·000	729	2·080	4·481	9·655	9·487
10	100	3·162	1000	2·154	4·642	10·000	10·0
11	121	3·317	1331	2·224	4·791	10·323	10·488
12	144	3·464	1728	2·289	4·932	10·627	10·954
13	169	3·606	2197	2·351	5·066	10·914	11·402
14	196	3·742	2744	2·410	5·192	11·187	11·832
15	225	3·873	3375	2·466	5·313	11·447	12·247
16	256	4·000	4096	2·520	5·429	11·696	12·649
17	289	4·123	4913	2·571	5·540	11·935	13·038
18	324	4·243	5832	2·621	5·646	12·164	13·416
19	361	4·359	6859	2·668	5·749	12·386	13·784
20	400	4·472	8000	2·714	5·848	12·599	14·142
21	441	4·583	9261	2·759	5·944	12·806	14·491
22	484	4·690	10648	2·802	6·037	13·006	14·832
23	529	4·796	12167	2·844	6·127	13·200	15·166
24	576	4·899	13824	2·884	6·214	13·389	15·492
25	625	5·000	15625	2·924	6·300	13·572	15·811
26	676	5·099	17576	2·962	6·383	13·751	16·125
27	729	5·196	19683	3·000	6·463	13·925	16·432
28	784	5·292	21952	3·037	6·542	14·095	16·733
29	841	5·385	24389	3·072	6·619	14·260	17·029
30	900	5·477	27000	3·107	6·694	14·422	17·321
31	961	5·568	29791	3·141	6·768	14·581	17·607
32	1024	5·657	32768	3·175	6·840	14·736	17·889
33	1089	5·745	35937	3·208	6·910	14·888	18·166
34	1156	5·831	39304	3·240	6·980	15·037	18·439
35	1225	5·916	42875	3·271	7·047	15·183	18·708
36	1296	6·000	46656	3·302	7·114	15·326	18·974
37	1369	6·083	50653	3·332	7·179	15·467	19·235
38	1444	6·164	54872	3·362	7·243	15·605	19·494
39	1521	6·245	59319	3·391	7·306	15·741	19·748
40	1600	6·325	64000	3·420	7·368	15·874	20·00
41	1681	6·403	68921	3·448	7·429	16·005	20·248
42	1764	6·481	74088	3·476	7·489	16·134	20·494
43	1849	6·557	79507	3·503	7·548	16·261	20·736
44	1936	6·633	85184	3·530	7·606	16·386	20·976
45	2025	6·708	91125	3·557	7·663	16·510	21·213
46	2116	6·782	97336	3·583	7·719	16·631	21·448
47	2209	6·856	103823	3·609	7·775	16·751	21·679
48	2304	6·928	110592	3·634	7·830	16·869	21·909
49	2401	7·000	117649	3·659	7·884	16·985	22·136
50	2500	7·071	125000	3·684	7·937	17·100	22·361

POWERS AND ROOTS

n	n^2	$\sqrt{n}$	n^3	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\sqrt{10n}$
51	2601	7·141	132651	3·708	7·990	17·213	22·583
52	2704	7·211	140608	3·733	8·041	17·325	22·804
53	2809	7·280	148877	3·756	8·093	17·435	23·022
54	2916	7·348	157464	3·780	8·143	17·544	23·238
55	3025	7·416	166375	3·803	8·193	17·652	23·452
56	3136	7·483	175616	3·826	8·243	17·758	23·664
57	3249	7·550	185193	3·849	8·291	17·863	23·875
58	3364	7·616	195112	3·871	8·340	17·967	24·083
59	3481	7·681	205379	3·893	8·387	18·070	24·290
60	3600	7·746	216000	3·915	8·434	18·171	24·495
61	3721	7·810	226981	3·936	8·481	18·272	24·698
62	3844	7·874	238328	3·958	8·527	18·371	24·900
63	3969	7·937	250047	3·979	8·573	18·469	25·100
64	4096	8·000	262144	4·000	8·618	18·566	25·298
65	4225	8·062	274625	4·021	8·662	18·663	25·495
66	4356	8·124	287496	4·041	8·707	18·758	25·690
67	4489	8·185	300763	4·062	8·750	18·852	25·884
68	4624	8·246	314432	4·082	8·794	18·945	26·077
69	4761	8·307	328509	4·102	8·837	19·038	26·268
70	4900	8·367	343000	4·121	8·879	19·129	26·458
71	5041	8·426	357911	4·141	8·921	19·220	26·646
72	5184	8·485	373248	4·160	8·963	19·310	26·833
73	5329	8·544	389017	4·179	9·004	19·399	27·019
74	5476	8·602	405224	4·198	9·045	19·487	27·203
75	5625	8·660	421875	4·217	9·086	19·574	27·386
76	5776	8·718	438976	4·236	9·126	19·661	27·568
77	5929	8·775	456533	4·254	9·166	19·747	27·749
78	6084	8·832	474552	4·273	9·205	19·832	27·928
79	6241	8·888	493039	4·291	9·244	19·916	28·107
80	6400	8·944	512000	4·309	9·283	20·000	28·284
81	6561	9·000	531441	4·327	9·322	20·083	28·460
82	6724	9·055	551368	4·344	9·360	20·165	28·636
83	6889	9·110	571787	4·362	9·398	20·247	28·810
84	7056	9·165	592704	4·380	9·435	20·328	28·983
85	7225	9·220	614125	4·397	9·473	20·408	29·155
86	7396	9·274	636056	4·414	9·510	20·488	29·326
87	7569	9·327	658503	4·431	9·546	20·567	29·496
88	7744	9·381	681472	4·448	9·583	20·646	29·665
89	7921	9·434	704969	4·465	9·619	20·724	29·833
90	8100	9·487	729000	4·481	9·655	20·801	30·000
91	8281	9·539	753571	4·498	9·691	20·878	30·166
92	8464	9·592	778688	4·514	9·726	20·954	30·332
93	8649	9·644	804357	4·531	9·761	21·029	30·496
94	8836	9·695	830584	4·547	9·796	21·105	30·659
95	9025	9·747	857375	4·563	9·830	21·179	30·822
96	9216	9·798	884736	4·579	9·865	21·253	30·984
97	9409	9·849	912673	4·595	9·899	21·327	31·145
98	9604	9·899	941192	4·610	9·933	21·400	31·305
99	9801	9·950	970299	4·626	9·967	21·472	31·464
100	10000	10·000	1000000	4·642	10·000	21·544	31·623

MATHEMATICAL SYMBOLS

$\gg$	Is much greater than.	$\therefore$	Therefore.
$>$	Is greater than.	Δ	Increment or Decrement.
$\equiv$	Identity.	$\parallel$	Parallel to.
$\cong$	Is approximately equal to.	$-$	Negative. Minus. Subtract.
$\neq$	Does not equal.	$\times$ or $\cdot$	Multiplied by.
$\leqq$	Less than or equal to.	$+$	Positive. Plus. Add.
$\geqq$	Greater than or equal to.	$\mp$	Negative or positive. Minus or Plus.
$\ll$	Is much less than.		
$<$	Is less than.	$\pm$	Positive or Negative. Plus or Minus.
$\lvert n \rvert$	Absolute value of n.		
$\perp$	Perpendicular to.	$\div$ or $:$	Divided by.
$\angle$	Angle.	$=$ or $::$	Equals.

UNITS

A	Ampere	V	Volt
Ah	Ampere-hour	W	Watt
C	Coulomb	Wh	Watt-hour
F	Farad	Ω	Ohm
H	Henry	C/S	Cycles per Second
db	Decibel		

Examples:—

$M\Omega$ = Megohm (meg.)

kW = Kilowatt.

mA = Milliamp

μV = Microvolt

$\mu\mu F$ = Micro-Microfarad.

Mc/s = Megacycles per second.

$k\,c/s$ = Kilocycles per second.

mH = Millihenry

μF = Microfarad.

pF = Pica-farad

MULTIPLES AND SUBMULTIPLES

M Mega. $= 10^6$

k Kilo. $= 10^3$

m Milli. $= 10^{-3}$

μ Micro $= 10^{-6}$

$\mu\mu$ Micró-micro. $\}= 10^{-12}$

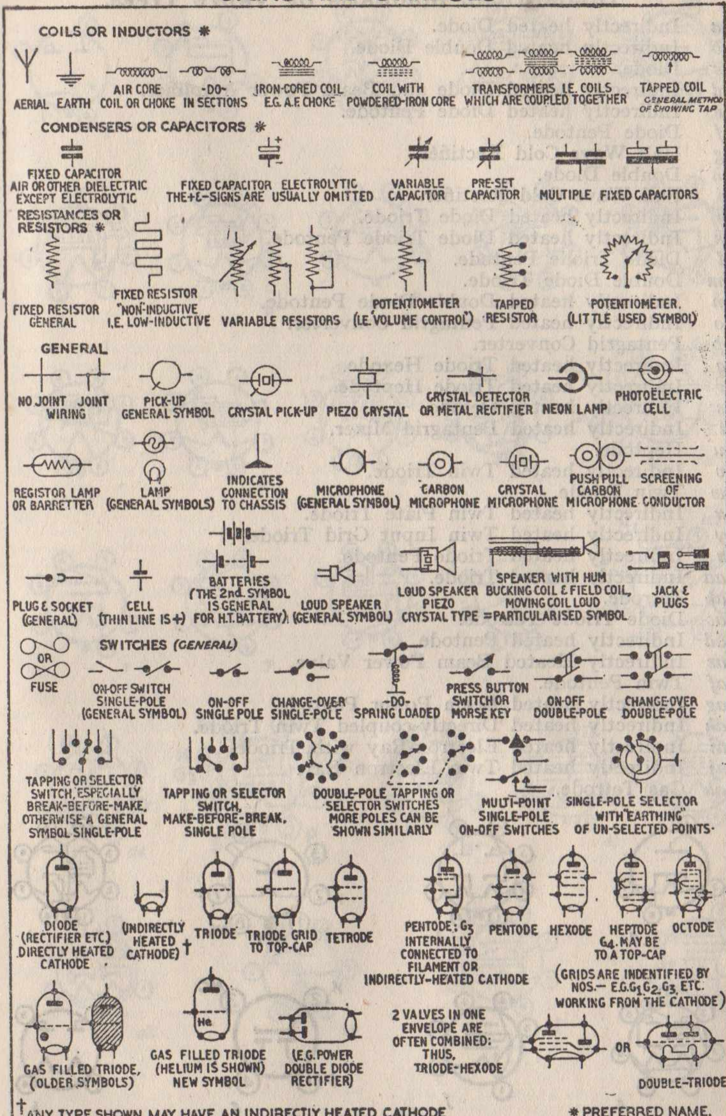
p Pica. $\}= 10^{-12}$

SYMBOLS

NORMALLY IN COMMON USE
IN RADIO AND ELECTRICAL FORMULAE

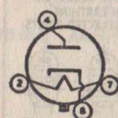
B	Magnetic Flux Density
C	Capacity.
E	Electromotive Force [E.M.F].
i	Instantaneous E.M.F.
f	Frequency.
G	Magneto-Motive-Force [M.M.F.].
$\mathcal{G}$	Conductance.
g or gm	Mutual Conductance of Valve.
H	Magnetic Field Strength.
I	Current.
i	Instantaneous Current.
K	Specific Inductive Capacity.
L	Self Inductance.
M	Mutual Inductance.
m or μ	Amplification Factor of Valve.
P	Power
Q	Quantity of Electricity.
R	Resistance.
Ra	A.C. Anode Resistance of Valve.
Rd	Dynamic Resistance of Tuned Circuit = L/CR.
S	Magnetic Reluctance.
t	Time
V	Potential Difference
W	Energy.
X	Reactance.
Z	Impedance.
λ	Wavelength.
μ	Valve Amplification Factor
μ	Magnetic Permeability
π	Ratio of Circumference to Diameter of Circle = 3·14 [approx.]
ρ	Specific Resistance
Φ	Magnetic Flux.
φ	Phase Angle.
ω	Angular Velocity

SIGNS AND SYMBOLS



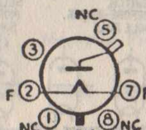
THEORETICAL DIAGRAMS OF VALVE TYPES.

a Indirectly heated Diode.
b Indirectly heated Double Diode.
c Diode.
d Indirectly heated Diode and Beam Power Amplifier.
e Indirectly heated Diode Pentode.
f Diode Pentode.
g Half Wave Cold Rectifier.
h Double Diode.
i Full Wave Cold Rectifier.
j Indirectly heated Diode Triode.
k Indirectly heated Diode Triode Pentode.
l Diode Triode Pentode.
m Double Diode Triode.
n Indirectly heated Double Diode Pentode.
o Indirectly heated Pentagrid Converter.
p Pentagrid Converter.
q Indirectly heated Triode Hexode.
r Indirectly heated Triode Heptode.
s Indirectly heated Octode.
t Indirectly heated Pentagrid Mixer.
u Heptode.
v Indirectly heated Twin Triode.
w Twin Triode.
x Indirectly heated Twin Plate Triode.
y Indirectly heated Twin Input Grid Triode.
z Indirectly heated Triode Pentode.
aa Indirectly heated Triode.
ab Tetrode.
ac Diode Triode Tetrode.
ad Indirectly heated Pentode.
ae Indirectly Heated Beam Power Valve.
af Twin Pentode.
ag Indirectly heated Beam Power Pentode.
ah Indirectly heated Directly-coupled Twin Triode.
ai Indirectly heated Electron-Ray with Triode.
aj Indirectly heated Twin Electron Ray.
ak Gas Tetrode.



a

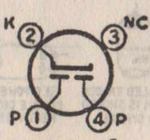
b



d

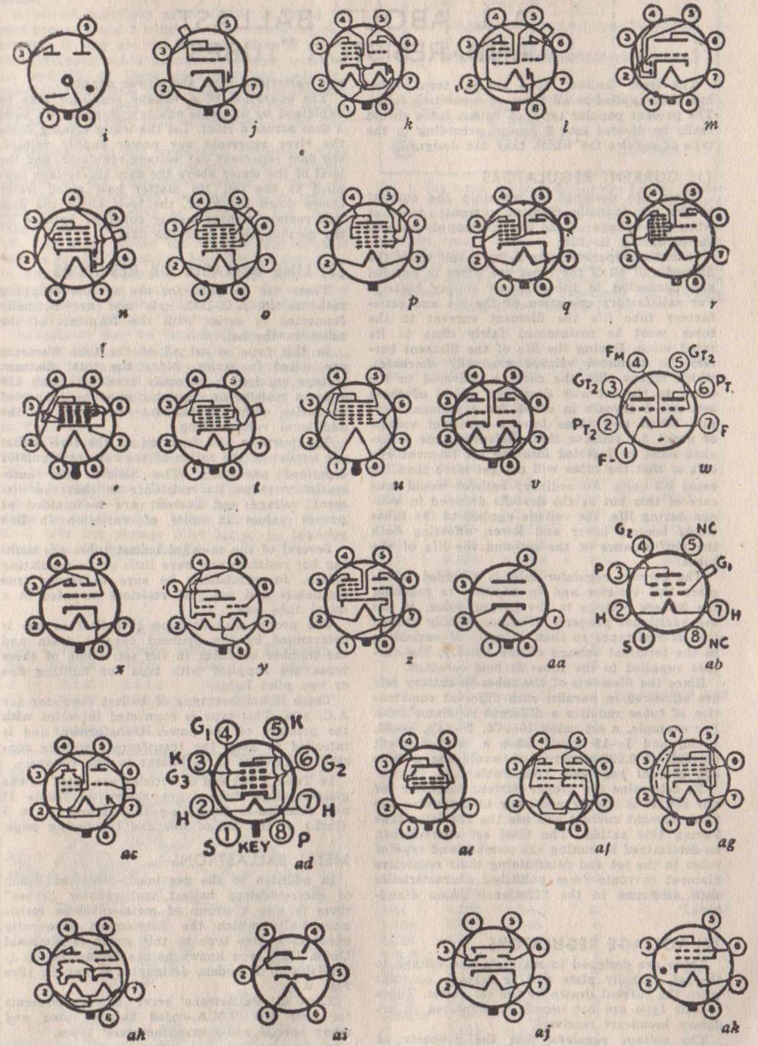
e

f



g

h


i
j
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s
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u
v
FM 4
5 GT2
GT2 3
6 PT.
PT2 2
7 F
F- 1
w
x
y
z
aa
G2 4
5 NC
G1
P 3
H 2
7 H
S 1
8 NC
ab
ac
G1 4
5 K
K
G3 3
6 G2
H 2
7 H
S 1 KEY 8 P
ad
ae
af
ag
ah
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ak

ALL ABOUT BALLAST AND RESISTOR "TUBES"

The term "ballast" is a general term which has been applied to all types of *regulating tubes.* The present popular types of ballast tubes should really be divided into 3 groups according to the type of service for which they are designed.

(1) CURRENT REGULATORS

These are designed to maintain the current to the set (usually filament current) constant when the voltage of the filament supply battery varies during its life.

In battery-operated sets using 2-volt tubes the filaments of all of the tubes are wired in parallel and connected to the filament supply battery. For satisfactory operation of the set and satisfactory tube life the filament current to the tubes must be maintained fairly close to its rated value. During the life of the filament battery its terminal voltage gradually decreases, which means that the current delivered to the tubes in the set also decreases. Many of these sets use 2 drycells in series for a filament supply. When new these have a terminal voltage of about 3.3 volts so that obviously some resistance must be inserted into the set filament circuit so that the tubes will not get more than the rated 2.0 volts. An ordinary resistor would take care of this but as the drycells dropped in voltage during life, the voltage applied to the tubes would become lower and lower, affecting both the performance of the set and the life of the tubes.

The *current regulator* tube is intended to replace this resistor and in addition to reducing the battery voltage to the proper value, it has the additional property of automatically changing its resistance so that, in spite of variations in the terminal voltage of the battery, the current supplied to the tubes is held constant.

Since the filaments of the tubes in battery sets are all wired in parallel each different combination of tubes requires a different regulator tube. For example, a set using 1—6C6, 2—34's, 1—32, 1—30, and 1—19 would have a total filament current of 0.620-ampere and would use a type 1J1 current regulator (see Table).

To determine the proper current regulator for any set, it is simply necessary to determine the total filament current and use the regulator tube having this rating. The total set current can be determined by noting the number and type of tubes in the set and determining their respective filament currents from published characteristics such as found in the "National Union Handbook."

(2) VOLTAGE REGULATORS

These are designed to maintain the voltage to the set (usually plate and/or screen) constant when the current drawn by the set varies. Tubes of this type are not usually encountered in ordinary broadcast receivers.

The *voltage regulator* has the property of automatically varying the amount of current which it draws so that the voltage across its terminals remains constant. If one of these regulators is connected as part of the voltage divider across a power supply, the voltage across the regulator will remain constant regardless of variations in current through the divider or voltage variations from the power supply.

The operation of a voltage regulator may be explained by a simple analogy. Suppose we build a dam across a river. Let the water coming down the river represent our power supply voltage, the dam represent our voltage regulator, and the level of the water above the dam the voltage supplied to the set. No matter how much water comes down the river, the level above the dam will remain approximately constant because all the surplus spills over the dam.

(3) LINE BALLASTS OR RESISTORS

These are designed for use as line dropping resistors in A.C.-D.C. sets and are normally connected in series with the filaments of the tubes in the set.

In this type of set all of the tube filaments are wired in series. Since the total filament voltage required is normally much less than 110 volts, a resistor or regulator must be connected in series with the filaments to make up the additional voltage drop.

The purpose and function of the *line ballast* are similar to the action of the current regulator described previously. The ballast tube automatically varies its resistance so that the filament voltage and current are maintained at proper values in spite of variation in line voltage.

Several of the so-called ballast tubes are nothing but resistors and have little or no regulating action. In purchasing be sure to secure true regulators and not just resistors mounted in a metal tube can.

The proper size or type of ballast to use is determined by the filament current drain and the number of tubes in the set. Some of these types are supplied with taps for lighting one or two pilot lights.

There is another type of ballast regulator for A.C. sets. This type is connected in series with the primary of the power transformer, and is intended to keep the transformer voltage constant regardless of variations in line voltage.

In Table I (at end of article) are listed all the glass-envelope tube types shown in Table II and referred-to in basing illustrations A to I (incl.) at the top of this and the facing page.

METAL BALLASTRONS

In addition to the previously-described group of glass-envelope ballast and resistor "tubes" there is also a group of metal-envelope resistance units which the Serviceman frequently encounters. One type in this group is National Union Co.'s type known as the Ballastron; it is available in 2 models, designated A and B. (See Fig. B.)

These 2 Ballastrons serve as replacements for over 100 R.M.A.-coded ballast tubes and many special radio manufacturers' types.

On the base of the Ballastron is an ingeniously-arranged metal strip (see Fig. 1A) which short-circuits 3 sections of the resistance unit inside the metal envelope. By snipping or filing this metal shunt all the way through at one or more of the 3 locations, between prongs 3 and 6, indicated by dots of colored paint, the short-circuit between any 2 prongs is thus removed and the respective resistance section cut into circuit.

A second ingenious arrangement is found in base prongs 2 and 8 which may be unscrewed and removed if they are not required. Here is where the difference exists between the type numbers (A and B) of these metal-envelope ballasts; removable terminals 2 and 8 tap onto the internal resistance unit (see Fig. 1B) to provide ballast operation of a pilot light as described in the caption of Fig. 1.

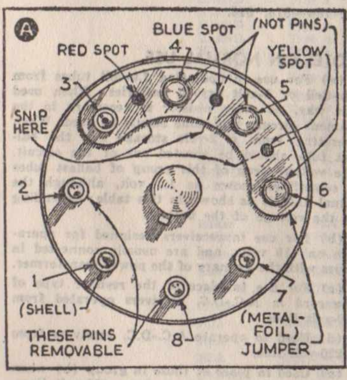
Terminal 1 is the connection ordinarily used on metal tubes to ground the shell. The resistance element of the Ballastrons, which is made by winding helical-wound resistance wire lengthwise on a mica strip as shown in Fig. B, is tapped-off to terminals 2 to 8 as shown in Fig. 1B. The drops across the various taps of this voltage divider are shown here for the first time in any radio magazine. The drop across the pilot light section of the divider is the same for either current rating (that is, for either the A or B type ballast "tube").

Ballastrons may be "matched" to the requirements of ballast resistors, carrying R.M.A.-code numbers, in accordance with the directions in the chart, Table III. Also, they may be adjusted to suit the characteristics embodied in various factory-coded units, some of which are listed in Table IV.

NOTE:—If a ballast tube has a first letter "B", disregard it (Example: Ballast tube No. BK-55-D is K-55-D on chart). If the first letter is "M," substitute "K" for it (Example: Ballast tube No. M-55-D is K-55-D on chart). To replace an I--C tube, follow directions for a K--C tube but change pilot lamps to 150 ma. (Type No. 40, brown bead.)

TABLE II

Type No.	Current Rating	Voltage Drop	+Normal Use	Exchange with
1-1	0.120	0.3-1.2	a	
1A1	0.500	0.3-1.2	a	5-1, 5E1, 6AA
1A2	(0.120			
	(0.320	0.3-1.2	a	30



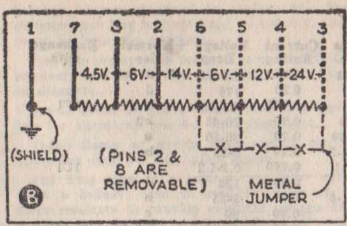


Fig. 1. The types A and B Ballastrons (metal ballast tubes) vary only in the rating of the resistance section between removable terminals 2 and 8. The type A is designed for a pilot light rated at 150 ma.; the type B is for a 250 ma. pilot light. The metal jumper may be snipped along the dotted lines that bisect the color-code dots, as shown at A, to unshort resistor sections inside the tube as shown at B (where X represents the snipping lines shown dotted in A).

Type No.	Current Rating	Voltage Drop	+Normal Use	Exchange with
1-A-5	0.1	5-25	b	
1B1	0.360	0.3-1.2	a	3H-1
1B2	(0.260			
	(0.360	0.3-1.2	a	31
1C1	0.750	0.3-1.2	a	7H-1
1C2	(0.120			
	(0.250	0.3-1.2	a	52
1D1	0.250	0.3-1.2	a	2H-1
1E1	0.480	0.3-1.2	a	
1F1	0.720	0.3-1.2	a	7-1
1G1	0.420	0.3-1.2	a	4-1
1J1	0.620	0.3-1.2	a	6-1
LH-1	0.180	0.3-1.2	a	
GM-1				
2	0.30	9.0	g	
2-A-5	0.20	5-25	b	
2H-1	0.240	0.3-1.2	a	1D1
2H-5	0.250	5-25	b	
3	0.30	128	d	
3-1	0.300	0.3-1.2	a	
3-40	0.30	45-80	c	300*, 50X3*, 5B*
3-150	0.30	30-60	e	
3-220	0.30	130-170	d	
3-A-5	0.30	5-25	b	
3H-1	0.360	0.3-1.2	a	1B1
3H-220	0.35	70-130	f	
4	0.40	115	d	
4-1	0.420	0.3-1.2	a	1G1
4-220	0.40	70-130	f	
4-A-5	0.40	5-25	b	
4H-5	0.45	5-25	b	
4H-220	0.45	70-130	f	
5	0.46	115	d	
5-1	0.500	0.3-1.2	a	1A1, 5E1, 6AA
5-16	0.500	0.3-1.2	g	
5-150	0.50	30-60	e	
5-220	0.50	70-130	f	
5-A-5	0.50	5-25	b	
5E1	0.500	0.3-1.2	a	1A1, 5-1, 6AA
5H-1	0.550	0.3-1.2	a	10AB, 1K1
5H-5	0.55	5-25	b	
5H-200	0.55	70-130	f	
6	0.695	0.3-1.2	a	
6-1	0.620	0.3-1.2	a	
6-20	0.60	20-40	h3	
6AA	0.500	0.3-1.2	a	1A1, 5-1, 5E1
6-A-5	0.60	5-25	b	
6H-1	0.660	0.3-1.2	a	

Type No.	Current Rating	Voltage Drop	+Normal Use	Exchange with
D6-1	0.060	0.3-1.2	a	
7	0.30	176	d	
7-1	0.720	0.3-1.2	a	1F1
7-20	0.70	20-40	h 3	
7-150	0.70	30-60	e	
7-A-5	0.70	5-25	b	
7H-1	0.760	0.3-1.2	a	1C1
8	0.30	132	d	
8-A-5	0.80	5-25	b	
9	0.30	90	c	
9-20	0.90	20-40	h 3	98, 100, 105, 106
9-150	0.90	30-60	e	
9-A-5	0.90	5-25	b	
9V10	0.80	5-25	b	
10-10	1.00	10-30	h 2	125
10AB	0.550	0.3-1.2	a	5H-1
10-A-5	1.00	5-25	b	
10V10	1.00	10-20	h 1	
11-10	1.10	10-30	h 2	118-415
11-20	1.10	20-40	h 3	110
11-150	1.10	30-60	e	038
11-A-5	1.10	5-25	b	
12-20	1.20	20-40	h 3	126
13-10	1.30	10-20	h 2	130
13-20	1.30	20-40	h 3	313
13-A-5	1.30	5-25	b	
14-20	1.40	20-40	h 3	314
14-A-5	1.40	5-25	b	
15-10	1.50	10-30	h 2	150
15-20	1.50	20-40	h 3	315
18-10	1.80	10-20	h 1	
20-A-5	2.00	5-25	b	
22-10	2.20	10-30	h 2	
30	(0.120			
	(0.320	0.3-1.2	a	1A2
31	(0.260			
	(0.360	0.3-1.2	a	1B2
038	1.10	38		11-150
42A1	0.30	42.3	m	
42A2	0.30	42.3	m-1	
42B2	0.30	42.3	m-2	
46A1	0.40	30-60	k	
46B1	0.30	30-60	k	
49A1	0.30	48.6	m	
49A2	0.30	48.6	m-1	
49B2	0.30	48.6	m-2	
52	(0.120			
	(0.250	0.3-1.2	a	1C2
55A1	0.30	54.9	m	
55A2	0.30	54.9	m-1	
55B2	0.30	54.9	m-2	
70	0.90	30-60	k1	
90	1.40	30-60	k1	
98	0.98	30	h 3	9-20
100	1.0	30		
105	1.05	30		9-20
106	1.06	30		9-20
110	1.10	30		11-20
118				11-10
125				10-10
126				12-20
130	1.3	20		13-10
140R	0.30	42.3	m	
140-R4	0.30	42.3	m -1	
140R8	0.30	42.3	m -2	
150	1.5	20		15-10
155				
158				
165R	0.30	48.6	m	
165R4	0.30	48.6	m -1	
165R8	0.30	48.6	m -2	
185R	0.30	54.9	m	
185R4	0.30	54.9	m -1	
185R8	0.30	54.9	m -2	
218				
313	1.3	30		13-20
314	1.4	30		14-20
315	1.5	30		15-20
415				11-10
425				
449				
460				
538	1.05	38		
838				
874	0.01-0.05	90	n	
876	0.70	40-60	h 4	
886	2.05	40-60	h	

*Line Resistor, not a tube.

+See notes following for explanation.

TABLE I

The ballast- and resistor-"tube" symbols shown at the top of pages 412 and 413 are identified with their respective tubes in Table II as follows:

[A]—1-A-5, 2-A-5, 2H-5, 3-150, 3-220, 3-A-5, 3H-220, 4-220, 4-A-5, 4H-5, 4H-220, 5-16, 5-150, 5-220, 5-A-5, 5H-5, 5H-220, 6-20, 6-A-5, 7-20, 7-150, 7-A-5, 8-A-5, 9-20, 9-150, 9-A-5, 10-10, 10-A-5, 10V10, 11-10, 11-20, 11-150, 11-A-5, 12-20, 13-10, 13-20, 13-A-5, 14-20, 14-A-5, 15-10, 15-20, 18-10, 20-A-5, 22-10.

[B]—1-1, 1A1, 1B1, 1C1, 1D1, 1E1, 1F1, 1G1, 1J1, LH-1, GM-1, 2, 2H-1, 3, 3-1, 3-40, 3H-1, 4, 4-1, 5, 5-1, 5E1, 5H-1, 6, 6-1, 6AA, 6H-1, D6-1, 7, 7-1, 7H-1, 8, 9, 10AB.

[C]—1A2, 1B2, 1C2, 30, 31, 52.

[E]—46A1, 46B1.

[F]—9V10, 70, 90.

[G]—42A1, 42A2, 42B2, 49A1, 49A2, 49B2, 55A1, 55A2, 55B2.

[H]—140R, 140R4, 140R8, 165R, 165R4, 165R8, 185R, 185R4, 185R8.

[I]—038, 98, 100, 105, 106, 110, 118, 125, 126, 130, 150, 155, 158, 218, 313, 314, 315, 415, 425, 449, 460, 538, 838.

[J]—874.

Screw—876, 886.

NOTES ON NORMAL USE

(a) For use in operating 2.0-volt tubes from Air-Cell or 3-volt drycell batteries. When used this way, no other resistor is necessary in the filament circuit, and none should be used. When operating from a 2-volt storage cell the ballast tube should be shorted out of the circuit. The voltage drop of this group of ballast tubes is sometimes shown as 1.0 volt, although the actual drop is as shown in this table; depending on the voltage of the battery.

(b) For use in receivers designed for operation on 110 volts, and are usually connected in series with the primary of the power transformer.

(c) For use in place of the resistor type of line cord in A.C.-D.C. receivers operated from 110-volt lines.

(d) Used to operate A.C.-D.C. receivers from a 220-volt line.

(e) Used in place of those in group (b) when operating 110-volt receivers from 150-volt lines.

(f) For use when **operating 110-volt receivers** from 220-volt lines.

(g) For use with sets designed to operate from 32-volt lighting plants.

(h) For use in the primary circuit of receivers designed for use with a ballast in series with the transformer primary. The primary of the transformer should be designed for the following voltages:—

h1 . . .100 volts   h3. . . . . .85 volts

h2. . . . . . .95 volts   h4. . . . . . .65 volts

(k-k1) These types are for use in Majestic receivers. Types marked (**) are manufactured by several manufacturers of tubes. The types marked k1 are designed to replace the fixed-resistor type line ballasts used as original equipment in Majestic receivers.

(m) To replace the resistor cord in A.C.-D.C. receivers and do not have tap on resistor shown in diagram.

(m-1) Same as above except that they have a tap for operating *one* 6-8 volt pilot light.

(m-2) Same as group (m) except tap for operating *two* 6-8 volt pilot lamps.

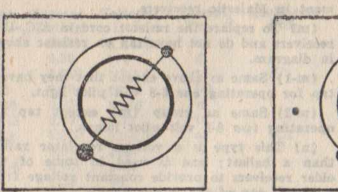
(n) This type is a voltage regulator rather than a ballast; and is used in some of the older receivers to provide constant voltage from a 90-volt tap of the power supply

Table III

R.M.A. Tube No.	Ballastron Equivalent	Cut Strip at Colors (R-Red, B-Blue, Y-Yellow)	Unscrew Pins and Clip Off Screws
85-A	Type B	R-B-Y	No. 2 and 8
79-A	Type B	R-B	No. 2 and 8
73-A	Type B	R-Y	No. 2 and 8
67-A	Type A	R-B-Y	No. 2 and 8
61-A	Type A	R-B	No. 2 and 8
55-A	Type A	R-Y	No. 2 and 8
49-A	Type A	R	No. 2 and 8
42-A	Type A	B-Y	No. 2 and 8
36-A	Type A	B	No. 2 and 8
30-A	Type A	Y	No. 2 and 8
24-A	Type A		No. 2 and 8
K-67-B	Type A	R-B-Y	No. 2
K-61-B	Type A	R-B	No. 2
K-55-B	Type A	R-Y	No. 2
K-49-B	Type A	R	No. 2
K-42-B	Type A	B-Y	No. 2
K-36-B	Type A	B	No. 2
K-30-B	Type A	Y	No. 2
K-24-B	Type A		No. 2
L-73-B	Type B	R-B-Y	No. 2
L-67-B	Type B	R-B	No. 2
L-61-B	Type B	R-Y	No. 2
L-55-B	Type B	R	No. 2
L-49-B	Type B	B-Y	No. 2
L-42-B	Type B	B	No. 2
L-36-B	Type B	Y	No. 2
L-30-B	Type B		No. 2
K-79-C	Type B	R-B-Y	No. 2
K-73-C	Type B	R-B	No. 2
K-67-C	Type B	R-Y	No. 2
K-61-C	Type B	R	No. 2
K-55-C	Type B	B-Y	No. 2
K-49-C	Type B	B	No. 2
K-42-C	Type B	Y	No. 2
K-36-C	Type B		No. 2
K-67-D	Type A	R-B-Y	None
K-61-D	Type A	R-B	None
K-55-D	Type A	R-Y	None
K-49-D	Type A	R	None
K-42-D	Type A	B-Y	None
K-36-D	Type A	B	None
K-30-D	Type A	Y	None
K-24-D	Type A		None
L-67-D	Type B	R-B-Y	None
L-61-D	Type B	R-B	None
L-55-D	Type B	R-Y	None
L-49-D	Type B	R	None
L-42-D	Type B	B-Y	None
L-36-D	Type B	B	None
L-30-D	Type B	Y	None
L-24-D	Type B		None

Table IV

Maker of Set	Part No.	Choose Tube	Remove Pins	Cut Strip
Emerson	2UR224	B	2	R-Y
Emerson	2UR215	B	2	R
Emerson	3CR241	B	NONE	R
Crosley	W43357	A	2	R
RCA	RC294 or 135K1	A	2	R
RCA	RC300 or 95K2	B	2	Y
RCA	RC345 or 190K1	A	2 & 8	R-Y
DeWald	8398	B	2	R
Fada	115.4	A	2 & 8	R



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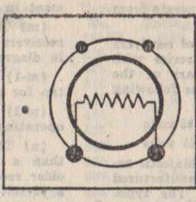

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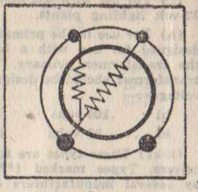

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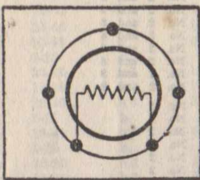

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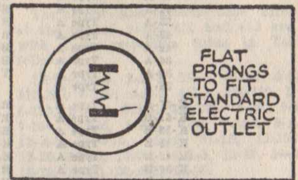
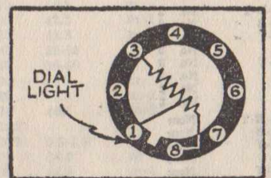

FLAT
PRONGS
TO FIT
STANDARD
ELECTRIC
OUTLET

F


DIAL
LIGHT
1
2
3
4
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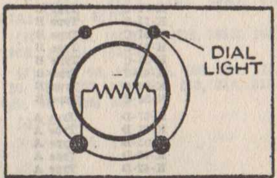
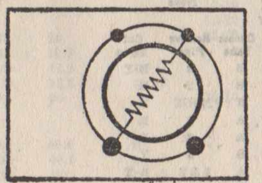
6
7
8

G


DIAL
LIGHT

H



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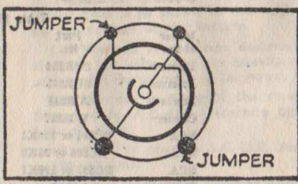

JUMPER
JUMPER

J

AMERICAN BATTERY VALVE SUBSTITUTION CHART.

COLUMN 1	COLUMN 2	CHANGES REQUIRED										
Type	Use to Replace	No Change	Fil. Volts	Fil. Current	Rewire Socket	Change Socket	Realign	Add Top Cap Connection	Remove Top Cap. Conn.	Reduce Bias	Increase Bias	Change Oper. Voltg.
		A	B	C	D	E	F	G	H	K	L	M
1A5GT/G	1A5G	A										
	1A5GT	A										
	1F4		B	C		E					L	
	1F5G		B	C							L	
	*1LA4					E						
	*1LB4					E				K		
1A7GT/G	1A7G	A										
	1A7GT	A										
	1B7G			C			F					
	1B7GT			C			F					
	1C7G		B	C			F					M
	1D7G		B	C			F					M
	1A6		B	C		E	F					M
	1C6		B	C		E	F					M
	1LA6					E	F	G				
	*1LC6					E	F	G				
1C5GT/G	1C5G	A										
	1C5GT	A										
	1G5G		B	C								M
	1G5GT		B	C								M
	1G5GT/G		B	C								M
1H5GT/G	1H5G	A										
	1H5GT	A										
	1B5/25S		B	C		E						M
	1H6G		B	C	D			G				M
	*1LH4					E		G				
1LA4	1A5G					E			H			
	1A5GT					E			H			
	*1A5GT/G					E			H			
	1F4		B	C		E			H		L	
	1F5G		B	C		E			H		L	
	*1LB4									K		
1LB4	*1LA4										L	
	1A5G					E					L	
	1A5GT					E					L	
1LB4	*1A5GT/G					E					L	
	1F4		B	C		E					L	M
	1F5G		B	C		E					L	M
	*1T5GT					E					L	
1LC6	1LA6						F					M
	1A7G					E	F		H			M
	1A7GT					E	F		H			M
	*1A7GT/G					E	F		H			M
	1B7G			C		E	F		H			M
	1B7GT			C		E	F		H			M
	1C7G		B	C		E	F		H			M
	1D7G		B	C		E	F		H			M
	1A6		B	C		E	F		H			M
	1C6		B	C		E	F		H			M
1LD5	1F6		B	C		E	F		H			M
	1F7G		B	C		E	F		H			M
1LE3	1E4G					E	F					
	1G4G					E	F			K		
	1G4GT					E	F			K		

*On list.

BY COURTESY RADIO-CRAFT PUBLISHING CO, U.S.A.

AMERICAN BATTERY VALVE SUBSTITUTION CHART.

COLUMN I	COLUMN 2	CHANGES REQUIRED										
Type	Use to Replace	No Change	Fil. Volts	Fil. Current	Rewire Socket	Change Socket	Realign	Add Top Cap Connection	Remove Top Cap. Conn.	Reduce Bias	Increase Bias	Change Oper. Voltg.
		A	B	C	D	E	F	G	H	K	L	M
	1G4GT/G					E	F			K		
	1H4G		B	C		E	F			K		M
	*30		B	C		E	F			K		M
1LH4	1H5G					E			H			
	1H5GT					E			H			
	*1H5GT/G					E			H			
	1B5/25S		B	C		E						M
	1H6G		B	C		E						M
1LN5	1LC5						F					M
	1N5G					E	F		H			
	1N5GT					E	F		H			
	*1N5GT/G					E	F		H			
	1A4P		B	C		E	F		H			M
	1A4T		B	C		E	F		H			M
	1B4P		B	C		E	F		H			M
	1D5G		B	C		E	F		H			M
	1D5GP		B	C		E	F		H			M
	1D5GT		B	C		E	F		H			M
	1E5G		B	C		E	F		H			M
	1E5GP		B	C		E	F		H			M
	1E5GT		B	C		E	F		H			M
1N5GT/G	1N5G	A					F					
	1N5GT	A					F					
	1A4P		B	C		E	F					M
	1A4T		B	C		E	F					M
	1B4P		B	C		E	F					M
	1D5G		B	C			F					M
	1D5GP		B	C			F					M
	1D5GT		B	C			F					M
	1E5G		B	C			F					M
	1E5GP		B	C			F					M
	1E5GT		B	C			F					M
	*1LN5					E	F	G				
	1LC5					E	F	G				M
1P5GT/G	1P5G	A					F					
	1P5GT	A					F					
1Q5GT/G	1Q5G	A										
	1Q5GT	A										
	3Q5G				D							
	3Q5GT				D							
	*3Q5GT/G				D							
1T5GT	1A5G		B	C								M
	1F4		B	C		E						M
	*1LB4					E				K		
3Q5GT/G	3Q5G	A										
	3Q5GT	A										
	1Q5G				D							
	1Q5GT				D							
	*1Q5GT/G				D							
30	1G4G		B	C		E				K		
	1G4GT		B	C		E				K		
	1G4GT/G		B	C		E				K		
	1H4G					E						
	1E4G		B	C		E					L	
	*1LE3		B	C		E					L	
34	32	A										

*On list.

BY COURTESY RADIO-CRAFT PUBLISHING CO, U.S.A.

CORRELATION OF AMERICAN VALVE TYPES FOR SUBSTITUTION

The data supplied by courtesy of
CLAUDE LYONS LTD., and
SYLVANIA ELECTRIC PRODUCTS INC., EMPORIUM, PENNA.

This correlation of Sylvania valve types is made available as a guide for simplifying valve substitution. In order to make the selection for substitution as large as possible two reference columns are given for each listed type—valves having " Equivalent " characteristics and tubes having " Similar " characteristics.

Equivalent Types—Valves listed as " Equivalent " are those which have electrical characteristics and circuit applications equivalent to the listed types.

Similar Types—Valves listed as " Similar " are those which have electrical characteristics and circuit applications similar to the listed types.

It is not implied that valves listed as " Equivalents " are interchangeable; however, many of them are directly interchangeable or interchangeable by a slight change in circuit constants. Such valves are marked with an asterisk (*). Types not marked with an asterisk in the " Equivalent " column may be made interchangeable by changing the base or filament rating.

The " Similar " valves are not interchangeable unless marked with an asterisk, but as the circuit applications and characteristics are similar these types can be made to function as substitutes, thus giving a wide selection of valves types from which to choose.

When making any substitution changes it will be necessary to refer to the operating characteristics and basing diagrams shown in " Bernards " Valve Manual No. 30, price 3/6, so that full benefit of the changes will be realized and no valve will be used in such a way that it will be abused.

In some cases realignment of tuned circuits may be necessary, particularly where capacitances differ. Also external shielding may be required, especially when replacing metal valves with glass types.

This chart is a war time expedient to be consulted when exact replacements are not available.

Type	Style	Service	Characteristics Equivalent To	Characteristics Similar To
0A4G	G	Rectifier	....	....
0Z4	Metal	Rectifier	0Z4G*	6X5GT/G
0Z4G	G	Rectifier	0Z4*	6X5GT/G
01A §	Glass	Amplifier	....	30
1A4P	Glass	R-F Amplifier	1A4T*	1D5GP
1A4T	Glass	R-F Amplifier	1A4P*	....
1A5G §	GT	Power Amplifier	1A5GT/G*	1C5GT,/G 1G5G
1A5GT §	GT	Power Amplifier	1A5GT/G*	1C5GT/G, 1G5G
1A5GT/G	GT	Power Amplifier	1A5G*, 1A5GT*	1C5GT/G, 1G5G
1A6	Glass	Pentagrid Converter	1D7G	1C6
1A7G §	G	Pentagrid Converter	1A7GT/G*	1C7G, 1D7G, 1A6
1A7GT §	GT	Pentagrid Converter	1A7GT/G*	1A6, 1C7G, 1D7G

Type	Style	Service	Characteristics Equivalent To	Characteristics Similar To
1A7GT/G	GT	Pentagrid Converter	1A7G*, 1A7GT*	1A6, 1C7G, 1D7G
1B4P§	Glass	R-F Amplifier	1E5GP	32
1B5/25S	Glass	Duodiode Detector	1H6G	....
1B7G§	G	Pentagrid Converter	1B7GT/G*	1C6, 1C7G
1B7GT§	GT	Pentagrid Converter	1B7GT/G*	1C6, 1C7G
1B7GT/G	GT	Pentagrid Converter	1B7G*, 1B7GT*	....
1C5G§	G	Power Output Amp.	1C5GT/G*	1A5GT/G, 1G5G
1C5GT§	GT	Power Amplifier	1C5GT/G*	1A5GT/G, 1G5G
1C5GT/G	GT	Power Amplifier	1C5G*, 1C5GT*	1A5GT/G, 1G5G
1C6	Glass	Pentagrid Converter	1C7G	1A6
1C7G	G	Pentagrid Converter	1C6	1A6, 1A7GT/G, 1D7G
1D5GP	G	R-F Amplifier	1A4P	1N5GT/G, 34
1D5GT	G	R-F Amplifier	1A4P	34
1D7G§	G	Pentagrid Converter	1A6	1A7GT/G, 1C6, 1C7G
1D8GT	GT	Diode Tri. Pent.	1LB4 and 1LH4	....
1E4G§	G	Triode	1LE3	....
1E5GP§	G	R-F Amplifier	1B4P	32
1E7G§	G	Power Output Pent.	....	(Two 1F4's)
1F4	Glass	Power Output Pent.	1F5G	33, 1G5G, 1J5G
1F5G	G	Power Output Pent.	1F4	33, 1G5G, 1J5G
1F6	Glass	Duodiode Pentode	1F7G	1B5/25S, 1H6G
1F7G	G	Duodiode Pentode	1F6	1B5/25S, 1H6G
1G4G§	G	Triode	1G4GT/G*	30, 1H4G
1G4GT§	GT	Triode	1G4GT/G*	30, 1H4G
1G4GT/G	GT	Triode	1G4G*, 1G4GT*	30, 1H4G
1G5G§	G	Power Output Pent.	....	1F4, 1F5G
1G6G§	G	Power Amplifier	1G6GT/G*	19, 1J6G
1G6GT§	GT	Power Amplifier	1G6GT/G*	19, 1J6G
1G6GT/G	GT	Power Amplifier	1G6G*, 1G6GT*	19, 1J6G
1H4G	G	Amplifier	30	....
1H5G§	G	Diode Triode Amp.	1H5GT/G*	1B5/25S
1H5GT§	GT	Diode Triode	1H5GT/G*	1B5/25S
1H5GT/G	GT	Diode Triode	1H5G*, 1H5GT*	1B5/25S
1H6G	G	Duodiode Detector	1B5/25S	1F6
1J5G§	G	Power Output Pent.	....	1F4, 1F5G, 1G5G, 33
1J6G	G	Power Output Amp.	19‡	(Two 31's)
1LA4	Lock-In	Power-Amplifier	1A5GT/G	1C5GT/G
1LA6	Lock-In	Pentagrid Converter	1A7GT/G	1A6
1LB4	Lock-In	Power Amplifier	....	1T5GT
1LC5§	Lock-In	R-F Amplifier	1LN5*	1N5GT/G
1LC6	Lock-In	Pentagrid Converter	1LA6*, 1A7GT/G	1A6
1LD5	Lock-In	Diode Pentode	....	1S5
1LE3	Lock-In	Triode	1E4G	....
1LH4	Lock-In	Diode Triode	1H5GT/G	1B5/25S
1LN5	Lock-In	R-F Amplifier	1LC5*	1N5GT/G
1N5G§	G	R-F Amplifier	1N5GT/G*	1A4P, 1D5GP

Type	Style	Service	Characteristics Equivalent To	Characteristics Similar To
1N5GT§	GT	R-F Amplifier	1N5GT/G*	1LN5, 1LC5
1N5GT/G	GT	R-F Amplifier	1N5G*, 1N5GT*	1LN5, 1LC5
1N6G§	G	Diode Pentode	....	....
1P5G§	G	R-F Amplifier	1P5GT/G*	1N5GT/G
1P5GT§	GT	R-F Amplifier	1P5GT/G*	1N5GT/G
1P5GT/G	GT	R-F Amplifier	1P5G*, 1P5GT*	1N5GT/G
1Q5G§	G	Power Amplifier	1Q5GT/G*	1C5GT/G
1Q5GT§	GT	Power Amplifier	1Q5GT/G*	1C5GT/G
1Q5GT/G	GT	Power Amplifier	1Q5G*, 1Q5GT*	1C5GT/G
1R5	Miniature	Converter	....	1A6, 1A7GT/G
1S4	Miniature	Power Amplifier	....	1Q5GT/G, 1C5GT/G
1S5	Miniature	Diode Pentode	1LD5	....
1T4	Minature	R-F Amplifier	1N5GT/G,1LN5	....
1T5GT	GT	Power Amplifier	....	1C5GT/G, 1LB4
1V	Glass	Rectifier	....	12Z3
2A3	Glass	Power Output Tri.	6A3♯, 6B4G♯	45
2A4G	G	Gas Triode	....	2051
2A5	Glass	Power Output Pent.	6F6G♯, 42♯	47
2A6	Glass	Duodiode Detector	6Q7G♯, 75♯	....
2A7, 2A7S§	Glass	Pentagrid Converter	6A7♯, 6A7S♯	....
2B7§, 2B7S§	Glass	Duodiode Pentode	6B7♯, 6B7S♯	....
2E5§	Glass	Tuning Indicator	6E5♯	....
2S/4S§	Glass	Duodiode Detector	....	....
2W3§	Glass	Rectifier	....	80
2Z2/G84§	Glass	Rectifier	....	....
3A8GT	GT	Diode Triode Pent.	1H5GT/G, and 1N5GT/G	....
3LF4	Lock-In	Power Amplifier	3Q5GT/G	....
3Q5G§	G	Power Amplifier	3Q5GT/G*	3LF4
3Q5GT§	GT	Power Amplifier	3Q5GT/G*	3LF4
3Q5GT/G	GT	Power Amplifier	3Q5G*, 3Q5GT*	3LF4
3S4	Miniature	Power Amplifier	....	3Q5GT/G
5T4§	Metal	Rectifier	5U4G*	5V4G*, 83V
5U4G	G	Rectifier	5Z3, 5X4G	5T4
5V4G	G	Rectifier	83V	5T4
5W4§	Metal	Rectifier	5W4GT/G*	5Y3GT/G*, 5Z4, 80
5W4G§	G	Rectifier	5W4GT/G*	5Y3GT/G*
5W4GT§	GT	Rectifier	5W4GT/G*	5Y3GT/G*
5W4GT/G	GT	Rectifier	5W4*, 5W4G*, 5W4GT*	5Y3GT/G*
5X4G	G	Rectifier	5Z3, 5U4G	....
5Y3G§	G	Rectifier	5Y3GT/G*	5Z4*
5Y3GT§	GT	Rectifier	5Y3GT/G*, 80, 5Y4G	5Z4*
5Y3GT/G	GT	Rectifier	5Y3G*, 5Y3GT*	5Z4*
5Y4G§	G	Rectifier	5Y3GT/G*, 80	5Z4
5Z3	Glass	Rectifier	5U4G, 5X4G	83

Type	Style	Service	Characteristics Equivalent To	Characteristics Similar To
5Z4	Metal	Rectifier	....	5Y3GT/G*, 5Y4G
6A3	Glass	Power Output Tri.	2A3♯, 6B4G	45
6A4/LA§	Glass	Power Output Pent.	....	41
6A5G§	G	Power Output Tri.	....	6A3, 6B4G*
6A6	Glass	Power Output Amp.	6N7, 6N7G, 53♯	....
6A7, 6A7S§	Glass	Pentagrid Converter	6A8†, 6A8G, 2A7♯, 2A7S♯	....
6A8	Metal	Pentagrid Converter	6A7†, 6A8G†*	6D8G
6A8G	G	Pentagrid Converter	6A7, 6A8†*	6D8G
6A8GT	GT	Pentagrid Converter	6A8*, 6A8G*	6A7
6AB5/6N5	Glass	Tuning Indicator	....	6E5
6AB7/1853	Metal	Pentode Amplifier	....	7H7, 7L7
6AC5G§	G	Power Amplifier	6AC5GT/G*	....
6AC5GT§	GT	Power Amplifier	6AC5GT/G*	....
6AC5GT/G	GT	Power Amplifier	6AC5G*, 6AC5GT*	....
6AC7/1852	Metal	Pentode Amplifier	....	7V7
6AD6G§	G	Tuning Indicator	6AF6G*	6E5
6AD7G	G	Triode Pentode	....	....
6AE5G§	G	Amplifier	6AE5GT/G*	....
6AE5GT§	GT	Amplifier	6AE5GT/G*	6J5GT/G
6AE5GT/G	GT	Amplifier	6AE5G*, 6AE5GT*	6J5GT/G
6AE6G§	G	Double Triode	....	....
6AE7GT§	GT	Twin Triode	....	....
6AF5G§	G	Amplifier	....	....
6AF6G§	G	Tuning Indicator	6AD6G*	....
6AG7	Metal	Pentode Amplifier	....	....
6B4G	G	Power Output Tri.	6A3, 2A3♯	6A5G, 45
6B5	Glass	Power Output Amp.	6N6G	42
6B7, 6B7S§	Glass	Duodiode Pentode	6B8G	6B8†
6B8	Metal	Duodiode Pentode	6B8G*	6B7
6B8G	G	Duodiode Pentode	6B8†	6B7
6C5	Metal	Triode Amplifier	6C5GT/G*	6J5GT/G, 6L5G, 6P5GT/G, 37, 76
6C5G§	G	Triode Amplifier	6C5†, 6C5GT/G*	6J5GT/G, 6L5G, 6P5GT/G, 37, 76
6C5GT§	GT	Triode Amplifier	6C5GT/G*	....
6C5GT/G	GT	Triode Amplifier	6C5*, 6C5G*, 6C5GT*	....
6C6	Glass	R-F Amplifier	6D7, 1221, 1223	6J7, 6J7G, 6W7G, 77*
6C7§	Glass	Duodiode Tri. Det.	6R7GT/G	75, 85
6C8G	G	Duotriode Amplifier	....	6F8G
6D6	Glass	R-F Amplifier	6E7, 6U7G	6K7, 6K7G, 6S7G 78*
6D7§	Glass	R-F Amplifier	6C6, 1221, 1223	6J7, 6J7G, 6W7G, 77
6D8G	G	Pentagrid Converter	....	6A7, 6A8, 6A8G
6E5	Glass	Tuning Indicator	2E5♯	6G5, 6T5, 6U5/6G5
6E6§	Glass	Power Output Amp.	....	....

Type	Style	Service	Characteristics Equivalent To	Characteristics Similar To
6E7 §	Glass	R-F Amplifier	6D6, 6U7G	6K7, 6K7G, 6S7G, 78
6F5	Metal	Triode Amplifier	6F5GT/G*	6K5GT/G
6F5G §	G	Triode Amplifier	6F5GT/G*	6K5GT/G
6F5GT §	GT	High Mu Triode	6F5GT/G*	6K5GT/G
6F5GT/G	GT	Triode Amplifier	6F5*, 6F5G*, 6F5GT*	6K5GT/G
6F6	Metal	Power Output Pent.	6F6G*	42, 2A5♯
6F6G	G	Power Output Pent.	6F6*	42, 2A5♯
6F7, 6F7S §	Glass	Triode Pent. Amp.	6P7G	....
6F8G	G	Twin Triode	6F8*, 7N7	6C8G (two 6J5GT/G's)
6G6G	G	Power Output Pent.	....	....
6H4GT	GT	Rectifier	....	....
6H6	Metal	Duodiode	6H6GT/G†*	7A6
6H6G §	G	Duodiode	6H6GT/G*	7A6
6H6GT §	GT	Double Diode	6H6GT/G*	7A6
6H6GT/G	GT	Double Diode	6H6*, 6H6G*, 6H6GT*	7A6
6J5	Metal	Triode Amplifier	6J5GT/G†*	6C5GT/G, 6L5G, 37, 76
6J5G §	G	Triode Amplifier	6J5GT/G*	6C5GT/G, 6L5G, 6P5GT/G, 37, 76
6J5GT §	GT	Triode	6C5GT/G*, 6J5GT/G*	....
6J5GT/G	GT	Triode	6J5*, 6J5G*, 6J5GT*	6C5GT/G*, 6P5GT/G
6J7	Metal	R-F Amplifier	6J7GT†*, 77†	6C6, 6W7G
6J7G	G	R-F Amplifier	6J7GT†*, 77	6C6, 6W7G
6J7GT	GT	Pentode Amplifier	6J7G*, 7C7	....
6J8G	G	Triode Hep. Con.	....	6K8
6K5G §	G	Triode Amplifier	6K5GT/G*	6F5GT/G
6K5GT §	GT	Amplifier	6K5GT/G*	6F5GT/G
6K5GT/G	GT	Amplifier	6K5G*, 6K5GT*	6F5GT/G
6K6G §	G	Power Output Pent.	6K6GT/G*, 41	6F6GT/G, 42
6K6GT §	GT	Power Amplifier	6K6GT/G*, 41	6F6GT/G, 42
6K6GT/G	GT	Power Amplifier	6K6G*, 6K6GT*	6F6GT/G, 42
6K7	Metal	R-F Amplifier	6K7G†*, 78†	6D6, 6S7G, 6U7G
6K7G	G	R-F Amplifier	6K7†*, 78	6D6, 6S7G, 6U7G
6K7GT	GT	Pentode Amplifier	6K7G*, 77, 7A7	....
6K8	Metal	Triode Hex. Con.	6K8GT, 6K8G*	6J8G
6K8G	G	Triode Hex. Con.	6K8*, 6K8GT*	....
6K8GT	GT	Triode Hex. Con.	6K8G*	....
6L5G	G	Triode Amplifier	....	6C5GT/G, 6J5GT/G, 6P5GT/G, 76
6L6	Metal	Power Output Amp.	6L6G*	....
6L6G	G	Power Output Amp.	6L6*	....
6L7	Metal	Pentagrid Mixer	6L7G†*, 1612	....
6L7G	G	Pentagrid Mixer	6L7†*, 1612	....
6N6G	G	Power Output Amp.	6B5	6F6G, 42
6N7	Metal	Power Output Amp.	6A6, 6N7G*	53♯
6N7G §	G	Power Output Amp.	6A6, 6N7*	53♯

Type	Style	Service	Characteristics Equivalent To	Characteristics Similar To
6P5G§	G	Triode Amplifier	56♯, 76, 6P5GT/G*	37, 6C5GT/G, 6J5GT/G, 6L5G
6P5GT§	GT	Triode Amplifier	76, 6P5GT/G*	37, 6C5GT/G, 6J5GT/G, 6L5G
6P5GT/G	GT	Triode Amplifier	6P5G*, 6P5GT*	37, 6C5GT/G, 6J5GT/G, 6L5G
6P7G§	G	Triode Pent. Amp.	6F7, 6F7S	....
6Q7	Metal	Duodiode Triode	6Q7G†*	6T7G, 75
6Q7G	G	Duodiode Triode	6Q7†*	6T7G, 75
6Q7GT	GT	Duodiode Triode	6Q7G*	6T7G, 75
6R7	Metal	Duodiode Triode	6R7GT/G†*	6V7G, 85
6R7G§	G	Duodiode Triode	6R7GT/G†*	6V7G, 85
6R7GT§	GT	Duodiode Triode	6R7GT/G*	6V7G, 85
6R7GT/G	GT	Duodiode Triode	6R7*, 6R7G*, 6R7GT*	6V7G, 85
6S7	Metal	Pentode Amplifier	6S7G*	....
6S7G§	G	Pentode Amplifier	6S7*	6D6, 6J7, 6K7G, 6U7G, 78
6SA7	Metal	Pentagrid Converter	6SA7GT/G*, 7Q7	....
6SA7GT§	GT	Pentagrid Converter	6SA7GT/G*, 7Q7	....
6SA7GT/G	GT	Pentagrid Converter	6SA7*, 6SA7GT*	....
6SC7	Metal	Twin Triode	7F7	....
6SD7GT	GT	Pentode Amplifier	....	7H7, 7L7
6SF5	Metal	High Mu Triode	6SF5GT*, 7B4	6F5GT/G
6SF5GT	GT	High Mu Triode	6SF5G*, 7B4	....
6SF7	Metal	Diode-Pentode	7E7	6B8G, 6B7
6SG7	Metal	R-F Pentode	7W7	....
6SH7	Metal	R-F Pentode	7W7	....
6SJ7	Metal	Pentode Amplifier	6SJ7GT*, 7C7	....
6SJ7GT	GT	Pentode Amplifier	6SJ7*, 7C7	....
6SK7	Metal	Pentode Amplifier	6SK7GT/G*, 7A7	....
6SK7GT§	GT	Pentode Amplifier	6SK7GT/G*, 7A7	....
6SK7GT/G	GT	Pentode Amplifier	6SK7*, 6SK7GT*	....
6SL7GT	GT	Duo-Triode	7F7	6SC7
6SN7GT	GT	Duo-Triode	7N7, 6F8G	Two 6J5GT/G's
6SQ7	Metal	Duodiode Triode	6SQ7GT/G*, 7B6	....
6SQ7GT§	GT	Duodiode Triode	6SQ7GT/G*, 7B6	....
6SQ7GT/G	GT	Duodiode Triode	6SQ7*, 6SQ7GT*	....
6SR7	Metal	Duodiode Triode	6R7GT/G, 7E6	....
6SS7	Metal	R-F Pentode	6SK7GT/G	7A7
6ST7	Metal	Duodiode Tri.	6SR7, 6R7GT	6SQ7GT/G
6T5§	Glass	Tuning Indicator	6U5/6G5*	6E5
6T7G§	G	Duodiode Tri. Amp.	....	6Q7, 6Q7G, 75
6U5/6G5	Glass	Tuning Indicator	6G5*, 6T5*	6E5
6U7G	G	R-F Amplifier	6D6, 6E7	6K7, 6K7G*, 6S7G
6V6	Metal	Power Output Amp.	6V6GT/G*	....
6V6G§	G	Power Output Amp.	6V6GT/G*	....

Type	Style	Service	Characteristics Equivalent To	Characteristics Similar To
6V6GT§	GT	Power Amplifier	6V6GT/G*, 7C5	....
6V6GT/G	GT	Power Amplifier	6V6*, 6V6G*, 6V6GT*	....
6V7G§	G	Duodiode Triode	55§, 85	6R7GT/G
6W7G	G	R-F Amplifier	....	6C6, 6J7, 6J7G, 77
6X5§	Metal	Rectifier	6X5GT/G*, 84	0Z4G
6X5G§	G	Rectifier	6X5GT/G*, 84	0Z4G
6X5GT§	GT	Rectifier	6X5GT/G* 84	0Z4G
6X5GT/G	GT	Rectifier	6X5*, 6X5G*, 6X5GT*	0Z4G
6Y5§	Glass	Rectifier	....	6X5GT/G, 84
6Y6G§	G	Power Output Amp.	....	....
6Y7G	G	Power Output Amp.	79	6Z7G
6Z5§	Glass	Rectifier	....	....
6ZY5G	G	Rectifier	....	....
6Z7G	G	Power Output Amp.	....	6Y7G, 79
7A4	Lock-In	Triode	6J5GT/G	....
7A5	Lock-In	Power Amplifier	....	35A5, 7B5
7A6	Lock-In	Duodiode	6H6GT/G	....
7A7	Lock-In	Pentode Amplifier	6SK7GT/G	....
7A8	Lock-In	Octode Converter	6A8GT	....
7B4	Lock-In	Triode	6F5GT/G	....
7B5	Lock In	Power Amplifier	6K6GT/G, 41	....
7B6	Lock-In	Duodiode Triode	75, 6SQ7GT/G	....
7B7	Lock-In	Pentode Amplifier	7A7*, 78	6SK7GT/G
7B8	Lock-In	Pentagrid Converter	7A8*, 6A8GT	....
7C5	Lock-In	Power Amplifier	6V6GT/G	....
7C6	Lock-In	Duodiode Triode	7B6*, 6SQ7GT/G	....
7C7	Lock-In	Pentode Amplifier	6SJ7GT	....
7E6	Lock-In	Duodiode Triode	6SR7	....
7E7	Lock-In	Duodiode Pentode	6B8G	....
7F7	Lock-In	Twin Triode	6SC7	....
7G7/1232	Lock-In	Pentode Amplifier	....	7V7
7H7	Lock-In	Pentode Amplifier	....	7L7
7J7	Lock-In	Triode Hep. Con.	6J8G	....
7L7	Lock-In	Pentode Amplifier	....	7H7
7N7	Lock-In	Twin Triode	6F8G	....
7Q7	Lock-In	Pentagrid Converter	6SA7GT/G	....
7S7	Lock-In	Triode Hep. Con.	....	7J7
7V7	Lock-In	Pentode Amplifier	7W7*	....
7W7	Lock-In	Pentode Amplifier	7V7*	....
7Y4	Lock-In	Rectifier	6X5GT/G	....
7Z4	Lock-In	Rectifier	....	7Y4
10	Glass	Power Output Tri.	210T*	50
12A	Glass	Power Output Tri.	....	01A, 71A
12A5§	Glass	Power Output Pent.	....	....
12A7	Glass	Rectifier & Amplifier	....	25A7GT/G
12A8G§	G	Pentagrid Converter	12A8GT/G*	....
12A8GT§	GT	Pentagrid Converter	12A8GT/G*	....
12A8GT/G	GT	Pentagrid Converter	12A8G*, 12A8GT*	....

Type	Style	Service	Characteristics Equivalent To	Characteristics Similar To
12B8GT	GT	Triode-Pent.	....	....
12C8	Metal	Duodiode Pentode	6B8 (Pentode Section)	....
12F5GT	GT	High Mu Triode	6F5GT/G	....
12J5GT	GT	Triode	6J5GT/G	....
12J7GT§	GT	Pentode Amplifier	12J7GT/G*	....
12J7GT/G	GT	Pentode Amplifier	12J7GT*	
12K7G§	G	Pentode Amplifier	6K7G, 12K7GT/G*	....
12K7GT§	GT	Pentode Amplifier	6K7G, 12K7GT/G*	....
12K7GT/G	GT	Pentode Amplifier	12K7G*, 12K7GT*	....
12K8	Metal	Tri-Hexode Con.	6K8‡	....
12Q7G§	G	Duo-Diode Triode	12Q7GT/G*	6Q7G
12Q7GT§	GT	Duodiode Triode	12Q7GT/G*	6Q7GT
12Q7GT/G	GT	Duodiode Triode	12Q7G*, 12Q7GT*	6Q7GT
12SA7	Metal	Pentagrid Converter	12SA7GT/G*	6SA7
12SA7GT§	GT	Pentagrid Converter	12SA7GT/G*	6SA7GT
12SA7GT/G	GT	Pentagrid Converter	12SA7*, 12SA7GT*	6SA7GT
12SC7	Metal	Twin-Triode Amp.	....	6SC7, 7F7
12SF5	Metal	High Mu Triode	12F5GT, 12SF5GT*	....
12SF5GT	GT	High Mu Triode	12F5GT, 12SF5G*	....
12SF7	Metal	Diode-Pentode	7E7	6B8G, 6B7
12SG7	Metal	R-F Pentode	14W7	....
12SH7	Metal	R-F Pentode	14W7	....
12SJ7	Metal	R-F Amplifier	12SJ7GT*	6SJ7GT
12SJ7GT	GT	R-F Amplifier	12SJ7*	6SJ7GT
12SK7	Metal	R-F Amplifier	12SK7GT/G*	6SK7GT/G
12SK7GT§	GT	R-F Amplifier	12SK7GT/G*	6SK7GT/G
12SK7GT/G	GT	R-F Amplifier	12SK7*, 12SK7GT*	6SK7GT/G
12SL7GT	GT	Duotriode	14F7	....
12SN7GT	GT	Duotriode	14N7	Two 12J5GT's
12SQ7	Metal	Duodiode Triode	12SQ7GT/G*	6SQ7GT/G
12SQ7GT§	GT	Duodiode Triode	12SQ7GT/G*	6SQ7GT/G
12SQ7GT/G	GT	Duodiode Triode	12SQ7*, 12SQ7GT*	6SQ7GT/G
12SR7	Metal	Duodiode Triode	....	6SR7GT
12Z3	Glass	Rectifier	....	1V
14A4§	Lock-In	Triode Amplifier	7A4	6J5GT/G
14A7/12B7	Lock-In	Pentode Amplifier	7A7	6SK7GT/G
14B6§	Lock-In	Duodiode Triode	7B6	6SQ7GT/G
14B8§	Lock-In	Pentagrid Converter	7B8	6A8GT
14C5§	Lock-In	Power Amplifier	7C5	6V6GT/G
14C7	Lock-In	Pentode Amplifier	7C7	6SJ7GT
14E6§	Lock-In	Duodiode Triode	7E6	6SR7GT
14F7§	Lock-In	Twin Triode Amp.	7F7	6SL7GT
14H7	Lock-In	Pentode Amplifier	7H7	....
14J7	Lock-In	Triode Hex. Con.	7J7	6J8G
14N7§	Lock-In	Twin Triode	7N7	6F8G
14Q7	Lock-In	Pentagrid Converter	7Q7	6SA7GT/G

Type	Style	Service	Characteristics Equivalent To	Characteristics ⊕ Similar To
14S7	Lock-In	Triode Hex. Con.	7S7	6J8G
14W7	Lock-In	Pentode Amplifier	7W7	....
14Y4§	Lock-In	Rectifier	7Y4	6X5GT/G
15§	Glass	R-F Pentode	....	24A
18§	Glass	Power Output Amp.	....	2A5, 42
19	Glass	Power Output Amp.	1J6G♯	(Two 31's)
20§	Glass	Power Output Amp.	....	X99
22§	Glass	R-F Amplifier	....	1B4P, 32
24A, 24S§	Glass	R-F Amplifier	....	35/51, 35S/51S
25A6§	Metal	Power Output Amp.	25A6GT/G*, 43	....
25A6G§	G	Power Output Amp.	25A6GT/G*, 43	....
25A6GT§	GT	Pentode Amplifier	25A6GT/G*, 43	....
25A6GT/G	GT	Pentode Amplifier	25A6*, 25A6G*, 25A6GT*	....
25A7G§	G	Rectifier & Amplifier	25A7GT/G*	12A7
25A7GT§	GT	Pentode-Rectifier	25A7GT/G*	....
25A7GT/G	GT	Pentode-Rectifier	25A7G*, 25A7GT*	....
25AC5G§	G	Power Triode	25AC5GT/G*	....
25AC5GT§	GT	Power Triode	25AC5GT/G*	....
25AC5GT/G	GT	Power Triode	25AC5G*, 25AC5GT*	....
25B5§	Glass	Power Amplifier	25N6G	....
25B6G§	G	Power Output Amp.	....	25A6G, 43
25B8GT§	GT	Pentode Triode	....	....
25C6G	G	Power Amplifier	6Y6G	....
25L6§	Metal	Power Output Amp.	25L6GT/G*	....
25L6G§	G	Power Output Amp.	25L6GT/G*	....
25L6GT§	GT	Power Amplifier	25L6GT/G*	....
25L6GT/G	GT	Power Amplifier	25L6*, 25L6G*, 25L6GT*	....
25Y5§	Glass	Rectifier	25Z5	....
25Z5	Glass	Rectifier	25Z6GT/G	....
25Z6	Metal	Rectifier	25Z3, 25Z6GT/G*	....
25Z6G§	G	Rectifier	25Z5, 25Z6GT/G*	....
25Z6GT§	GT	Rectifier	25Z5, 25Z6GT/G*	....
25Z6GT/G	GT	Rectifier	25Z6*, 25Z6G*, 25Z6GT*	....
26	Glass	Amplifier	....	....
27, 27S§	Glass	Amplifier	....	56*, 56S
30	Glass	Amplifier	1H4G	....
31§	Glass	Power Output Amp.	....	....
32	Glass	R-F Amplifier	....	1A4T, 1D5GT
32L7GT	GT	Tetrode, Rectifier	....	70L7GT
33	Glass	Power Output Amp.	....	1F4, 1F5G, 1G5G, 1J5G
34	Glass	R-F Amplifier	....	1D5GT, 1A4P, 1A4T, 1D5GP, 1N5GT/G
35/51	Glass	R-F Amplifier	35S, 51S	24A

Type	Style	Service	Characteristics Equivalent To	Characteristics Similar To
35S/51S§	Glass	R-F Amplifier	35/51	24S
35A5	Lock-In	Power Amplifier	35L6GT/G	....
35L6G§	G	Power Amplifier	35L6GT/G*	25L6GT/G
35L6GT§	GT	Power Amplifier	35L6GT/G*	25L6GT/G
35L6GT/G	GT	Power Amplifier	35L6G*, 35L6GT*	25L6GT/G 50L6GT
35Y4	Lock-In	Rectifier	35Z5GT/G	....
35Z3	Lock-In	Rectifier	35Z4GT	....
35Z4GT	GT	Rectifier	35Z3	....
35Z5G§	G	Rectifier	35Z5GT/G*, 35Y4	....
35Z5GT§	GT	Rectifier	35Z5GT/G*, 35Y4	....
35Z5GT/G	GT	Rectifier	35Z5G*, 35Z5GT*	....
36	Glass	R-F Amplifier	....	6C6, 6J7
37	Glass	Triode Amplifier	....	6C5GT/G, 6J5GT/G, 6P5GT/G, 76*
38	Glass	Power Output Amp.	....	6K6GT/G, 41
39/44	Glass	R-F Amplifier	....	6D6, 6K7, 6K7G, 6S7G, 78
40§	Glass	Amplifier	....	....
40Z5/45Z5GT	GT	Rectifier	35Z5GT/G	....
41	Glass	Power Output Pent.	6K6G	38, 42
42	Glass	Power Output Pent.	2A5♯, 6F6G	6F6
43	Glass	Power Output Pent.	25A6GT/G	48
45	Glass	Power Output Tri.	....	2A3
46	Glass	Power Output Amp.	....	....
47	Glass	Power Output Pent.	....	2A5
48§	Glass	Power Output Tet.	....	43
49§	Glass	Power Output Tet.	....	....
50	Glass	Power Output Tri.	....	10
50A5	Lock-In	Power Amplifier	50L6GT	....
50C6G§	G	Power Amplifier	....	25C6G
50L6GT	GT	Power Amplifier	....	25L6GT/G 35L6GT/G
50Y6G§	G	Rectifier	50Y6GT/G*	35Y4
50Y6GT§	GT	Rectifier	50Y6GT/G*	35Y4
50Y6GT/G	GT	Rectifier	50Y6G*, 50Y6GT*	35Y4
50Z7G§	G	Rectifier	....	....
53	Glass	Power Output Amp.	6A6♯, 6N7♯, 6N7G♯	....
55§, 55S§	Glass	Duodiode Triode	6V7G♯, 85♯	....
56, 56S§	Glass	Triode Amplifier	76♯	27, 27S
56AS§	Glass	Triode Amplifier	76♯	....
57, 57S§	Glass	R-F Amplifier	6C6♯	77
57AS§	Glass	R-F Amplifier	6C6♯	....
58, 58S§	Glass	R-F Amplifier	6D6♯, 6E7♯, 6U7G♯	....
58AS§	Glass	R-F Amplifier	6D7♯, 6E7♯, 6U7G♯	78
59	Glass	Power Output Amp.	....	....

Type	Style	Service	Characteristics Equivalent To	Characteristics Similar To
70A7GT	GT	Rect. Pentode	....	70L7GT
70L7GT	GT	Tetrode, Rectifier	32L7GT	....
71A	Glass	Power Output Tri.	....	12A
75, 75S	Glass	Duodiode Triode	2A6ƒ	6Q7, 6Q7G, 6T7G
76	Glass	Triode Amplifier	6P5GT/G, 56ƒ	6L5G, 6C5GT/G, 6J5GT/G, 37*
77	Glass	R-F Amplifier	6J7†, 6J7G	6C6*, 6W7G
78	Glass	R-F Amplifier	6K7†, 6K7G	6D6*, 6S7G
79	Glass	Power Output Amp.	6Y7G	....
80	Glass	Rectifier	5Y3GT/G, 5Y4G	....
81	Glass	Rectifier	....	....
82	Glass	Rectifier	....	....
83	Glass	Rectifier	....	83V, 5U4G, 5X4G, 5Z3, 5Z4G
83V	Glass	Rectifier	5Z4G	83
84/6Z4	Glass	Rectifier	6X5GT/G	....
85	Glass	Duodiode Triode	6V7G, 55ƒ	6R7GT/G
85AS§	Glass	Duodiode Triode	....	6R7GT/G, 85
89§	Glass	Power Output Amp.	....	....
V99§	Glass	Triode Amplifier	....	X99, 30ƒ
X99§	Glass	Triode Amplifier	....	V99, 20, 30ƒ
182B/482B§	Glass	Power Output Amp.	....	183/483*, 71A
183/483§	Glass	Power Output Amp.	....	182B/482B*, 71A
117L7GT§	GT	Tetrode, Rectifier	117L7/M7GT*	32L7GT, 70L7GT
117M7GT§	GT	Tetrode, Rectifier	117L7/M7GT*	32L7GT, 70L7GT
117L7/M7GT	GT	Tetrode, Rectifier	117L7GT*, 117M7GT*	32L7GT, 70L7GT
117N7GT	GT	Tetrode, Rectifier	....	32L7GT, 70L7GT
117P7GT	GT	Rect. Pentode		117L7/M7GT
117Z6G§	G	Rectifier	117Z6GT/G*	....
117Z6GT§	GT	Rectifier	117Z6GT/G*	....
117Z6GT/G	GT	Rectifier	117Z6G*, 117Z6GT*	....
210-T	Glass	Power Output Amp.	10*	....
485§	Glass	Triode Amplifier	....	27
864	Glass	Triode Amplifier	....	....
1221	Glass	Non-mic. Amplifier	1223, 6C6	6J7, 6J7G, 6W7G, 77
1223	G	Non-mic. Amplifier	1221, 6C6	6J7, 6J7G, 6W7G, 77
1231	Special	Triple Grid Amp.	....	....
1612	Metal	Non-mic. Amplifier	6L7, 6L7Gƒ	....
2051	G	Gas Tetrode	....	2A4G
XXD	Lock-In	Twin Triode	14AF7*	14N7
XXFM	Lock-In	Duodiode Triode	....	....
XXL	Lock-In	Triode	....	7A4

SYMBOLS: *—Indicates direct interchangeability. In some cases realignment of tuned circuits may be necessary particularly where capacitances differ.
ƒ—Equivalent Characteristics except for filament rating.
†—Characteristics same as listed type except capacitances. §—Types no longer manufactured.

INTERCHANGEABLE TUBES

All types of Sylvania Tubes listed in the Table of Contents and not referred to hereafter, are interchangeable with competitive tubes bearing identical designation. Example—Sylvania 01A replaces any 01, 01A, or 01AA, and 6A7 replaces any 6A7, etc. Metal and "G" tubes having corresponding tube numbers may be interchanged, but realignment of any tuned circuit may be necessary to obtain maximum performance. An external shield may be required on "G" tubes when used to replace corresponding metal types, and the shield should be grounded. All other types which are interchangeable, but have different type designations, follow:

Type No.	Sylvania No.	Type No.	Sylvania No.	Type No.	Sylvania No.
0Z3	Δ	6Q6G/6T7G	6T7G	80M	83
0Z4	0Z4	6Q7MG	6Q7G+	81M	81
1A4	1A4T	6R7MG	6R7G+	82V	82
1A4P	1A4P	6T5	6U5/6G5	84	84/6Z4
1A4T	1A4T	6T7G/6Q6G	6T7G	G84	2Z2/G84
1,KR1	1V	6W5G	6X5G	G84/2Z2	2Z2/G84
1B4	1B4P	6Y5V	6Y5	88	83†
1B4T	1B4P	6Z3	1V	95	2A5
1B4/951	1B4P	6Z4	84/6Z4	96	1V
1D5G	1D5GT	6Z4/84	84/6Z4	98	84
1D5GP	1D5GP	6Z5/12Z5	6Z5	143D	2X2/879
1D5GT	1D5GT	7A7LM	7A7	182B	182B/482B
1E5G	1E5GP	7B5LT	7B5	183	183/483
1E5GP	1E5GP	7B6LM	7B6	288	83V
1E5GT	1E5GP	7B8LM	7B8	401	401
2A3H	2A3	7C5LT	7C5	482A	71A
2Z2	2Z2/G84	12Z5	6Z5	482B	182B/482B
G2, 2S	2S/4S	13	80	483	183/483
G4, 4S	2S/4S	14Z3	12Z3	484	485
5T4	5T4 or 5U4G	16, 16B	81	585	50
KR5	6A4/LA	22AC	24A	586	50
5W4G	5W4 or 5Y3G	25S	1B5/25S	P-861	84
5Y3	5Y3G	KR25	2A5	951	1B4P
5Y4	5Y4G	25Z5MG	25Z6G+	985	Δ
5Z4G	5V4G or 5Z4	27HM	56	986	83†
5Z4MG	5Z4 or 5V4G	KR-28	84	AD	1V
6A4	6A4/LA	35	35/51	AF	82
6A8MG	6A8G+	35A5LT	35A5	AG	83
6AB6G	6N6G	35S	35S/51S	AX	01A
6B6	6Q7G+	35Z3LT	35Z3	B	V99
6B6G	6Q7G+	36A	36	BA	Δ
6C5MG	6C5G+	37A	37	BH	Δ
6D5	Δ	38A	38	BR	Δ
6D5G	Δ	39A	39/44	D½	81
6F5MG	6F5G+	43MG	25A6+	D1	80
6F6MG	6F6G+	44	39/44	DE1	27
6G5/6H5	6U5/6G5	45A	45	E	20
6H5	6U5/6G5	HZ50	12Z3	G	40
6H6MG	6H6G+	51	35/51	H	00A
6J7MG	6J7G+	51S	35S/51S	H2-10	2X2/879
6K7MG	6K7G+	59B	Δ	LA	6A4/LA
6L7MG	6L7G+	64, 64A	36‡	PZ	47

INTERCHANGEABLE TUBES (continued)

TYPE No.	SYLVANIA No.	TYPE No.	SYLVANIA No.	TYPE No.	SYLVANIA No.
6N6MG	6N6G	65, 65A	39/44‡	PZH	Δ
6P7	6P7G	67, 67A	37‡	RE-1	80
6Q6	6T7G	68, 68A	38‡	RE-2	81
6Q6G	6T7G	71, 71B	71A	SO-2	50

GT TUBE REPLACEMENTS—"GT" tubes may be directly replaced with Sylvania "GT" tubes having like type numbers. Example: Sylvania 6A8GT will replace any 6A8GT. The Sylvania "GT" tubes available are listed on current price literature.

When no Sylvania like type number is available, a Sylvania metal tube of like type number (Example: Sylvania 12SA7 will replace any 12SA7GT) or a Sylvania "G" tube of like type number may be used if space in the receiver permits. In such cases a slight realignment of the circuit may be necessary for some types.

ΔSpecial information regarding the replacement of these tubes or any tubes not listed will be furnished upon request.

†When receiver's transformer will stand one ampere additional filament current.

‡Only when used in auto receivers or AC receivers not having series filament.

+Indicates that Metal or "G" types may be interchanged, but realignment of the circuit may be necessary. In some cases an external shield may be required on the "G" tubes when replacing metal tubes.

VALVE BIAS RESISTOR CHART

(For push-pull operation use ½ R and double the wattage rating)

NOTE: Less the voltage drop through indicated coupling resistor in megohms:
#0.05 ‡0.1 †0.25 *0.3 Δ0.5 §1.0

Type	Use	Plate Volts	Grid Volts	Screen Volts	Cathode Current Ma.	Bias Resistor Ohms	Rating Watts
01A	Amp.	135	-9	....	3.0	3000	½
		90	-4.5	....	2.5	2000	½
	Bias Det.	135	-13.5	....	0.2	65000	½
		90	-7.5	....	0.2	40000	½
1A4	Amp.	180	-3	67.5	3.0	1000	½
1A5G	Power Amp. Pentode	90	-4.5	90	4.8	950	½
1A6	Pent. Conv.	180	-3	67.5	5.5	500	½
		135	-3	67.5	5.9	500	½
1B4	Amp.	180	-3	67.5	2.1	1500	½
	Biased Det.	180	-6	....	0.2	30000	½
		135	-4.5	....	0.2	22500	½
1B5/25S	Res.Coup.Volt Amp.	135	-3	....	0.8	3750	½
1C5G	Power Amp. Pent. .	90	-7.5	90	9.1	800	½
1C6	Pent. Conv.	180	-3	67.5	7.7	400	½
		135	-3	67.5	7.1	425	½
1C7G	See Type 1C6 . . .	...	....	....	......	......	....
1D5G	See Type 1A4 . . .	...	....	....	......	......	....
1D7G	See Type 1A6 . . .	...	....	....	......	......	....
1E5G	See Type 1B4 . . .	...	....	....	......	......	....
1E7G	Power Amp. . . .	135	-7.5	135	8.5	900	½

VALVE
BIAS RESISTOR CHART—Continued

(For push-pull operation use ½ R and double the wattage rating)

Type	Use	Plate Volts	Grid Volts	Screen Volts	Cathode Current Ma.	Bias Resistor Ohms	Rating Watts
1F4	Power Amp. . . .	135 90	−4.5 −3	135 90	10.4 5.1	430 600	½ ½
1F5G	See Type 1F4 . . .	...	....	....	......	......	....
1F6	Res. Coup. A-F Amp. R.F., I.F.	135† 135† 135† 180	−1.0 −1.5 −2.0 −1.5	135§ 135§ 135§ 67.5	0.4 0.4 0.4 2.9	2500 3750 5000 500	½ ½ ½ ½
1F7G	See Type 1F6 . . .	...	....	....	......	......	....
1G5G	Power Amp. . . .	90	−6.0	90	11.2	525	½
1H4G	See Type 30 . . .	...	....	....	......	......	....
1H6G	See Type 1B5/25S .	...	....	....	......	......	....
1J5G	Power Amp. Pent. .	135	−16.5	135	9.0	1800	½
1LA4	See Type 1A5G . .	...	....	....	......	......	....
1Q5G	Power Amplifier . .	90	−4.5	90	11.1	400	½
2A3	Power Amp. (1) . . P.P. (2)	250 300	−45 −62	....	60 80	750 780	3 5
2A5	See Type 42 . . .	...	....	....	......	......	....
2A6	See Type 75 . . .	...	....	....	......	......	....
2A7	See Type 6A7 . . .	...	....	....	......	......	....
2B7	See Type 6B7 . . .	...	....	....	......	......	....
6A3	Power Triode . . . Push-Pull	250 325	−45 −68	....	60 80	750 850	3 10
6A4/LA	Power Amp. . . . Pentode Single. . .	180 165 135 100	−12 −11 −9 −6.5	180 165 135 100	25.9 22.9 15.8 9.1	450 500 600 700	½ ½ ½ ½
6A5G	Power Amp. . . . Push-Pull, 2 Tubes .	250 325	−45 −68	....	60 80	750 850	3 10
6A6	Power Amp. Class A	294 250	−6 −5	....	7.0 6.0	850 850	½ ½
6A7	Pent. Conv.	250 100	−3 −1.5	100 50	10.6 4.6	280 325	½ ½
6A8	See Type 6A7 . . .	...	....	....	......	......	....
6A8G	See Type 6A7 . . .	...	....	....	......	......	....
6A8GT	See Type 6A8 . . .	...	....	....	......	......	....
6AB7/1853	Telev. Amp. Pent. .	300	−3	200	15.7	190	½

VALVE
BIAS RESISTOR CHART—Continued

(For push-pull operation use ½ R and double the wattage rating)

Type	Use	Plate Volts	Grid Volts	Screen Volts	Cathode Current Ma.	Bias Resistor Ohms	Rating Watts
6AC7/ 1852	Telev. Amp. Pent. .	300	-2	150	12.5	160	⅓
6B4G	See Type 6A3 . . .	...	....	....	......	......	....
6B7	Volt Amp. Pent. . .	250	-3	125	11.3	250	⅓
	R.F., I.F.	250	-3	100	7.5	400	⅓
		180	-3	75	4.3	750	⅓
		100	-3	100	7.5	400	⅓
	Volt Amp. Pent. . .	180	-2.1	25	0.6	4000	⅓
		135	-1.95	20	0.4	5000	⅓
		100	-2.15	20	0.23	10000	⅓
6B8	See Type 6B7 . . .	...	....	....	......	......	....
6B8G	See Type 6B7 . . .	...	....	....	......	......	....
6C5	Amp.	250	-8	....	8.0	1000	⅓
6C5G	See Type 6C5 . . .	...	....	....	......	......	....
6C6	Biased Det.	250 △	-4.8	100	0.43	10000	⅓
		250†	-1.95	50	0.65	3000	⅓
		100†	-1.83	30	0.183	10000	⅓
		100§	-1.16	12	0.063	18000	⅓
	Amp.	250	-3	100	2.5	1200	⅓
	Amp. Res. Coup. .	180†	-1.3	30	0.5	2500	⅓
		135†	-1.25	25	0.33	3500	⅓
		100†	-1.05	20	0.31	3500	⅓
6C8G	Phase Inverter. . .	250‡	-3.0	....	2.0	1500	⅕
	Twin Triode Amp. .	250‡	-3	....	2.0 Totl.	1500	⅓
		250*	-3	....	3.4 Totl	900	⅓
6D6	Amp.	250	-3	100	10.2	300	⅓
	Superhet. Mixer . .	250	-10	100	3.5	3000	⅓
6D8G	Pent. Conv.	250	-3.0	100	10.8	280	⅓
		135	-3.0	67.5	6.4	470	⅓
6E6	Power Amp. . . .	250	-27.5	....	36	750	2
		180	-20	....	23	850	1
6F5	Volt Amp.	250	-2	....	1.1	1800	⅓
		250†	-1.35	....	0.4	3500	⅓
6F5G	See Type 6F5 . . .	...	....	....	......	......	....
6F5GT	See Type 6F5 . . .	...	....	....	......	......	....
6F6	See Type 42 . . .	...	....	....	......	......	....
6F6G	See Type 42 . . .	...	....	....	......	......	....
6F7	Superhet.Conv.Pent.	250	-10	100	3.4	1700	⅓
	Triode	250*	0.1Me	g.Leak	2.4	......	....
	Diode Det.and Pent. A-F Amp. . . .	250*	-3	100	0.6	5000	⅓

VALVE

BIAS RESISTOR CHART—Continued

(For push-pull operation use ½ R and double the wattage rating)

Type	Use	Plate Volts	Grid Volts	Screen Volts	Cathode Current Ma.	Bias Resistor Ohms	Rating Watts
6F8G	Volt. Amp.	250 #	−5.5	....	4.8	1150	⅓
6G6G	Power Amp. Pent. .	180 135	−9 −6	180 135	17.5 13.5	500 450	⅓ ⅓
6J5G	Amp.	250	−8.0	....	9.0	900	⅓
6J5GT	See Type 6J5G . .	...	....	....	......	......	....
6J7	Biased Det.	250 △ 250† 250 △	−4.3 −2 −1.7	100 50 33	0.43 0.65 0.21	10000 3000 8000	⅓ ⅓ ⅓
	Amp.	250 100	−3 −1.5	100 100	2.5 2.5	1200 600	⅓ ⅓
6J7G	See Type 77 . . .	...	....	....	......	......	....
6J7GT	See Type 6J7 . . .	...	....	....	......	......	....
6J8G	Triode Hept. Conv.	250	−3	100	9.6	310	⅓
6K5G	See Type 6Q7 . . .	...	....	....	......	......	....
6K6G	See Type 41 . . .	...	....	....	......	......	....
6K6GT	See Type 41 . . .	...	....	....	......	......	....
6K7	Amp.	250 250 180 90	−3 −3 −3 −3	125 100 75 90	13.1 8.7 5.0 6.7	250 350 600 450	⅓ ⅓ ⅓ ⅓
6K7G	See Type 6K7 . . .	...	....	....	......	......	....
6K7GT	See Type 6K7 . . .	...	....	....	......	......	....
6K8	Triode Hex. Conv. .	250	−3	100	12.45	240	⅓
6K8G	See Type 6K8 . . .	...	....	....	......	......	....
6K8GT	See Type 6K8 . . .	...	....	....	......	......	....
6L5G	Amp.	250 100	−9.0 −3.0	....	8.0 4.0	1125 750	⅓ ⅓
6L6	Power Amp. . . .	350 300 250	−18.0 −12.5 −14.0	250 200 250	56.5 50.5 77	320 250 180	2 1 2
	Push-Pull 2 Tubes . Push-Pull 2 Tubes . Push-Pull 2 Tubes .	360 270 250	−22.5 −17.5 −16.0	270 270 250	93 145 130	240 120 120	3 3 3
6L6G	See Type 6L6 . . .	...	....	....	......	......	....
6L7	Mixer	250 250	−6 −3	150 100	14.9 11	500 350	⅓ ⅓
	Amp.	250	−3	100	10.8	300	⅓
6L7G	See Type 6L7 . . .	...	....	....	......	......	....
6N7	See Type 6A6 . . .	...	....	....	......	......	....

VALVE

BIAS RESISTOR CHART—Continued

(For push-pull operation use 1/3 R and double the wattage rating)

Type	Use	Plate Volts	Grid Volts	Screen Volts	Cathode Current Ma.	Bias Resistor Ohms	Rating Watts
6N7G	See Type 6A6 . . .	...	....	....	......	......	....
6P5G	See Type 76 . . .	...	....	....	......	......	....
6P7G	See Type 6F7 . . .	...	....	....	......	......	....
6Q7	Res.Coup.Volt Amp.	250†	-2.5	....	0.37	7000	1/3
6Q7G	See Type 6Q7 . . .	...	....	....	......	......	....
6Q7GT	See Type 6Q7 . . .	...	....	....	......	......	....
6R7	Res.Coup.Volt Amp.	250†	-6.5	....	0.65	10000	1/3
6R7G	See Type 6R7 . . .	...	....	....	......	......	....
6S7G	Amp.	250	-3.0	100	10.2	300	1/3
	Superhet. Mixer . .	250	-10.0	100	3.5	3000	1/3
6SA7	Pent. Converter . .	250	-2	100	12.5	160	1/3
		100	-2	100	12.3	160	1/3
6SC7	Twin Triode Amp. .	250	-2	....	4.0 Tot'l	500	1/3
		250†	-1.4	....	0.9 Tot'l	1500	1/3
6SF5	See Type 6F5 . . .	...	....	....	......	......	....
6SJ7	Amplifier	250	-3	100	3.8	800	1/3
		100	-3	100	3.8	800	1/3
6SK7	Amplifier	250	-3	100	11.6	260	1/3
		100	-3	100	11.5	260	1/3
6SQ7	See Type 75 . . .	...	....	....	......	......	....
6T7G	Res.Coup.Volt Amp.	250†	-2.5	....	0.31	8000	1/3
6U7G	See Type 6D6 . . .	...	....	....	......	......	....
6V6	Power Amp. . . .	315	-13.0	225	36.2	360	1
		250	-12.5	250	49.5	250	1
		180	-8.5	180	32	260	1
	Push-Pull 2 Tubes .	250	-15.0	250	75	200	2
6V6G	See Type 6V6 . . .	...	....	....	......	......	....
6V7G	See Type 85 . . .	...	....	....	......	......	....
6W7G	Amplifier	250	-3	100	2.5	1200	1/3
6Y6G	Power Amp. . . .	200	-14	135	63.2	220	1.0
		135	-13.5	135	61.5	220	1.0
6Y7G	See Type 79 . . .	...	....	....	......	......	....
7A4	Amplifier	250	-8	....	9	900	1/3
7A5	Power Amp. Pent .	125	-9	125	40.7	220	1/2
		110	-7.5	110	38.0	200	1/2
7A7	Amplifier	250	-3	100	10.6	300	1/3
7A8	Octode Conv. . . .	250	-3	100	10.7	300	1/3

VALVE
BIAS RESISTOR CHART—Continued

(For push-pull operation use ½ R and double the wattage rating)

Type	Use	Plate Volts	Grid Volts	Screen Volts	Cathode Current Ma.	Bias Resistor Ohms	Rating Watts
7B5	See Type 41 . . .	...	....	....	......	......	....
7B6	See Type 75 . . .	...	....	....	......	......	....
7B7	See Type 6S7G . .	...	....	....	......	......	....
7B8	See Type 6A7 . . .	...	....	....	......	......	....
7C5	Power Amp. . . .	250	-12.5	250	49.5	240	1.0
		180	-8.5	180	32	260	1.0
	Push-Pull, 2 Tubes .	250	-15.0	250	75	200	2.0
7C7	See Type 6W7G . .	...	....	....	......	......	....
7E6	See Type 6R7 . . .	...	....	....	......	......	....
7E7	R.F.,I.F.Amp.Pent.	250	-3	100	9.1	330	⅓
7F7	Twin Triode Amp. .	250‡	-1.5	....	1.6 Tot'l	930	⅓
		250†	-1.5	....	0.9 Tot'l	1700	⅓
7J7	Triode Hex. Conv. .	250	-3	100	10.3	290	⅓
7L7	See Type 6SA7 . .	...	....	....	......	......	....
10	Class A Amp. . . .	425	-40	....	18	2000	1
		350	-32	....	16	2000	1
		250	-23.5	....	10	2250	½
12-A	Class A Amp. . . .	180	-13.5	....	7.7	2000	⅓
		135	-9	....	6.2	1500	⅓
		90	-4.5	....	5.0	1000	⅓
	Biased Det. . . .	180	-20	....	0.2	100000	⅓
		135	-15	....	0.2	65000	⅓
12A5	Power Amp. Pent. .	180	-27	180	42	650	2
		100	-15	100	20	750	½
12A7	Power Amp. Pent. .	135	-13.5	135	10.8	1250	⅓
12A8G	See Type 6A8 . . .	...	....	....	......	......	....
12A8GT	See Type 6A8 . . .	...	....	....	......	......	....
12B8GT	R.F.,I.F.Amp.Pent.	90	-3	90	9.0	330	⅓
12C8	See Type 6B7 . . .	...	....	....	......	......	....
12F5GT	See Type 6F5 . . .	...	....	....	......	......	....
12J5GT	See Type 6J5 . . .	...	....	....	......	......	....
12J7GT	See Type 6J7 . . .	...	....	....	......	......	....
12K7G	See Type 6K7 . . .	...	....	....	......	......	....
12K7GT	See Type 6K7 . . .	...	....	....	......	......	....
12Q7G	See Type 6Q7 . . .	...	....	....	......	......	....
12Q7GT	See Type 6Q7 . . .	...	....	....	......	......	....

BIAS RESISTOR CHART—Continued

(For push-pull operation use ½ R and double the wattage rating)

Type	Use	Plate Volts	Grid Volts	Screen Volts	Cathode Current Ma.	Bias Resistor Ohms	Rating Watts
12SA7	See Type 6SA7 . .	...	....	....	......	......	....
12SC7	See Type 6SC7 . .	...	....	....	......	......	....
12SJ7	See Type 6SJ7 . .	...	....	....	......	......	....
12SK7	See Type 6SK7 . .	...	....	....	......	......	....
12SQ7	See Type 75 . . .	...	....	....	......	......	....
15	Det. Osc.	135	-1.5	67.5	2.15	700	⅓
18	See Type 42 . . .	...	....	....	......	......	....
20	Power Amp. . . .	135	-22.5	....	6.0	3750	⅓
		90	-16.5	....	2.8	6000	⅓
22	Amp. R.F.. . . .	135	-1.5	67.5	5.	300	⅓
		135	-1.5	45	2.3	600	⅓
24A	Amp.	250	-3	90	5.7	500	⅓
		180	-3	90	5.7	500	⅓
	Biased Det.	275†	-5	20–45	0.15	33000	⅓
25A6	See Type 43 . . .	...	....	....	......	......	....
25A6G	See Type 43 . .	...	....	....	......	......	....
25A7G	Power Amp. . . .	100	-15.0	100	24.5	600	½
25A7GT	See Type 25A7G .	...	....	....	......	......	....
25B6G	Power Amp. . . .	200	-23.0	135	63.8	360	2
		135	-22.0	135	63.5	350	2
		105	-16.0	105	50	320	1
25B8GT	See Type 12B8GT .	...	....	....	......	......	....
25C6G	See Type 6Y6G . .	...	....	....	......	......	....
25L6	Power Amp. . . .	110	-7.5	110	53	140	1
25L6G	See Type 25L6 . .	...	....	....	......	......	....
25L6GT	See Type 25L6 . .	...	....	....	......	......	....
26	Amp.	180	-14.5	....	6.2	2500	⅓
		135	-10	....	5.5	2000	⅓
		90	-7	....	2.9	2500	⅓
27	Amp.	250	-21	....	5.2	4000	⅓
		180	-13.5	....	5.0	2700	⅓
		135	-9	....	4.5	2000	⅓
		90	-6	....	2.7	2200	⅓
	Biased Det.	275	-33	....	0.2	150000	⅓
		250	-30	....	0.2	150000	⅓
30	Amp.	180	-13.5	....	3.1	4000	⅓
		135	-9	....	3.0	3000	⅓
		90	-4.5	....	2.5	2000	⅓
	Biased Det.	180	-18	....	0.2	75000	⅓
		135	-13.5	....	0.2	65000	⅓
		90	-9	....	0.2	40000	⅓

VALVE

BIAS RESISTOR CHART—Continued

(For push-pull operation use ½ R and double the wattage rating)

Type	Use	Plate Volts	Grid Volts	Screen Volts	Cathode Current Ma.	Bias Resistor Ohms	Rating Watts
31	Power Amp. . . .	180	-30	....	12.3	2500	½
		135	-22.5	....	8.0	2500	⅓
32	Amp.	180	-3	67.5	2.1	1500	⅓
		135	-3	67.5	2.1	1500	⅓
		180†	-1	30	0.36	• 3000	⅓
	Biased Det.	180‡	-6	....	0.25	25000	⅓
		135‡	-4.5	....	0.25	20000	⅓
32L7GT	Power Amp. . . .	90	-7	90	29.0	240	½
		90	-5	90	41.0	120	½
33	Power Amp. Pent. .	180	-18	180	27	650	½
		135	-13.5	135	17.5	750	⅓
34	Amp. R.F.	180	-3	67.5	3.8	850	⅓
		135	-3	67.5	3.8	850	⅓
		67.5	-3	67.5	3.8	850	⅓
	Superhet. Mixer . .	180	-5	67.5	2.8	2000	⅓
		135	-5	67.5	2.8	2000	⅓
		67.5	-5	67.5	2.8	2000	⅓
35/51	Amp. R.F.	250	-3	90	9.0	350	⅓
		180	-3	90	8.8	350	⅓
	Superhet. Mixer . .	250	-7	90	6.2	1250	⅓
35A5	Power Amp. . . .	110	-7.5	110	37.8	200	½
35L6G	Power Amp. . . .	110	-7.5	110	43.0	175	½
35L6GT	See Type 35L6G . .	...	....	....	......	......	....
36	Amp.	250	-3	90	3.6	850	⅓
		180	-3	90	3.5	850	⅓
		135	-1.5	67.5	3.2	500	⅓
		100	-1.5	55	2.2	750	⅓
37	Amp.	250	-18	....	7.5	2400	⅓
		180	-13.5	....	4.3	3000	⅓
		135	-9	....	4.1	2200	⅓
		90	-6	....	2.5	2400	⅓
	Biased Det.	250	-28	....	0.2	100000	⅓
		180	-20	....	0.2	100000	⅓
		135	-15	....	0.2	75000	⅓
		90	-10	....	0.2	50000	⅓
38	Power Amp. Pent.	250	-25	250	25.8	1000	1
		180	-18	180	16.4	1100	½
		135	-13.5	135	10.5	1300	⅓
		100	-9	100	8.2	1100	⅓
39/44	Amp.	250	-3	90	7.2	400	⅓
		180	-3	90	7.2	400	⅓
		90	-3	90	7.2	400	⅓
	Superhet. Mixer . .	250	-7	90	3.5	2000	⅓
		180	-7	90	3.4	2000	⅓
		90	-7	90	3.4	2000	⅓
41	Power Amp. Pent. .	250	-18	250	37.5	500	1
		180	-13.5	180	21.5	650	½
		135	-10	135	14.7	700	⅓
		100	-7	100	10.6	650	⅓

VALVE
BIAS RESISTOR CHART—Continued

(For push-pull operation use ½ R and double the wattage rating)

Type	Use	Plate Volts	Grid Volts	Screen Volts	Cathode Current Ma.	Bias Resistor Ohms	Rating Watts
42	Power Amp. Class A Pent.	285	-20	285	45	450	2
	Power Amp. Class A Pent.	250	-16.5	250	40 5	400	2
	Power Amp. Class A Triode	250	-20	....	31	650	1
	Class AB₂ Push-Pull Pent.	375	-26	250	78	335	3
	Class AB₂ Push-Pull Triode	350	-38	....	48	800	2
43	Power Amp. Pent.	160	-18	120	39.5	450	2
		135	-20	135	45	450	1
		95	-15	95	24	625	½
45	Power Amp.	275	-56	....	36	1500	5
		250	-50	....	34	1500	3
		180	-31.5	....	31	1000	2
46	Class A Driver	250	-33	....	22	1500	1
47	Power Amp. Pent.	250	-16.5	250	37	450	1
48	Power Amp. Tet.	125	-22.5	100	64	350	2
		95	-20	95	64	350	2
49	Power Amp. Class A Tri.	135	-20	....	6.0	3500	⅓
50	Power Amp.	450	-84	....	55	1500	5
		400	-70	....	55	1250	5
		350	-63	....	45	1500	5
		300	-54	....	35	1500	2
53	See Type 6A6	...	....	....	......	......	....
55	See Type 85	...	....	....	......	......	....
56	See Type 76	...	....	....	......	......	....
57	See Type 6C6	...	....	....	......	......	...
58	See Type 6D6	...	....	....	......	......	...
59	Power Amp. Class A Tri.	250	-28	....	26	1000	1
	Power Amp. Class A Pent.	250	-18	250	44	400	1
70L7GT	See Type 35L6G	...	....	....	......	......	..
71A	Power Amp.	180	-40.5	....	20	2000	1
		135	-27	....	17.3	1500	½
		90	-16.5	....	10	1500	⅓
75	Res.Coup.Volt Amp.	250†	-1.35	....	0.4	3500	⅓
		180†	-1.3	....	0.24	5000	⅓
		135†	-1.1	....	0.09	11000	⅓
	Impedance Coup.	250	-2	....	0.8	2500	⅓
76	Amp.	250	-13.5	....	5.0	2700	⅓
	Biased Det.	250	-20	....	0.2	100000	⅓
77	Amp.	250	-3	100	2.9	1000	⅓
		100	-1.5	60	2.1	700	⅓
	Biased Det.	250 △	-4.3	100	0.43	10000	⅓
		250†	-1.95	50	0.65	3000	⅓
		250†	-1.95	36	0.155	12500	⅓

VALVE
BIAS RESISTOR CHART—Continued

(For push-pull operation use ½ R and double the wattage rating)

Type	Use	Plate Volts	Grid Volts	Screen Volts	Cathode Current Ma.	Bias Resistor Ohms	Rating Watts
78	Amp.	250	-3	125	13.1	250	⅓
		250	-3	100	8.7	350	⅓
		180	-3	75	5.0	600	⅓
		90	-3	90	6.7	450	⅓
79	Power Amp. Class A Tri.	250†	-1.5	....	0.5	3000	⅓
85	Amp. (Trans. Coup.)	250	-20	....	8.0	2500	⅓
		180	-13.5	....	6.0	2250	⅓
		135	-10.5	....	3.7	2800	⅓
	Amp. (Res. Coup.) ..	180†	-7	....	0.47	15000	⅓
		135†	-7	....	0.31	20000	⅓
		100†	-5	....	0.23	20000	⅓
89	Power Amp. Class A Tri.	250	-31	....	32	1000	2
		180	-22.5	....	20	1250	1
		160	-20	....	17	1250	½
	Class A Pent. . . .	250	-25	250	37.5	750	2
		180	-18	180	23	750	½
		135	-13.5	135	16.2	850	⅓
99	Amp.	90	-4.5	....	2.2	2000	⅓
	Biased Det.	90	-10.5	....	0.2	50000	⅓
182B/ 482B	Power Amp.	250	-35	....	20	1750	1
183/483	Power Amp.	250	-65	....	20	3250	2
210T	See Type 10 . . .	...	....	....	......	......	....
485	Amp.	180	-9	....	5.8	1600	⅓
864	Amp.	135	-9	....	3.5	2500	⅓
		90	-4.5	....	2.9	1500	⅓
	Biased Det.	135	-15	....	0.2	75000	⅓
		90	-10.5	....	0.2	50000	⅓
950	See Type 1J5G . .	...	....	....	......	......	....
1221	See Type 6C6 . . .	...	....	....	......	......	....
1223	See Type 6C6 . . .	...	....	....	......	......	....
1231	Telev. Amp. Pent.	300	-2.5	150	12.5	200	⅓
	Telev. Amp. Tet.	300	-2.5	150	12.5	200	⅓
	Telev. Amp. Triode	250	-5.2	....	13	400	⅓
7G 7/1232	Amplifier	250	-2	100	8.0	250	⅓
1612	See Type 6L7 . . .	...	....	....	......	......	....

Note: Less the voltage drop through indicated coupling resistor in megohms:
#0.05 ‡0.1 †0.25 *0.3 △0.5 §1.0

The information in this section is supplied by courtesy of Claude Lyons, Ltd., Liverpool and London, and Sylvania Corp., U.S.A.

VALUE AND DEFINITION OF UNITS USED IN RADIO AND ELECTRICITY.

Unit Name.	*Measure of Unit.*	*Alphabetical Symbol of Unit.*	*Equation for finding value of Unit.*
Acceleration ...	cm/sec^2	a	$a = v \div T$.
Admittance ...	Mho.	y, Y.	$Y = 1 \div Z$
Angular Velocity	Radians/ Second.	w	$w = 6.2832f = 2\pi f$
Capacitance ...	Farad. F.	C.	$C = Q \div E$. $C = Q \div V$.
Capacitive Reactance.	Ohm. Ω	Xc.	$Xc = -1 \div 6.2832fC$ $Y = -1 \div 2\pi fC$.
Charge—Quantity	Coulomb	q. Q.	$Q = 1T$.
Conductance ...	Mho.	g. G.	$\left\{ G = R \div (X^2+R^2) \text{ or } 1 \div R. \right.$
Conductivity ...	Mho. cm.	Y	$Y = 1 \div p$
Current	Ampere A.	i. I.	$\left\{ I = Q \div T. \quad I = E \div Z. \quad I = E \div R. \right.$
Elastance ...	Daraf	S	$S = 1 \div C$.
Electromotive Force (E.M.F.).	Volt V.	e. E.	$E = RI$.
Field Intensity ...	Gauss	H.	—
Flux Density ...	Gauss	B_1	$B_1 = \varnothing \div \lambda$.
Force	Dyne	F	$F = ma$.
Frequency ...	Cycles per second	f	$f = 1 \div T$.
Impedance ...	Ohm. Ω	Z	$Z = \sqrt{X^2+R^2}$
Inductive— Reactance.	Ohm. Ω	X_L	$X_L = 6.2832fL$ $2\pi fL$.
Length	Centimeter	l	—
Magnetic Flux ...	Maxwell or Weber	$\varnothing$	$\varnothing = B_1\lambda = H\mu\lambda$.
Magnetising Force	Oersted or Gilbert $\div$ cm.	H	$H = M \div 1$ or $4\pi \text{ ꝏ } \varnothing \div (10\Lambda)$.
Magnetic Induction	$Weber/cm_2$	B_2	$B_2 = \mu H$.
Magnetomotive Force.	Gilbert or ($1 \div 4\pi$amp. turn)	M	$M = 4\pi \text{ ꝏ } \varnothing$.
Mass	Gram.	m	—
Mutual Inductance.	Henry H.	M.	
Permeability ...	—	μ	$\mu = B_1 \div H$.
Permeance ...	Weber $\div$ ($1 \div 4\pi$amp. turn)	P	$P = 1 \div R$
Potential ...	Volt	V_1	$V_1 = W \div q$.
Power	Watt W.	P	$P = EI$. $P = W \div T$.
Reactance ...	Ohm. Ω	X	$\left\{ X = [6.2832fL - (1 \div 6.2832fC)]. \quad X = [2\pi fL - (1 \div 2\pi fC)]. \quad X = [X_L - (1 \div wC]. \right.$

VALUE AND DEFINITION OF UNITS USED IN RADIO AND ELECTRICITY.—*contd.*

Unit Name.	*Measure of Unit.*	*Alphabetical Symbol of Unit.*	*Equation for finding value of Unit.*
Reluctance ...	($1 \div 4\pi$amp. turn) $\div$ Weber	*R*	$R = M \div Ø = \Lambda \div \mu\lambda$.
Reluctivity ...	—	*v*	$v = 1 \div \mu$.
Resistance ...	Ohm. Ω	r. R.	$R = E \div I$. $R = V_1 \div I$.
Resistivity ...	Ohm. cm.	*p*	—
Self Inductance...	Henry H.	L	$L = X_L \div 2\pi f$.
Susceptance ...	Mho.	b. B.	$B = X \div (X^2 + R^2)$.
Time	Second	t. T.	$T = 1 \div f$.
Velocity	Cm./Second	v	$v = 1 \div T$.
Work or Energy	Joule J.	W	$W = Fl$.

λ = Area in sq. cms. ꝏ = Number of turns.
Λ = Length of path in cms. Ø = Electric current in amps.

BRITISH TYPE VALVE EQUIVALENTS.

Where there is a standard American type number which is included in the British range, the British valve may always be used as a replacement for the American Valve.

MULLARD—BRIMAR.

Brimar.	Mullard.	Brimar.	Mullard.
DDA1	2D4A	7C6	—
HLA1	904V	7C7	—
HL2A	354V	7D3	—
HLB1	PM1HL	7D5	—
PA1	—	7D6	Pen 36C
Pen A1	Pen 4VA	7D7	—
Pen B1	PM22A	7D8	—
R1	IW2	7V4	—
R2	IW3	8A1	SP4
R3	IW4	8D2	—
VL5-61	—	9A1	VP4
VSGA1	MM4V	9A3	VP4B
1A7	IW3	9D2	—
1D4	UR3C	10D1	2D13C
1D5	—	11A1	TDD4
1LH4	—	11A2	TDD4
1LA4E	—	11D3	TDD13C
1LA6E	—	11D5	—
1LN5E	—	15A2	FC4
4D1	HL13C	15D1	FC13C
5B1	PM12A	15D2	—
7A2	Pen 4VA	16D1	—
7A3	Pen A4	20A1	TH4B
7A7	—	20D2	—
7A8E	—	4033A	—
7B5E	—	4043A	—
7B6	—	4215A	—
7B7E	—	4205D	—
7B8	—	4205E	—
7C5	—		

MULLARD—COSSOR.

Cossor	Mullard	Cossor	Mullard	Cossor	Mullard
AG8	—	41MHL	354V	220OT	PM22A
DD/Pen	—	41MLF	154V	220P	PM2
DD4	2D4A	41MP	TT4	220PA	PM2A
DDL4	2D4A	41MPG	FC4	220RC	—
DDT	TDD4	41MPT	—	220SG	PM12
DDT16	—	41MXP	ACO64	220TH	TH2
DHL	—	41MXPA	ACO44	220VS	PM12M
DP	—	41MRC	354V	220VSG	—
DP/10	—	41MSG	S4V	225DU	—
DVSG	—	41MTB	904V	230HPT	PM22
DVS/Pen	—	41MTL	354V	230PT	PM22
MP/Pen	Pen4VA	41MTS	—	230XP	PM252
MP/PenA	Pen4VA	41PGD	FC4	240B	PM2B
MS/Pen	SP4	41STH	TH4	240QP	QP22B
MS/PenA	SP4	41XP	TT4	302THA	TH30C
MS/PenB	SP4B	41MP/Pen	PenA4	402OT	—
MSVG/HA	S4VA	41MPT	—	402P	—
MSG/LA	S4VB	420T	PenA4	402Pen	—
MVSG	MM4V	420T/DD	—	405BU	—
MVS/Pen	VP4	42PTB	—	408BU	DW2
MVS/PenB	—	42SPT	—	410HF	PM4DX
M41/SG	S4VA	431U	IW4/350	410LF	PM4DX
OM3	EB34	441U	IW4	410P	—
OM4	EBC33	45LU	FW4/500	410RC	—
OM5	EF36	44SU	—	410SG	PM14
OM6	EF39	202DDT	TDD13C	412BU	DW2
OM8	—	202MPG	FC13C	412SU	—
OM9	EL32	202SPB	—	415PT	PM24
OM10	—	202STH	TH21C	415XP	—
PT41	PM24M	202VP	—	425XP	—
PT41B	PM24B	202VPB	—	442BU	DW4/350
PT220	PM22	203THA	—	460BU	DW4/500
TP410	PM24	206PT	—	506BU	DW2
SU2130	—	210Det	PM2DX	600T	—
SU2150	—	210DDT	TDD2A	610HF	—
2XP	ACO42	210DG	—	610LF	—
4THA	TH4B	210HF	PM1HF	610P	PM256
4TP	—	210HL	PM2HL	610RC	—
4TPB	TSP4	210LF	PM1LF	610SG	—
4TSA	—	210PG	FC2	610XP	PM256
4TSP	—	210PGA	FC2A	612BU	—
4XP	ACO44	210RC	PM1A	615PT	PM25
4/100BU	FW4/500	210SPG	FC2	620T	—
13DHA	TDD13C	210SPT	—	624BU	—
13PGA	FC13C	210VPA	VP2	625P	PM256
13SPA	—	210VPT	—	660SU	—
13VPA	—	215P	PM2	660T	—
40PPA	—	215SG	PM12	680HF	—
40SUA	—	220B	PM2B	680P	—
41MDG	—	220DD	2D2	680XP	—
41MH	904V	220HPT	PM22A	825BU	DW30
41MHF	354V	220IPT	—	845BU	DW30

MULLARD—EKCO.

Ekco	Mullard	Ekco	Mullard	Ekco	Mullard
DT41	TDD4	OP41	PenB4	R41	DW4/500
VP41	VP4B	OP42	PenA4	2D41	2D4B
DTU1	TDD13C	TX41	TH4B	T41	354V
VPU1	VP13C	DO42	Pen 4DD		

MULLARD—EVER-READY.

Ever-Ready	Mullard	Ever-Ready	Mullard	Ever-Ready	Mullard
AZ1	AZ1	C70E	Pen36C	K23A	TDD2
A11B	IW3	C80B	FC13	K23B	TDD2A
A11C	IW4	DK1	DK1	K30A	PM1HF
A11D	IW4/350	DF1	DF1	K30B	PM1LF
A27D	Pen4DD	DAC1	DAC1	K30C	PM1HL
A23A	TDD4	DL1	DL1	K30D	PM2DX
A30B	904V	DL2	DL2	K30E	PM2DL
A30D	354V	EB4	EB4	K30G	PM2A
A36A	TH4	EBC3	EBC3	K30K	PM2HL
A36B	TH4B	EBC33	EBC33	K33A	PM2B
A36C	TH4B	EBL1	EBL1	K33B	PM2BA
A40M	MM4V	C23B	TDD13C	K40B	PM12A
A50A	SP4	C30B	HL13C	K40N	PM12M
A50B	SP4B	C36A	TH21C	K50M	VP2
A50M	VP4	C36C	TH30C	K50N	VP2B
A50N	VP4A	C50B	SP13C	K70B	PM22A
A50P	VP4B	C50N	VP13C	K70D	PM22D
A70B	Pen4VA	ECH2	ECH2	K77A	QP22A
A70C	PenA4	ECH3	ECH3	K80A	FC2
A70D	PenA4	ECH33	ECH33	K80B	FC2A
A70E	PenB4	EF8	EF8	S11D	DW4/350
A80A	FC4	EF9	EF9	S30C	ACO44
CY31	CY31	EF39	EF39	S30D	ACO42
C10B	UR1C	EL3	EL3		
C20C	2D13C	EL32	EL32		

MULLARD—FERRANTI.

Ferranti	Mullard	Ferranti	Mullard	Ferranti	Mullard
DA	HL13C	PT2	PM22A	VHTA	FC13A
D4	354V	PT4	PenA4	VHTZ	—
ER4	HVR2	PT4D	—	VHT2	FC2
HAD	TDD13C	P4	—	VHT2A	FC2
HP2	PM2B	RA	—	VHT4	FC4
HSD	—	RS	—	VPTA	—
H2D	TDD2	RZ	UR1C	VPTS	—
H4D	TDD4	R4	DW4/350	VPTSB	—
LP4	ACO44	R4A	DW4	VPT4	VP4
L2	PM2A	R5	—	VPT4A	VP4A
PTA	—	R13A	—	VPT4B	VP4A
PTAD	—	SD	—	VS2	PM12M
PTS	—	SPTS	—	VS4	VM4V
PTSD	—	SPT4A	SP4	ZD	2D13C
PTZ	—	SP4	SP4		

BRITISH VALVE SUBSTITUTES.
MULLARD—MARCONI—OSRAM.

Marconi	Mullard	Marconi	Mullard	Marconi	Mullard
A537	—	HD23	TDD2A	MH40	—
A748	—	HD24	TDD2A	MH41	904V
A831	—	HL2	PM1HL	MH42	—
B21	PM2B	HL2/C	PM1HF	MHD4	TDD4
B30	—	HL8	—	MHL4	244V
B63	6A6	HL21	PM2HL	MHL4/C	164V
BL62	—	HL210	PM2HL	MKT4	—
D8	—	HL410	PM4DX	ML4	TT4
D41	2D4A	HL610	—	MPT4	—
D42	—	GU5	—	MPT41	—
D43	—	KT2	PM22A	MPT42	—
D63	6H6G	KT21	PM22D	MS4B	S4VB
DA30	DO30	KT24	PM22D	MS4/C	S4V
DA60	—	KT30	—	MSP4	SP4
DE5	PM256	KT32	25L6G	MSP4C	—
DE5A	—	KT33C	—	MSP41	—
DE5B	—	KT35	—	MU12	IW3
DEH612	—	KT41	PenA4	MU14	IW4
DEL612	—	KT42	Pen4VA	MX40	FC4
DET5	—	KT44	—	N14	—
DET8	—	KT61	—	N30	—
DG2	—	KT63	6F6G	N31	—
DH	—	KT66	6L6G	N40	Pen4VA
DHD	—	KT72	—	N41	PenA4
DHL	—	KT73	—	N42	Pen4VA
DH30	—	KTW61(M)	—	N43	—
DH42	TDD4	KTW63	6K7G	N63	6F6G
DH63 (M)	6Q7G	KTW73(M)	—	N66	6L6G
DH73 (M)	—	KTZ41	—	P2	PM2
DL	—	KTZ63	6J7G	P2/B	PM2
DL63	6R7G	KTZ73 (M)	—	P8	—
DN30	—	L2/B	PM2DX	P215	PM2
DN41	—	L11	—	P240	PM202
DPT	—	L12	DA2	P410	—
DS	—	L21	PM2DX	P415	—
DSB	—	L30	—	P425	—
DSP1	—	L63	6J6G	P610	PM256
H2	PM1A	L210	PM1LF	P625	PM256
H8	—	L410	PM4DX	P625A	PM256
H11	—	L610	—	PT2	PM22A
H12	DA1	LP2	PM2A	PT4	PM24M
H30	—	LP2/C	PM2	PT16	—
H42	—	LS5	—	PT25H	DO30
H63	6F5G	LS5A	—	PT240	PM22
H210	PM1A	LS5B	—	PT425	PM24
H410	—	LS6A	—	PT625	PM25
H610	—	LS7	—	PX2	ACO42
HA1	AT4	LS7B	—	PX4	ACO44
HA2	4671	LS8	—	PX4/C	—
HD14	—	LS9D	—	PX25	DO24
HD21	TDD2A	MH4	354V	PX25A	DO26
HD22	TDD2A	MH4/C	354V	QP21	—

MULLARD—MARCONI—OSRAM.—*contd.*

Marconi	Mullard	Marconi	Mullard	Marconi	Mullard
S2/C	PM12	U30	—	X14	—
S8	—	U31	—	X21	FC2
S12	DAS1	U50	5Y3G	X22	FC2A
S21	PM12	U52	5U4G	X23	TH2
S22	PM12A	U70	—	X24	TH2
S23	PM12	U71	—	X30	—
S24	PM12A	U134	—	X31	—
S215	PM12	VDP1	—	X32	—
S410	—	VDS	—	X41	TH4B
S610	—	VMP4	VP4	X41C	—
S625	—	VMP4G	VP4A	X42	FC4
U4	—	VMS4	MM4V	X63 (M)	6A6G
U5	—	VMS4B	MM4V	X64	6L7G
U6	—	VP21	—	X65	—
U8	DW30	VS2	PM12M	X73 (M)	—
U9	DW2	VS24	PM12M	X75	—
U9/C	DW2	W21	VP2	ZA1	AP4
U10	DW4/350	W30	—	ZA2	4672
U12	DW3	W31	—	Z14	—
U14	DW4	W42	—	Z21	SP2
U16	HVR1	W63	6K7G	Z30	—
U17	—	WD30	—	Z62	—
U18	FW4/500	WD40	—	Z63	6J7G

MULLARD—MAZDA.

Mazda	Mullard	Mazda	Mullard
P650	—	PenDD4020	—
PA20	ACO42	PenDD4021	—
PA40	DO30	PD220	PM2B
Pen24	—	PD220A	PM2B
Pen25	—	PP3/250	ACO44
Pen44	—	PP3/425	—
Pen45	—	PP5/400	DO24
PenDD45	—	PP3521	—
Pen46	—	QP25	—
PenDD61	—	QP230	QP22B
Pen141	—	QP240	QP22A
Pen220	PM22A	RH1	DW30
Pen220A	PM22	S215A	PM12
Pen230	PM22	S215B	PM12A
Pen231	PM22D	S215VM	PM12M
Pem383	—	SG215	PM12
Pen425	PM24	SP22	—
PenDD453	—	SP41	—
Pen1330	—	SP42	—
Pen1340	—	SP141	—
PenDD1340	—	SP210	SP2
Pen2020	—	SP215	SP2
PenDD2530	—	SP1320	—
Pen3530	Pen36C	SP1330	—
Pen3820	Pen36C	SP2020	—

MULLARD—MAZDA—*contd.*

Mazda	Mullard	Mazda	Mullard
SP2220	—	UU120/250	DW3
TH41	—	UU120/350	DW3
TH233	—	UU120/500	DW4
TH2320	TH21C	UU2	IW3
TH2321	TH30C	UU3	IW3
TP22	—	UU4	IW3
TP23	—	UU5	IW4
TP25	—	UU6	—
TP26	—	UU7	—
TP1340	—	UU8	—
TP2620	—	UU4020	UR3C
TV250	—	V312	—
UD41	—	V914	2D4A
U21	—	VP22	—
U22	—	VP23	—
U403	—	VP41	—
U4020	—	VP133	—
U30/250	DW2	VP210	VP2
U60/500	DW3	VP215	—
U65/550	DW30	VP1320	—
U75/300	DW3	VP1321	—
UU60/250	DW2	VP1322	VP13C

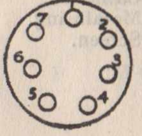
MULLARD VALVE SUBSTITUTES FOR EMERGENCIES.
SUBSTITUTION OF TDD4 FOR THE SD4.

Change connections as below :—

Connections for SD4 Pin Number.		Connections for TDD4 Pin Number.
1	Not used with SD4	1
2	Disconnect and take this lead to ...	TOP CAP
3	Disconnect and insulate end of lead ...	
4, 5, 6	These connections remain as they are at present.	4, 5, 6
7	Disconnect and take wire to	3
TOP CAP	" " " " "	7

Join together pins 1 and 6.

In some cases the lead to top cap may have to be screened.



BASE PIN NUMBERING VIEWED FROM FREE END OF PINS.

SUBSTITUTION OF EB34 FOR THE EAB1.

In Phillips Receiver Type 753A and 895X, also Mullard MAS 17, MAS 109 and MAS 112.

Circuit Alterations.

1. Change valve holder to octal type.
2. Change connections as below.

Contact EAB1 holder.		Contact on EB34 holder.
No. 1.	to	1.
2.	"	2.
3.	"	7.
4.	"	4.
5.	"	3.
7. Insulate end of lead.		
8.	"	5.

Join together pins 4 and 8.

Under these conditions the set should operate as before, but without the A.V.C. delay characteristic.

MULLARD VALVE TYPE EPM1.

No supplies are available.

With circuit modification this valve may be replaced by the MULLARD Type EF9 in Mullard and Philips sets as detailed :—

(1) Lead to contact 5 disconnected and insulated.
(2) Lead to contact 6 disconnected and extended, and fitted with top cap adaptor to reach the top cap of the EF9.
(3) Join together contact 4 and 5.
(4) Reduce the anode coupling and resistances from approximately 130,000 ohms. to 50,000 ohms. It may be necessary to continue the screening on the lead formerly to contact 6 as far as the top cap, though in many cases this will not be necessary. Should the top cap of the EF9 touch the tuning scale it may be necessary to bend the platform for the EFM1 slightly so as to give a small clearance. Under these conditions the set should operate as before but without the tuning.

EMERGENCY REPLACEMENT AND SUBSTITUTE TYPES FOR MULLARD RECEIVING VALVES.

Explanation of Symbols.

Type of Base :

A ...	British 4-pin.
B ...	Continental 6 -pin.
C ...	Continental 7-pin.
E ...	American 7-pin.
G ...	American 4-pin.
H ...	British 3-pin.
Hiv ...	Midget deaf-aid.
J ...	American 6-pin.
K ...	American Octal.
M ...	British 7-pin.
N ...	American 5-pin.
O ...	British 5-pin
P ...	British 8 side-contact.
R ...	British 9-pin.
V ...	British 5 side-contact.
W ...	Special 4-pin.
ES ...	Edison Screw.

Electrode Symbols :

A, A1, A2 ...	Anodes.
Ao	Oscillator Anode.
D, D1, D2 ...	Diode Anodes
F	Filament.
H	Heater.
G	Grid (Grids marked G1, G2, etc., G1 being nearest the cathode).
Go	Oscillator grid.
K, K1, K2 ...	Cathode.
M	Metallising.
S	Screen.

MULLARD EMERGENCY REPLACEMENTS.—*contd.*

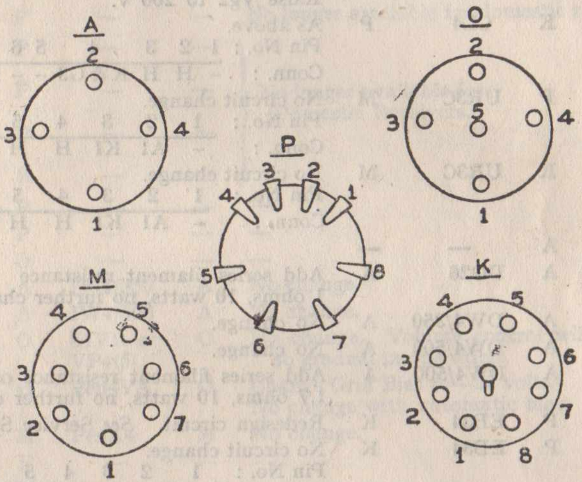
The symbol "TC" shown in the base connections is used to indicate the top cap.

Where marked with * there is no recommended substitute.

A radio set may not perform with the same degree of efficiency when the original valve is substituted by an emergency equivalent. The purpose of this information is to assist in keeping sets in operation under difficult conditions.

BASE DIAGRAMS AND PIN NUMBERING.

The A, O, P, M and K bases only have been shown, as these are the only types which occur as standard bases under REMARKS, where the holder connections are to be changed.



Original Type	Base	Substitute Type	Base	Remarks
ACO54	A	ACO44	A	Redesign circuit — There is no valve which will directly replace these valves, and full working conditions of the ACO44 should be studied before substitution is made.
ACO64	A	ACO44	A	ditto
ACO84	A	ACO44	A	ditto
ACO84N	A	ACO44	A	ditto
AC104	A	ACO44	A	ditto
AZ2	P	DW4/500	A	DW4/500—Va 500, Ia 120 mA Pin No. : 1 2 3 4 Connection : A1 A F F
AZ3	P	IW4/350	A	No circuit change. Pin No. : 1 2 3 4 Connection : A1 A F F

MULLARD EMERGENCY REPLACEMENTS—*contd.*

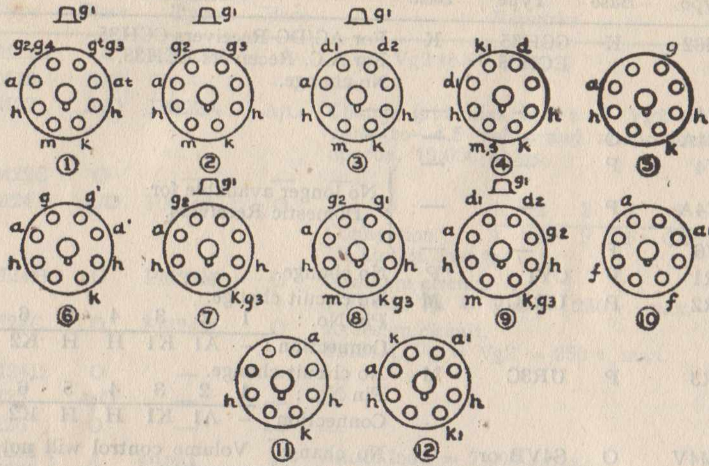
Original Type	Base	Substitute Type	Base	Remarks
AZ32	K	DW4/500	A	Pin No. : 1 2 3 4 Connection : A1 A F F
AZ33	K	IW4/350	A	No circuit change. Pin No. : 1 2 3 4 Connection : A1 A F F
CL6	P	CL4	P	Change bias resistance to 170 ohms. Raise Vg2 to 200 v.
CL36	K	CL4	P	As above. Pin No. : 1 2 3 4 5 6 7 8 TC Conn. : – H H K & G3 – – G2 A G1
CY2	P	UR3C	M	No circuit change. Pin No. : 1 2 3 4 5 6 7 Conn. : – A1 K1 H H K2 A2
CY32	K	UR3C	M	No circuit change. Pin No. : 1 2 3 4 5 6 7 Conn. : – A1 K1 H H K2 A2
*DO20	A	—	—	
DO25	A	DO26	A	Add series filament resistance 1 ohms, 10 watts, no further change.
DW3	A	DW4/350	A	No change.
DW4	A	DW4/500	A	No change.
DW30	A	DW4/500	A	Add series filament resistance of approx. 1.7 ohms, 10 watts, no further change.
EAB1	P	EB34	K	Redesign circuit. *See* Service Sheet.
EB4	P	EB34	K	No circuit change. Pin No. : 1 2 3 4 5 6 7 8 Conn. : M & S H D1 K1 D2 – H K2
*EBF1	P	—	—	—
*EBF2	P	—	—	—
*EBF32	K	—	—	—
ECH2	P	ECH3	P	No change. ECH3 if 0.2A
ECH33	K	CCH35	K	For AC/DC Receivers—CCH35. For A/C Receivers—ECH35.
EFM1	P	EF9	P	Redesign circuit Without Tuning Indicator } *See* special Service Sheet.
EH2	P	ECH3	P	Use Hexode section only in extreme cases.
EK3	P	EK2	P	Raise screen volts to 200. EK2 If = 0.2A.
EL5	P	EL35	K	EL35 Vg2 250 v. max. Change bias resistance to 180 ohms. Pin No. : 1 2 3 4 5 6 7 8 Conn. : – H A G2 G1 – H G3 & K

Original Type	Base	Substitute Type	Base	Remarks
EL6	P	EL35	K	EL35 Vg2 250 v. max. Change bias resistance to 180 ohms. Pin No.: 1 2 3 4 5 6 7 8 / Conn.: – H A G2 G1 – H G3&K
EL36	K	EL35	K	EL35 Vg2 250 v. max. Change bias resistance to 180 ohms.
EM1	P	—	—	No longer available for domestic receivers.
EM2	P	—	—	No longer available for Domestic Receivers.
EM3	P	—	—	No longer available for Domestic Receivers.
EM4	P	—	—	No longer available for Domestic Receivers.
EM35	K	—	—	No longer available for Domestic Receivers.
*EZ2	P	—	—	—
*EZ3	P	—	—	—
*HL20	O	—	—	—
IW3	A	IW4/350	A	No change.
IW4	A	IW4/500	A	No change.
MM4V	O	S4VB or VP4(5)	O	No change. Volume control will not be so gradual in operation.
Pen4V	O	Pen4VA	O	Change Grid Bias to—22 volts. No change with automatic bias.
Pen4VB	M	PenA4	M	No change.
*Pen13	P	—	—	—
*Pen13C	M	—	—	—
*Pen20	O/M	—	—	—
Pen26	P	CL4	P	Change bias resistance to 170 ohms. C14 Vg2—200 volts.
PM1A	A	PM2HL	A	No change.
PM1HF	A	PM2HL	A	No change.
PM1HL	A	PM2HL	A	No change.
PM1LF	A	PM2HL	A	Change grid bias to—1.5 volts.
PM2	A	PM2A	A	Change grid bias to—6.0 volts.
*PM2BA	M	—	—	—
PM2DL	A	PM2HL	A	No change.
PM2DX	A	PM2HL	A	No change.
*PM4	A	—	—	—
*PM4DX	A	—	—	—
PM12	A	PM12M	A	Raise Vg2 to 90 volts.

Original Type	Base	Substitute Type	Base	Remarks
PM12A	A	PM12M	A	Raise Vg2 to 90 volts.
*PM13	A/O	—	—	—
PM22	A/O	PM22A	A/O	Change grid bias at Va = Vg2 = 135 volts to—4.5 volts, and anode load to approx. 19,000 ohms.
*PM22C	O	—	—	—
PM24	A/O	PM24A	O	Pin No. : 1 2 3 4 5 Connection : A G1 F F G2 No circuit change.
PM24B	O	PM24M	O	Redesign circuit. PM24M, Va = Vg2 = 250 v. max.
PM24C	O	PM24M	O	Redesign circuit. PM24M, Va = Vg2 = 250 v. max.
*PM24D	O	—	—	—
*PM25	A/O	—	—	—
*PM26	O	—	—	—
PM202 } PM252 }	A	PM2A	A	Anode load = 7,000 ohms. Change bias to—6.0 v.
*QP22A	R	—	—	—
SD4	M	TDD4	M	Redesign circuit. *See* Service Sheet.
*SD20	M	—	—	—
*SG20	O	—	—	—
*SP20	O	—	—	—
SP4C	P	SP4B	M	No circuit change. Pin. No. : 1 2 3 4 5 6 7 TC Conn. : M A G3 H H K G2 G1
S4V	A/O	S4VB or SP4(5)	O	No circuit change. Pin No. : 1 2 3 4 5 TC Connection : G2 G1 H H K A
S4VA	O	S4VB or SP4(5)	O	No change.
TDD2	O	TDD2A	O	Change grid bias to—1.5 volts. Not suitable as Class B driver.
TDD13	P	TDD13C	M	No circuit change. Pin No. : 1 2 3 4 5 6 7 TC Conn. : D1 M D2 H H K A G1
*TDD25	M	—	—	—
TH4A	M	TH4B	M	No change.
*TH13C	M	—	—	—
TH22C	M	TH30C	M	No change.

Original Type	Base	Substitute Type	Base	Remarks
TH62	K	CCH35 ECH35	K	For AC/DC Receivers CCH35. For A.C. Receivers ECH35. No change.
*TT4	O	—	—	—
*TT4A	O	—	—	—
TV4	P	—	—	
TV4A	P	—	—	No longer available for Domestic Receivers.
TV6	P	—	—	
UR1	P	CY1	P	No change.
UR2	P	UR3C	M	No circuit change. Pin No. : 1 2 3 4 5 6 7 Connection : – A1 K1 H H K2 A2
UR3	P	UR3C	M	No circuit change. Pin No. : 1 2 3 4 5 6 7 Connection : – A1 K1 H H K2 A2
VM4V	O	S4VB or VP4(5)	O	No change. Volume control will not be so gradual in operation.
*VM20	O	—	—	—
*VP20	O	—	—	—
54V	O	ACO44	A	Redesign circuit.
*2D2	O	—	—	—
2D4	O	2D4A	O	No circuit change. Pin No. : 1 2 3 4 5 Connection : D2 D1 H H K 2D4A has no top cap.
*2D4B	M	—	—	—
2D13	V	2D13C	O	No circuit change. Pin. No. : 1 2 3 4 5 Connection : D2 D1 H H K
104V	O	TT4	O	Anode load 10,000 ohms.
154V	A	164V	O	No circuit change. Pin No. : 1 2 3 4 5 Connection : A G1 H H K Cathode connected to side terminal.
244V	O	354V	O	No change.
484V	O	354V	O	Change grid bias to—4.5 volts or bias resistance to 700 ohms.
944V	O	904V	O	No change.

BASE CONNECTIONS OF MULLARD "E" SERIES OCTAL BASES



BASE CONNECTIONS OF MULLARD "E" SERIES OCTAL BASES.

Type of Valve.	Base No. on Diagram.
CCH35	1
ECH35	1
ECH33	1
EF36	2
EF39	2
EBC33	3
EB34	4
EC31	5
ECC31	6
EL32	7
CL33	8
EL33	8
EL35	8
EL36	8
EBL31	9
CBL31	9
AZ31	10
AZ32	10
CY31	11
UY31	11
CY32	12

THE SYMBOLS DENOTING ELECTRODES.

Anode ... ... a

Diode-anode ... ... d

In the case of double and multiple diodes : d1, d2, etc., d1 being nearest to the base of the valve.

Filament (directly heated) ... ... f

Filament (indirectly heated) ... ... h

Grid... ... ... g

For multiple-grid valves : g1, g2, etc., g1 being nearest to the cathode.

Indirectly heated cathode ... ... k

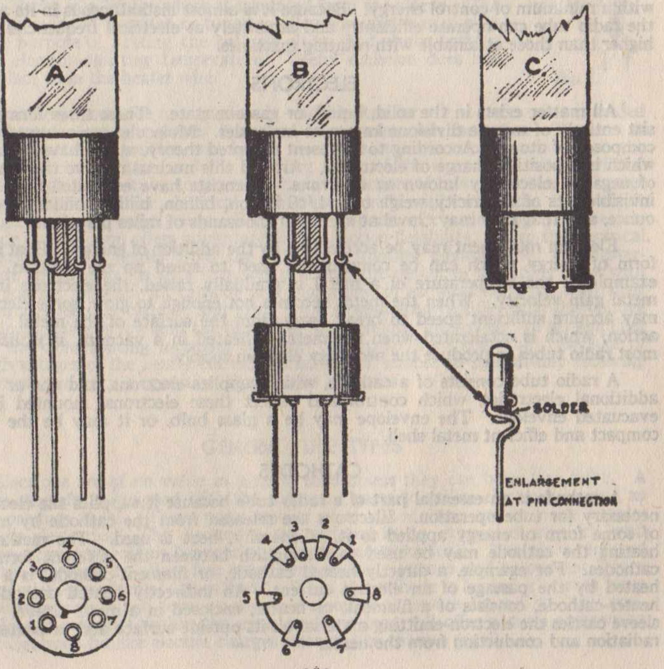
Metallisation ... ... m

Electrodes of identical assemblies are distinguished by accents, thus : a, a′, a″

TO SUBSTITUTE FROM AMERICAN 1.4 V. BATTERY VALVES TO MULLARD VALVES.

To Convert 1A7G to DK1	To Convert 1N5G to DF1	To Convert 1H5G to DAC1	To Convert 1C5G to DL2
Octal 1 to 'P' –	Octal 1 to 'P' –	Octal 1 to 'P' –	Octal 1 to 'P' –
„ 2 to „ 2	„ 2 to „ 2	„ 2 to „ 2	„ 2 to „ 2
„ 3 to „ 8	„ 3 to „ 8	„ 3 to „ 8	„ 3 to „ 8
„ 4 to „ 7	„ 4 to „ 7	„ 4 to „ –	„ 4 to „ 7
„ 5 to „ 6	„ 5 to „ –	„ 5 to „ 6	„ 5 to „ 6
„ 6 to „ 5	„ 6 to „ –	„ 6 to „ –	„ 6 to „ –
„ 7 to „ 3	„ 7 to „ 3	„ 7 to „ 3	„ 7 to „ 3
„ 8 to „ –	„ 8 to „ –	„ 8 to „ –	„ 8 to „ –

To convert octal base 1.4 volt valves for use in side contact sockets, first attach wires to octal pins, as indicated in the above table and illustration A. Next thread on salvaged 'P' valve base, illustration B, and finally cut off wires and solder to 'P' base, illustration C.



RADIO VALVES

and their applications with explanation of characteristics and testing.

By courtesy of R. C. A. Harrison, N.J., U.S.A.

Electrons and Electrodes

The radio tube is a marvelous device. It makes possible the performing of operations, amazing in conception, with a precision and a certainty that are astounding. It is an exceedingly sensitive and accurate instrument—the product of coordinated efforts of engineers and craftsmen. Its construction requires materials from every corner of the earth. Its use is world-wide. Its future possibilities, even in the light of present-day accomplishments, are but dimly foreseen; for each development opens new fields of design and application.

The importance of the radio tube lies in its ability to control almost instantly the flight of the millions of electrons supplied by the cathode. It accomplishes this with a minimum of control energy. Because it is almost instantaneous in its action, the radio tube can operate efficiently and accurately at electrical frequencies much higher than those attainable with rotating machines.

ELECTRONS

All matter exists in the solid, liquid, or gaseous state. These three forms consist entirely of minute divisions known as molecules. Molecules are assumed to be composed of atoms. According to a present accepted theory, atoms have a nucleus which is a positive charge of electricity. Around this nucleus revolve tiny charges of negative electricity known as electrons. Scientists have estimated that these invisible bits of electricity weigh only 1/46 billion, billion, billion, billionths of an ounce, and that they may travel at speeds of thousands of miles per second.

Electron movement may be accelerated by the addition of energy. Heat is one form of energy which can be conveniently used to speed up the electron. For example, if the temperature of a metal is gradually raised, the electrons in the metal gain velocity. When the metal becomes hot enough to glow, some electrons may acquire sufficient speed to break away from the surface of the metal. This action, which is accelerated when the metal is heated in a vacuum, is utilized in most radio tubes to produce the necessary electron supply.

A radio tube consists of a cathode, which supplies electrons, and one or more additional electrodes, which control and collect these electrons, mounted in an evacuated envelope. The envelope may be a glass bulb, or it may be the more compact and efficient metal shell.

CATHODES

A cathode is an essential part of a radio tube because it supplies the electrons necessary for tube operation. Electrons are released from the cathode by means of some form of energy applied to it. Generally, heat is used. The method of heating the cathode may be used to distinguish between the different forms of cathodes. For example, a directly heated cathode, or filament-cathode, is a wire heated by the passage of an electric current. An indirectly heated cathode, or heater-cathode, consists of a filament, or heater, enclosed in a metal sleeve. The sleeve carries the electron-emitting material on its outside surface and is heated by radiation and conduction from the heater

A filament, or directly heated cathode, may be further classified by identifying the filament or electron-emitting material. The materials in regular use are tungsten, thoriated-tungsten, and metals which have been coated with alkaline-earth oxides. Tungsten filaments are made from the pure metal. Since they must operate at high temperatures (a dazzling white) to emit sufficient electrons, a relatively large amount of filament power is required. Thoriated-tungsten filaments are made from tungsten impregnated with thoria. Due to the presence of thorium, these filaments liberate electrons at a more moderate temperature of about 1700°C (a bright yellow) and are, therefore, much more economical of filament power than are pure tungsten filaments. Alkaline earths are usually applied as a coating on a nickel alloy wire or ribbon. This coating, which is dried in a relatively thick layer on the filament, requires only a very low temperature of about 700-750°C (a dull red) to produce a copious supply of electrons. Coated filaments operate very efficiently and require relatively little filament power. However, each of these cathode materials has special advantages which determine the choice for a particular application.

Fig. 1

Directly heated filament cathodes require comparatively little heating power. They are used in almost all of the tube types designed for battery operation because it is, of course, desirable to impose as small a drain as possible on the batteries. Examples of battery-operated filament types are the 1A7-GT, 1F5-G, 1H4-G, 1H5-G, and 31. A-c operated types having directly heated filament-cathodes are the 2A3 and 45.

An indirectly heated cathode, or heater-cathode, consists of a thin metal sleeve coated with electron-emitting material. Within the sleeve is a heater which is insulated from the sleeve. The heater is made of tungsten or tungsten-alloy wire and is used only for the purpose of heating the cathode sleeve and sleeve coating to an electron-emitting temperature. Useful emission does not take place from the heater wire.

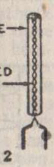


Fig. 2

The heater-cathode construction is well adapted for use in radio tubes intended for operation from a-c power lines and from automobile batteries. The use of separate parts for emitter and heater functions, the electrical insulation of the heater from the emitter, and the shielding effect of the sleeve may all be utilized in the design of the tube to prevent the introduction of hum from the a-c heater supply and to minimize electrical interference which might enter the tube circuit through the heater-supply line. From the viewpoint of circuit design, the heater-cathode construction offers advantages in connection flexibility, due to the electrical separation of the heater from the cathode. Another advantage of the heater-cathode construction is that it makes practical the design of a rectifier tube with close spacing between its cathode and plate, and of an amplifier tube with close spacing between its cathode and grid. In a close-spaced rectifier tube the voltage drop in the tube is low and the regulation is, therefore, improved. In an amplifier tube, the close spacing increases the gain obtainable from the tube. Because of the advantages of the heater-cathode construction, almost all present-day receiving tubes designed for a-c operation have heater cathodes.

GENERIC TUBE TYPES

Electrons are of no value in a radio tube unless they can be put to work. A tube is, therefore, designed with the necessary parts to utilize electrons as well as as to produce them. These parts consist of a cathode and one or more supplementary electrodes. The electrodes are enclosed in an evacuated envelope with the necessary connections brought out through air-tight seals. The air is removed from the envelope to allow free movement of the electrons and to prevent injury to the emitting surface of the cathode. When the cathode is heated, electrons leave the cathode surface and form an invisible cloud in the space around it. Any positive electric potential within the evacuated envelope will offer a strong attraction to the electrons (unlike electric charges attract; like charges repel).

DIODES

The simplest form of radio tube contains two electrodes, a cathode and an anode (plate) and is often called a "diode", the family name for a two-electrode tube. In a diode, the positive potential is supplied by a suitable electrical source connected between the plate terminal and a cathode terminal. Under the influence of the positive plate potential, electrons flow from the cathode to the plate and return through the external plate-battery circuit to the cathode, thus completing the circuit. This flow of electrons is known as the plate current and may be measured by a sensitive current meter

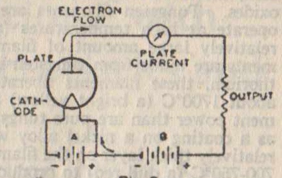


Fig. 3

If a negative potential is applied to the plate, the free electrons in the space surrounding the cathode will be forced back to the cathode and no plate current will flow Thus, the tube permits electrons to flow from the cathode to the plate but not from the plate to the cathode. If an alternating voltage is applied to the plate, the plate is alternately made positive and negative. Plate current flows only during the time when the plate is positive. Hence the current through the tube flows in one direction and is said to be rectified See Fig. 4. Diode rectifiers are used in a-c receivers to convert a.c. to d.c. for supplying "B," "C," and screen voltages to the other tubes in the receiver. Rectifier tubes may have one plate and one cathode. The 1-v and 12Z3 are of this form and are called **half-wave rectifiers**, since current can flow only during one-half of the alternating-current cycle. When two plates and one or more cathodes are used in the same tube, current may be obtained on both halves of the a-c cycle. The 5T4, 5Y3-G and 5Z3 are examples of this type and are called **full-wave rectifiers.**

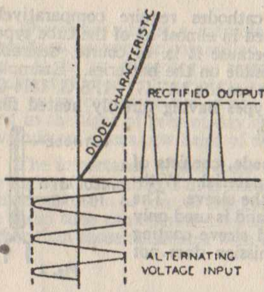


Fig. 4

Not all of the electrons emitted by the cathode reach the plate. Some return to the cathode while others remain in the space between the cathode and plate for a brief period to form an effect known as **space-charge.** This charge has a repelling action on other electrons which leave the cathode surface and impedes their passage to the plate. The extent of this action and the amount of space-charge depend on the cathode temperature and the plate potential The higher the plate potential, the less is the tendency for electrons to remain in the space-charge region and repel others. This effect may be noted by applying increasingly higher plate voltages to a tube operating at a fixed heater or filament voltage. Under these conditions, the maximum number of available electrons is fixed, but increasingly higher plate voltages will succeed in attracting a greater proportion of the free electrons.

Beyond a certain plate voltage, however, additional plate voltage has little effect in increasing the plate current. The reason is that all of the electrons emitted by the cathode are already being drawn to the plate. This maximum current is called **saturation current** (see Fig 5) and because it is an indication of the total number of electrons emitted, it is also known as the **emission current, or, simply emission.** Tubes are sometimes tested by measurement of their emission current. However, in this test it is generally not feasible to measure the full value of emission because this value would be sufficiently large to cause change in the tube's characteristics, or to damage the tube. For that reason, the test value of current in an emission test is less than the full emission current However, this test value is larger than the maximum value which will be required from the cathode in the use of the tube. The emission test, therefore, indicates whether the tube's cathode can supply a sufficiently large number of electrons for satisfactory operation of the tube.

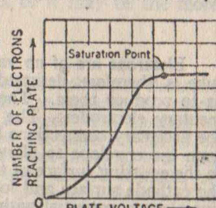


Fig. 5

If space charge were not present to repel electrons coming from the cathode, it follows that the same plate current could be produced at a lower plate voltage. One way to make the effect of space charge small is to make the distance between plate and cathode small. This means is used in rectifier types, such as the 83-v and the 25Z5, having heater-cathodes. In these types the radial distance between cathode and plate is only about two hundredths of an inch. Another means for reducing space-charge effect is utilized in the **mercury-vapor rectifier tubes,** such as the 83. This tube contains a small amount of mercury, which is partially vaporized when the tube is operated The mercury vapor consists of mercury atoms permeating the space inside the bulb. These atoms are bombarded by the electrons on their way to the plate. If the electrons are moving at a sufficiently high speed ,the collisions will tear off electrons from the mercury atoms. When this happens, the mercury atom is said to be **"ionized,"** that is, it has lost one or more electrons and, therefore, is charged positive. Ionization, in the case of mercury vapor, is made evident by a bluish-green glow between the cathode and plate. When ionization due to bombardment of mercury atoms by electrons leaving the filament occurs, the space-charge is neutralized by the positive mercury ions so that increased numbers of electrons are made available. A mercury-vapor rectifier has a small voltage drop between cathode and plate (about 15 volts). This drop is practically independent of current requirements up to the limit of emission of electrons from the filament, but is dependent to some degree on bulb temperature.

An **ionic-heated cathode rectifier tube** is another type which depends for its operation on gas ionization. The 0Z4 and 0Z4-G are tubes in this classification. They are of the full-wave design and contain two anodes and a coated cathode sealed in a bulb under a reduced pressure of inert gas. The cathode in each of these types becomes hot during tube operation but the heating effect is caused by bombardment of the cathode by the ions from within the tube rather than by heater or filament current from an external source The internal structure of the tube is designed so that when sufficient voltage is applied to the tube, ionization of the gas occurs between the anode which is instantaneously positive and the cathode. Under normal operating voltages, ionization does not take place between the anode that is negative and the cathode This, of course, satisfies the principle of rectification. The initial small flow of current through the tube is sufficient to raise the cathode temperature quickly to incandescence whereupon the cathode emits electrons. The voltage drop in such tubes is slightly higher than that of the usual hot-cathode gas rectifiers because energy is taken from the ionization discharge to keep the cathode at operating temperature. Proper operation of these rectifiers requires that a minimum load current always flow in order to maintain the cathode at the temperature required to supply sufficient emission

TRIODES

When a third electrode, called the **grid,** is placed between the cathode and plate, the tube is known as a triode, the family name for a three-electrode tube. The grid usually is a winding of wire extending the length of the cathode. The spaces between turns are comparatively large so that the passage of electrons from cathode to plate is practically unobstructed by the turns of the grid. The purpose of the grid is to control the flow of plate current. When a tube is used as an amplifier, a negative d-c voltage is usually applied to the grid. Under this condition the grid does not draw appreciable current.

The number of electrons attracted to the plate depends on the combined effect of the grid and plate polarities. When the plate is positive, as is normal, and the d-c grid voltage is made more and more negative, the plate is less able to attract electrons to it and plate current decreases. When the grid is made less and less negative the plate more readily attracts electrons to it and plate current increases. Hence, when the voltage on the grid is varied in accordance with a signal, the plate

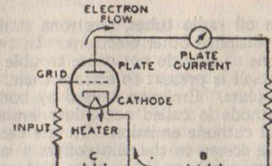


Fig. 6

current varies with the signal. Because a small voltage applied to the grid can control a comparatively large amount of plate current, the signal is amplified by the tube. Typical three-electrode tube types are the 6C5, 76, and 2A3

The grid, plate, and cathode of a triode form an electrostatic system, each electrode acting as one plate of a small condenser. The capacitances are those existing between grid and plate, plate and cathode, and grid and cathode. These capacitances are known as **interelectrode capacitances.** Generally, the capacitance between grid and plate is of the most importance. In high-gain radio-frequency amplifier circuits, this capacitance may act to produce undesired coupling between the **input circuit,** the circuit between grid and cathode, and the **output circuit,** the circuit between plate and cathode. This coupling is undesirable in an amplifier because it may cause instability and unsatisfactory performance

TETRODES

The capacitance between grid and plate can be made small by mounting an additional electrode, called the screen, in the tube. With the addition of the screen, the tube has four electrodes and is, accordingly, called a tetrode. The screen is mounted between the grid and the plate and acts as an electrostatic shield between them, thus reducing the grid-to-plate capacitance. The effectiveness of this shielding action is increased by connecting a by-pass condenser between screen and cathode. By means of the screen and this by-pass condenser, the grid-plate capacitance of a tetrode is made very small. In practice, the grid-plate capacitance is reduced from an average of 8.0 micromicrofarads ($\mu\mu$f) for a triode to 0.01 $\mu\mu$f or less for a screen-grid tube.

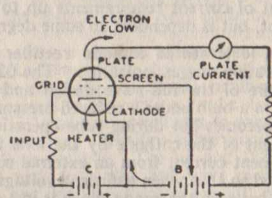


Fig 7

The screen has another desirable effect in that it makes plate current practically independent of plate voltage over a certain range. The screen is operated at a positive voltage and, therefore, attracts electrons from the cathode. But because of the comparatively large space between wires of the screen, most of the electrons drawn to the screen pass through it to the plate. Hence the screen supplies an electrostatic force pulling electrons from the cathode to the plate. At the same time the screen shields the electrons between cathode and screen from the plate so that the plate exerts very little electrostatic force on electrons near the cathode. Hence, as long as the plate voltage is higher than the screen voltage, plate current in a screen-grid tube depends to a great degree on the screen voltage and very little on the plate voltage. The fact that plate current in a screen-grid tube is largely independent of plate voltage makes it possible to obtain much higher amplification with a tetrode than with a triode. The low grid-plate capacitance makes it possible to obtain this high amplification without plate-to-grid feedback and resultant instability. Representative screen-grid types are the 32 and 24-A.

PENTODES

In all radio tubes, electrons striking the plate may, if moving at sufficient speed, dislodge other electrons. In two- and three-electrode types, these dislodged electrons usually do not cause trouble because no positive electrode other than the plate itself is present to attract them. These electrons, therefore, are drawn back to the plate. Emission caused by bombardment of an electrode by electrons from the cathode is called **secondary emission** because the effect is secondary to the original cathode emission. In the case of screen-grid tubes, the proximity of the positive screen to the plate offers a strong attraction to these secondary electrons and particularly so if the plate voltage swings lower than the screen voltage. This effect lowers the plate current and limits the permissible plate-voltage swing for tetrodes.

The plate-current limitation is removed when a fifth electrode is placed within the tube between the screen and plate. This fifth electrode is known as the suppressor and is usually connected to the cathode. Because of its negative potential with respect to the plate, the suppressor retards the flight of secondary electrons and diverts them back to the plate where they cannot cause trouble. The family name for a five-electrode tube is "pentode." In power-output pentodes the suppressor makes possible higher power output with lower grid-driving voltage; in radio-frequency amplifier pentodes the suppressor permits of obtaining high voltage amplification at moderate values of plate voltage. These desirable features are due to the fact that the plate-voltage swing can be made very large as compared with that of tetrodes. In fact, the plate voltage may be as low as, or lower than, the screen voltage without serious loss in signal gain capability. Representative power-amplifier pentodes are the 1A5-G, 6F6 and 25A6; representative r-f amplifier pentodes are the 1N5-G, 6J7, and 12SJ7.

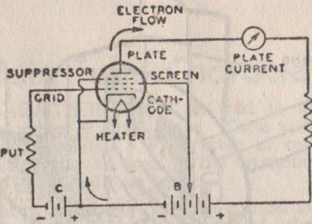


Fig. 8

BEAM POWER TUBES

A beam power tube is a tetrode or pentode in which use is made of directed electron beams to contribute substantially to its power-handling capability. Such a tube contains a cathode, a control-grid, a screen, a plate, and, optionally, a suppressor grid. When a beam power tube is designed without an actual suppressor, the electrodes are so spaced that secondary emisssion from the plate is suppressed by space-charge effects between screen and plate. The space charge is produced by the slowing up of electrons traveling from a high-potential screen to a lower potential plate. In this low-velocity region, the space charge produced is sufficient to repel secondary electrons emitted from the plate and to cause them to return to the plate. Beam power tubes of this design employ beam-forming plates at cathode potential to assist in producing the desired beam effects and to prevent stray electrons from the plate from returning to the screen outside of the beam. A feature of a beam power tube is its low screen current. The screen and the grid are spiral wires wound so that each turn of the screen is shaded from the cathode by a grid turn. This alignment of the screen and grid causes the electrons to travel in sheets between the turns of the screen so that very few of them flow to the screen. Because of the effective suppressor action provided by space charge and because of the low current drawn by the screen, the beam power tube has the advantages of high power output, high power sensitivity, and high efficiency.

Fig. 9 shows the structure of a beam power tube employing space-charge suppression and illustrates how the electrons are confined to beams. The beam condition illustrated is that for a plate potential less than the screen potential. The high-density space-charge region is indicated by the heavily dashed lines in the beam. Note that the edges of the beam-forming plates coincide with the dashed portion of the beam and thus extend the space-charge potential region beyond the beam boundaries to prevent stray secondary electrons from returning to the screen outside of the beam. The 6L6 and 6L6-G are examples of beam power tubes utilizing this construction.

In place of the space-charge effect just described, it is also feasible to use an actual suppressor to repel the secondary electrons. Examples of beam power tubes using an actual suppressor are the 6V6 and 6G6-G.

INTERNAL STRUCTURE OF TYPE 6L6 BEAM POWER TUBE

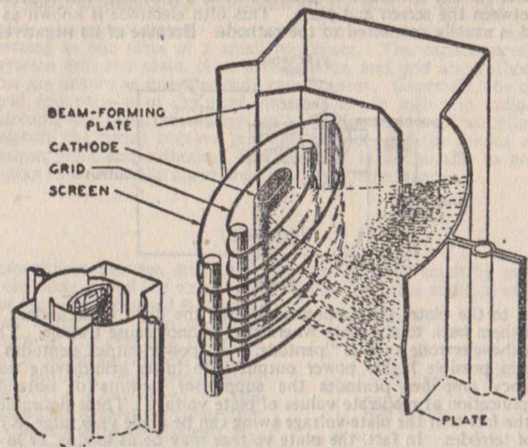


Fig. 9

MULTI-ELECTRODE and MULTI-UNIT TUBES

Early in the history of tube development and application, tubes were designed for general service; that is, a single tube type—a triode— was used as a radio-frequency amplifier, an intermediate-frequency amplifier, an audio-frequency amplifier, an oscillator or as a detector. Obviously, with this diversity of application, one tube did not meet all requirements to the best advantage.

Later and present trends of tube design are the development of "specialty" types. These types are intended either to give optimum performance in a particular application or to combine in one bulb functions which formerly required two or more tubes. The first class of tubes includes such examples of specialty types as the 6F6, 12SJ7, 6L7, and 6K8. Types of this class generally require more than three electrodes to obtain the desired special characteristics and may be broadly classed as multi-electrode types. The 6L7 is an especially interesting type in this class. This tube has an unusually large number of electrodes, namely seven, exclusive of the heater. Plate current in the tube is varied at two different frequencies at the same time. The tube is designed primarily for use as a mixer in superheterodyne receivers. In this use, the tube mixes the signal frequency with the oscillator frequency to give an intermediate-frequency output.

Tubes of the multi-electrode class often present interesting possibilities of application besides the one for which they are primarily designed. The 6L7, for instance, can also be used as a variable-gain audio amplifier in volume-expander and compressor application. The 6F6, besides its use as a power output pentode, can also be connected as a triode and used as a driver for a pair of 6L6's.

The second class includes multi-unit tubes such as the duplex-diode triodes 1H6-G and 6SQ7, as well as the duplex-diode pentodes 1F7-GV and 12C8 and the twin class A and class B types, 6C8-G and 6B8, respectively. In this class also is included the multi-unit type 1D8-GT This tube combines in one bulb three units—a diode for use as detector and avc, a triode for use as the first audio-frequency amplifier, and a power-output pentode. Related to multi-unit tubes are the electron-ray types 6E5 and 6N5. These combine a triode amplifier with a fluorescent target. Full-wave rectifiers are also multi-unit types.

A third class of tubes combines features of each of the other two classes. Typical of this third class are the pentagrid-converter types 1A7-G and 12SA7

These tubes are similar to the multi-electrode types in that they have seven electrodes. all of which affect the electron stream; and they are similar to the multi-unit tubes in that they perform simultaneously the double function of oscillator and mixer in superheterodyne receivers.

Radio Tube Characteristics

The term "CHARACTERISTICS" is used to identify the distinguishing electrical features and values of a radio tube. These values may be shown in curve form or they may be tabulated. When given in curve form. they are called characteristic curves and may be used for the determination of tube performance and the calculation of additional tube factors.

Tube characteristics are obtained from electrical measurements of a tube in various circuits under certain definite conditions of voltages. Characteristics may be further described by denoting the conditions of measurements. For example. Static Characteristics are the values obtained with different d-c potentials applied to the tube electrodes, while Dynamic Characteristics are the values obtained with an a-c voltage on the control grid under various conditions of d-c potentials on the electrodes. The dynamic characteristics, therefore, are indicative of the performance capabilities of a tube under actual working conditions.

Static characteristics may be shown by plate characteristics curves and transfer (mutual) characteristics curves. These curves present the same information, but in two different forms to increase its usefulness. The plate characteristic curve is obtained by varying plate voltage and measuring plate current for different control-grid bias voltages. while the transfer-characteristic curve is obtained by varying control-grid bias voltage and measuring plate current for different plate voltages. A plate-characteristic family of curves is illustrated by Fig. 10. Fig. 11 gives the transfer characteristic family of curves for the same tube.

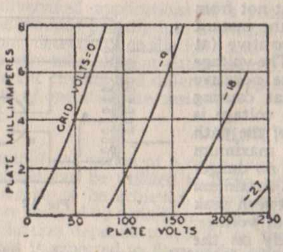


Fig 10

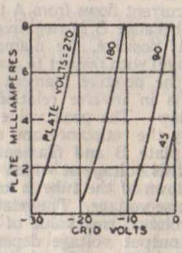


Fig. 11

Dynamic characteristics include amplification factor. plate resistance. control-grid—plate transconductance and certain detector characteristics. and may be shown in curve form for variations in tube-operating conditions.

The **amplification factor**, or μ, is the ratio of the change in plate voltage to a change in control-electrode voltage in the opposite direction. under the condition that the plate current remains unchanged. and that all other electrode voltages are maintained constant. For example, if, when the plate voltage is made 1 volt more positive, the grid voltage must be made 0.1 volt more negative to hold plate current unchanged, the amplification factor is 1 divided by 0.1, or 10. In other words, a small voltage variation in the grid circuit of a tube has the same effect on the plate current as a large plate voltage change—the latter equal to the product of the grid voltage change and amplification factor. The μ of a tube is useful for calculating stage gain as discussed on page 320

Plate resistance (r_p) of a radio tube is the resistance of the path between cathode and plate to the flow of alternating current. It is the quotient of a small change in plate voltage by the corresponding change in plate current and is expressed in ohms, the unit of resistance. Thus, if a change of 0.1 milliampere (0.0001 ampere) is produced by a plate voltage variation of 1 volt, the plate resistance is 1 divided by 0.0001, or 10000 ohms.

Control-grid—plate transconductance, or simply **transconductance** (g_m), is a factor which combines in one term the amplification factor and the plate resistance, and is the quotient of the first by the second. This term is also known as mutual conductance. Transconductance may be more strictly defined as the ratio of a small change in plate current (amperes) to the small change in the control-grid voltage producing it, under the condition that all other voltages remain unchanged. Thus, if a grid-voltage change of 0.5 volt causes a plate-current change of 1 milliampere (0.001 ampere), with all other voltages constant, the transconductance is 0.001 divided by 0.5, or 0.002 mho. A "mho" is the unit of conductance and was named by spelling ohm backwards. For convenience, a millionth of a mho or a micromho, is used to express transconductance. So, in the example, 0.002 mho is 2000 micromhos.

Conversion transconductance (g_c) is a characteristic associated with the mixer (first detector) function of tubes and may be defined as the quotient of the intermediate-frequency (i-f) current in the primary of the i-f transformer by the applied radio-frequency (r-f) voltage producing it: or more precisely, it is the limiting value of this quotient as the r-f voltage and i-f current approach zero. When the performance of a frequency converter is determined, conversion transconductance is used in the same way as control-grid—plate transconductance is used in single-frequency amplifier computations.

Maximum peak inverse voltage characteristic of a rectifier tube is the highest peak voltage that a rectifier tube can safely stand in the direction opposite to that in which it is designed to pass current. In other words, it is the safe arc-back limit with the tube operating within the specified temperature range Referring to Fig. 12, when plate A of a full-wave rectifier tube is positive, current flows from A to C, but not from B to C, because B is negative. At the instant plate A is positive, the filament is positive (at high voltage) with respect to plate B. The voltage between the positive filament and the negative plate B is in inverse relation to that causing current flow The peak value of this voltage is limited by the resistance and nature of the path between plate B and filament. The maximum value of this voltage at which there is no danger of breakdown of the tube is known as maximum peak-inverse voltage. The relations between peak inverse voltage, rms value of a-c input voltage, and d-c output voltage depend largely on the individual characteristics of the rectifier circuit and the power supply The presence of line surges or any other transient, or wave-form distortion may raise the actual peak voltage to a value higher than that calculated for sine-wave voltages. Therefor, the actual inverse voltage. and not the calculated value, should be such as not to exceed the rated maximum peak inverse voltage for the rectifier tube. A cathode-ray oscillograph or a spark gap connected across the tube is useful in determining the actual peak inverse voltage In single-phase, full-wave circuits with sine-wave input and with no condenser across the output, the peak inverse voltage on a rectifier tube is approximately 1.4 times the rms value of the plate voltage applied to the tube. In single-phase, half-wave circuits with sine-wave input and with condenser input to the filter the peak inverse voltage may be as high as 2.8 times the rms value of the applied plate voltage. In polyphase circuits, mathematical determination of peak inverse voltage requires the use of vectors.

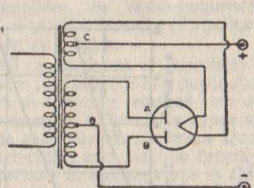


Fig 12

Maximum peak plate current is the highest steady-state peak current that a rectifier tube can safely stand in the direction in which it is designed to pass current. The safe value of this peak current in hot-cathode types of rectifiers is a function of the available emission and the duration of the pulsating current flow from the rectifier tube during each half cycle. In a given circuit, the actual value of peak plate current is largely determined by filter constants. If a large choke is used in the filter circuit next to the rectifier tubes, the peak plate current is not much greater than the load current, but if a large condenser is used in the filter next to the rectifier tubes, the peak current is often many times the load current. In order to determine accurately the peak current in any circuit, the best procedure usually is to measure it with a peak-indicating meter or to use an oscillograph.

Plate dissipation is the power dissipated in the form of heat by the plate as a result of electron bombardment. It is the difference between the power supplied to the plate of the tube and the power delivered by the tube to the load.

Screen dissipation is the power dissipated in the form of heat by the screen as a result of electron bombardment. With tetrodes and pentodes, the power dissipated in the screen circuit is added to the power in the plate circuit to obtain the total B-supply input power.

The **plate efficiency** of a power amplifier tube is the ratio of the a-c power output to the product of the average d-c plate voltage and d-c plate current at full signal, or

$$\text{Plate efficiency (\%)} = \frac{\text{power output watts}}{\text{average d-c plate volts} \times \text{average d-c plate amperes}} \times 100$$

The **power sensitivity** of a tube is the ratio of the power output to the square of the input signal voltage (RMS) and is expressed in mhos as follows:

$$\text{Power sensitivity (mhos)} = \frac{\text{power output watts}}{(\text{input signal volts, RMS})^2}$$

Radio Tube Applications

The diversified applications of a radio tube may, within the scope of this chapter, be grouped broadly into five kinds of operation. These are: Amplification, rectification, detection, oscillation, and frequency conversion. Although these operations may take place at either radio or audio frequencies and may involve the use of different circuits and different supplemental parts, the general considerations of each kind of operation are basic.

AMPLIFICATION

The amplifying action of a radio tube was mentioned under TRIODES, page 7. This action can be utilized in radio circuits in a number of ways, depending upon the results to be achieved. Four classes of amplifier service recognized by engineers are covered by definitions standardized by the Institute of Radio Engineers. This classification depends primarily on the fraction of input cycle during which plate current is expected to flow under rated full-load conditions. The classes are class A, class AB, class B, and class C. The term, cut-off bias, used in these definitions is the value of grid bias at which plate current is some very small value.

Class A Amplifier. A class A amplifier is an amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows at all times.

Class AB Amplifier. A class AB amplifier is an amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows for appreciably more than half but less than the entire electrical cycle.

Class B Amplifier. A class B amplifier is an amplifier in which the grid bias is approximately equal to the cut-off value so that the plate current is approximately zero when no exciting grid voltage is applied, and so that plate current in a specific tube flows for approximately one-half of each cycle when an alternating grid voltage is applied.

Class C Amplifier. A class C amplifier is an amplifier in which the grid bias is appreciably greater than the cut-off value so that the plate current in each tube is zero when no alternating grid voltage is applied, and so that plate current flows in a specific tube for appreciably less than one-half of each cycle when an alternating grid voltage is applied

NOTE:—To denote that grid current does not flow during any part of the input cycle, the suffix 1 may be added to the letter or letters of the class identification. The suffix 2 may be used to denote that grid current flows during some part of the cycle.

For radio-frequency amplifiers which operate into a selective tuned circuit as in radio transmitter applications, or under requirements where distortion is not an important factor, any of the above classes of amplifiers may be used, either with a single tube or a push-pull stage. For audio-frequency amplifiers in which distortion is an important factor, only class A amplifiers permit single-tube operation. In this case, operating conditions are usually chosen so that distortion is kept below the conventional 5% for triodes and the conventional 7 to 10% for tetrodes or pentodes. Distortion can be reduced below these figures by means of special circuit arrangements such as that discussed under inverse feedback. With class A amplifiers, reduced distortion with improved power performance can be obtained by using a push-pull stage for audio service. With class AB and class B amplifiers, a balanced amplifier stage using two tubes is required for audio service

As a class A voltage amplifier, a radio tube is used to reproduce grid voltage variations across an impedance or a resistance in the plate circuit. These variations are essentially of the same form as the input signal voltage impressed on the grid but of increased amplitude. This is accomplished by operating the tube at a suitable grid bias so that the applied grid-input voltage produces plate-current variations proportional to the signal swings. Since the voltage variation obtained in the plate circuit is much larger than that required to swing the grid, amplification of the signal is obtained. Fig 13 gives a graphical illustration of this method of amplification and shows, by means of the grid-voltage vs. plate-current characteristics curve the effect of an input signal (S) applied to the grid of a tube. O is the resulting amplified plate-current variation.

The plate current flowing through the load resistance (R) of Fig. 14 causes a voltage drop which varies directly with the plate current. The ratio of this voltage variation produced in the load resistance to the input signal voltage is the voltage

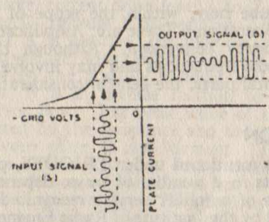


Fig. 13

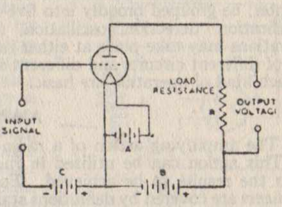


Fig. 14

amplification or gain, provided by the tube. The voltage amplification due to the tube is expressed by the following convenient formulas:

$$\text{Voltage amplification} = \frac{\text{amplification factor} \times \text{load resistance}}{\text{load resistance} + \text{plate resistance}}, \text{ or}$$

$$\frac{\text{transconductance in micromhos} \times \text{plate resistance} \times \text{load resistance}}{1000000 \times (\text{plate resistance} + \text{load resistance})}$$

From the first formula, it can be seen that the gain actually obtainable from the tube is less than the tube's amplification factor but that the gain approaches the amplification factor when the load resistance is large compared to the tube's plate resistance. Fig. 15 shows graphically how the gain approaches the mu of the tube as load resistance is increased. From the curve it can be seen that to obtain high gain in a voltage amplifier, a high value of load resistance should be used.

In a resistance-coupled amplifier, the load resistance of the tube is approximately equal to the resistance of the plate resistor in parallel with the grid resistor of the following stage. Hence, to obtain a large value of load resistance, it is necessary

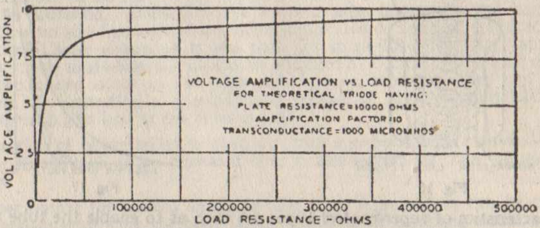


Fig. 15

to use a plate resistor and a grid resistor of large resistance. However, the plate resistor should not be too large because the flow of plate current through the plate resistor produces a voltage drop which reduces the plate voltage applied to the tube. If the plate resistor is too large, this drop will be too large the plate voltage on the tube will be too small and the voltage output of the tube will be too small. Also, the grid resistor of the following stage should not be too large, the actual maximum value being dependent on the particular tube type. A higher value of grid resistance is permissible when cathode bias is used than when fixed bias is used. When cathode bias is used a loss in bias due to grid-emission effects is nearly completely offset by an increase in bias due to the voltage drop across the cathode resistor The recommended values of plate resistor and grid resistor for the tube types used in resistance-coupled circuits, and the values of gain obtainable, are shown in the RESISTANCE-COUPLED AMPLIFIER SECTION

The **input impedance** of a radio tube that is, the impedance between grid and cathode, consists of (1) the capacitance between grid and cathode, (2) a resistance component resulting from the time of transit of electrons between cathode and grid, and (3) a resistance component developed by the part of the cathode lead inductance which is common to both the input and output circuits. Components (2) and (3) are dependent on the frequency of the incoming signal. The input impedance is very high at audio frequencies when a tube is operated with its grid biased negative Hence, in a class A_1 or class AB_1 transformer-coupled audio amplifier the loading imposed by the grid on the input transformer is negligible The secondary impedance of a class A_1 or class AB_1 input transformer can, therefore be made very high since the choice is not limited by the input impedance of the tube however transformer design considerations may limit the choice. At the higher radio frequencies the input impedance may become very low even when the grid is negative, due to the finite time of passage of electrons between cathode and plate and to the appreciable lead reactance This impedance drops very rapidly as the frequency is raised and increases input-circuit loading. In fact, the input impedance may become low enough at very high radio frequencies to affect appreciably the gain and selectivity of a preceding stage. Tubes such as the Acorn* types have been developed to have low input capacitances, low electron transit time and low lead inductance so that their input impedance is high even at the ultra-high radio frequencies.

A **super-control amplifier tube** is a modified construction of a pentode or a tetrode type and is designed to reduce modulation-distortion and cross-modulation in radio-frequency stages. **Cross-modulation** is the effect produced in a radio receiver by an interfering station "riding through" on the carrier of the station to which the receiver is tuned. **Modulation-distortion** is a distortion of the modulated carrier and appears as audio-frequency distortion in the output. This effect is produced by a radio-frequency amplifier stage operating on an excessively curved

* Registered Trademark

characteristic when the grid bias has been increased to reduce volume. The offending stage for cross-modulation is usually the first radio-frequency amplifier, while for modulation-distortion, the cause is usually the last intermediate-frequency stage.

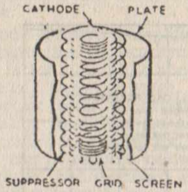


Fig. 16

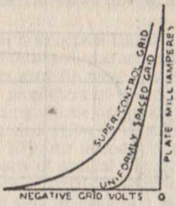


Fig. 17

The characteristics of super-control types are such as to enable the tube to handle both large and small input signals with minimum distortion over a wide range. A cross-section of the structure of a 6K7, a typical super-control pentode, is shown in Fig. 16. The super-control action is due to the structure of the grid which provides a variation in amplification factor with change in grid bias. The grid is wound with coarse spacing at the middle and with close spacing at the ends. When weak signals and low grid bias are applied to the tube, the effect of the non-uniform turn spacing of the grid on cathode emission and tube characteristics is essentially the same as for uniform spacing. As the grid bias is made more negative to handle larger input signals the electron flow from the sections of the cathode enclosed by the ends of the grid is cut off. The plate current and other tube characteristics are then dependent on the electron flow through the coarse section of the grid. This action changes the gain of the tube so that large signals may be handled with minimum distortion due to cross-modulation and modulation distortion. Fig. 17 shows a typical plate-current vs. grid-voltage curve for a super-control type compared with the curve for a type having a uniformly spaced grid. It will be noted that while the curves are similar at small grid-bias voltages, the plate current of the super-control tube drops quite slowly with large values of bias voltage. This slow change makes it possible for the tube to handle large signals satisfactorily. Since super-control types can accommodate large and small signals, they are particularly suitable for use in sets having automatic volume control. Super-control tubes also are known as remote cut-off types.

As a class A power amplifier, a radio tube is used in the output stage of radio receivers to supply relatively large amounts of power to the loudspeaker. For this application, large power output is of much greater importance than high-voltage amplification, so that gain possibilities are sacrificed in the design of power tubes to obtain power-handling capability. Power tubes of the triode type in class A service are characterized by low power sensitivity, low plate-power efficiency, and low distortion. Power tubes of the pentode type are characterized by high power sensitivity, high plate-power efficiency, and relatively high distortion. Beam power tubes such as the 6L6 have a still higher power sensitivity and efficiency and have a higher power output capability than triode or conventional pentode types.

A class A power amplifier is also used as a driver to supply power to a class AB or a class B output stage. It is usually advisable to use a triode type, rather than a pentode, in a driver stage because of the lower distortion of the triode.

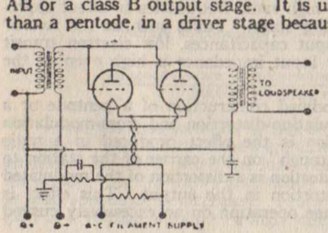


Fig. 18

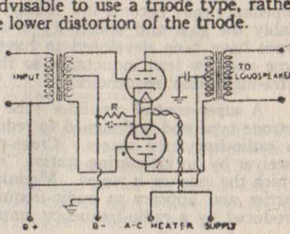


Fig. 19

Either **push-pull or parallel operation** of power tubes may be employed with class A amplifiers to obtain increased output. The parallel connection (Fig. 18) provides twice the output of a single tube with the same value of grid-signal voltage. The push-pull connection (Fig. 19) requires twice the input-signal voltage, but has, in addition to an increase in power, a number of important advantages over single-tube operation. Distortion due to even-order harmonics and hum due to plate-supply-voltage fluctuations are either eliminated or decidedly reduced through cancellation. Since distortion is less than for single-tube operation, appreciably more than twice single-tube output can be obtained by decreasing the load resistance. Should oscillations occur in the push-pull or parallel stages, they can often be eliminated by connecting a non-inductive resistor of approximately 500 ohms in series with each grid lead at the tube socket.

Operation of power tubes so that the grids run positive is inadvisable except under conditions such as are discussed later in this section for class AB and class B amplifiers.

Power output for triodes as single-tube, class A amplifiers can be calculated without serious error from the plate family of curves by assuming a resistance load. The proper plate current, grid bias, and optimum load resistance, as well as the per cent second-harmonic distortion, can also be determined. The calculations are made graphically and are illustrated by Fig. 20 for given conditions. The procedure is as follows: Draw a straight line XY through the points P and X on the plate family of curves. P is known as the zero-signal bias point and may readily be located by determining the zero-signal bias, E_{c_o}, from the following formula

$$\text{Zero-signal bias (P)} = \frac{0.68 \times E_b}{\mu}$$

where E_b is the chosen value of d-c plate voltage at which the tube is to be operated and μ is the amplification factor of the tube. X is a point on the d-c bias curve at zero volts and is determined by the value of the maximum-signal plate current, I max., which is equal to twice the zero-signal plate current, or $2I_o$. In the case of filament types of tubes, the calculations are given on the basis of a d-c operated filament. When, however, the filament is a-c operated, the calculated value of d-c bias should be increased by approximately one half the filament-voltage rating of the tube.

Line XY is known as the load-resistance line. Its slope corresponds to the value of the load resistance. The load resistance in ohms is equal to (E max.—E min.) divided by (I max.—I min.), where E is in volts and I in amperes.

For power output calculations, it is assumed that the peak alternating grid voltage is sufficient (1) to swing the grid from the zero-signal bias value to zero bias on the positive swing and (2) to a value twice the zero-signal bias value on the negative swing. During the positive swing, the plate voltage and plate current reach values of E min. and I max.; during the negative swing, they reach values of E max. and I min. Since power is the product of voltage and current, the average power output, as indicated by a wattmeter, is given by

$$\text{Power output} = \frac{(\text{I max.} - \text{I min.})\,(\text{E max.} - \text{E min.})}{8}$$

where E is in volts, I in amperes, and power output in watts.

In the output of a power amplifier triode, some distortion is present. This distortion is predominately second-harmonic in single-tube amplifiers. The percentage of second-harmonic distortion may be calculated by the following formula:

$$\text{\% 2nd harmonic distortion} = \frac{\dfrac{\text{I max.} + \text{I min.}}{2} - I_o}{\text{I max.} - \text{I min.}} \times 100$$

where Io is the zero-signal plate current in amperes.

Example: Determine the load resistance and undistorted power output of a triode operated at 250 volts on the plate, given its amplification factor of 3.5 and its plate characteristics curves as shown in Fig. 20.

Procedure: Draw the load line XY through the operating point (P) and the zero d-c grid bias point (X)

$$P = \frac{0.68 \times 250}{3.5}, \text{ or } -48.5 \text{ volts}$$

$$X = 2 \times 0.0335, \text{ or } 0.067 \text{ ampere}$$

By substituting the curve values in the power output formula, we find

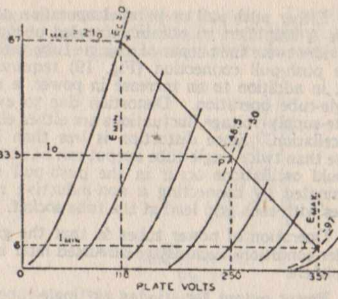


Fig. 20

$$\text{Power output} = \frac{(0.067 - 0.006)\ (357 - 118)}{8} = 1.8 \text{ watts}$$

The resistance of the load line XY is

$$\frac{357 - 118}{0.067 - 0.006}, \text{ or } 3920 \text{ ohms}$$

If now, the values from the curves are substituted in the distortion formula, we have

$$\text{2nd harmonic distortion} = \frac{\frac{0.067 + 0.006}{2} - 0.0335}{0.067 - 0.006} \times 100 = 4.9\%$$

It is customary to make the selection of load resistance such that the distortion as calculated from the above equation does not exceed 5 per cent. When the method shown above is used to determine the slope of the load resistance line, 2nd harmonic distortion in the output of a triode power amplifier is generally less than 5 per cent. Ordinarily, the plate load resistance for a single-tube amplifier is approximately equal to twice the plate resistance.

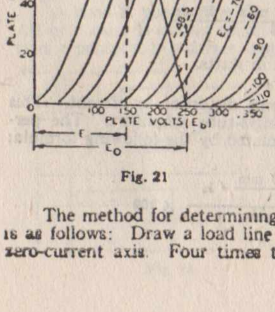


Fig. 21

Power output for triodes in push-pull power amplifiers may be determined by means of the plate family, given Eo as the desired operating plate voltage. The method is to erect a vertical line at E = 0.6 Eo (see Fig. 21), intersecting the Ec = 0 curve at the point I max. This establishes I max. Then,

$$\text{Power output} = \frac{I\ max \times Eo}{5}$$

If I max. is expressed in amperes and Eo in volts, power output is in watts.

Fig. 21 illustrates the application of this method to the case of two type 45's operated at Eo = 250 volts

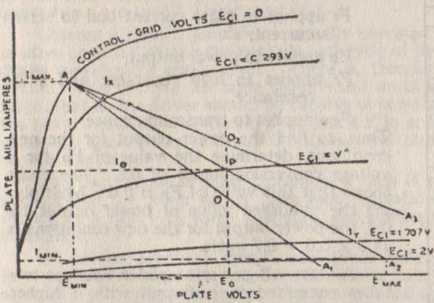
$$\text{Power output} = \frac{0.096 \times 250}{5} = 4.8 \text{ watts}$$

The method for determining the proper load resistance for triodes in push-pull is as follows: Draw a load line through I max. and through the Eo point on the zero-current axis. Four times the resistance represented by this load line is the plate-to-plate load for two triodes in a class A push-pull amplifier. From the curves in Fig. 21. we have

$$\text{Plate-to-plate load} = \frac{Eo - 0.6\ Eo}{I\ max.} \times 4 = \frac{100}{0.096} \times 4 = 4160 \text{ ohms}$$

This simple formula is applicable to all power output triodes, in push-pull. The operating grid-bias voltage can be anywhere between that specified for single-tube operation and that equal to one-half the grid-bias voltage required to produce plate-current cut-off at a plate voltage of 1.4 Eo. Thus, for single-tube operation of the type 45, the grid-bias voltage is recommended as -50 volts for 250 volts on the plate. Plate-current cut-off at 1.4 Eo, or 350 volts, occurs at -110 volts on the grid. One-half of this value is -55 volts, which is the most negative value permissible without departing from class A conditions. Operation beyond this point will be accompanied by rectification and will no longer be representative of a class A amplifier

Power output for pentode and for beam power tubes as class A amplifiers can be calculated in much the same way as for triodes. The calculations can be made graphically from a special plate family, as illustrated in Fig 22. From a point A just above the knee of the zero-bias curve, draw arbitrarily selected load lines to the zero plate-current axis. These lines should be on both sides of the operating point P whose position is determined by the desired operating plate voltage, Eo, and one half the maximum-signal plate current. Along any load line, say AA_1, measure the distance AO_1. On the same line, lay off any equal distance O_1A_1. For optimum operation, the change in bias from A to O_1 should nearly equal the change in bias from O_1 to A_1. If this condition cannot be met with one line, then another line should be selected. When the most satisfactory line has been chosen, its resistance may then be determined by the following formula



*V IS THE CONTROL-GRID BIAS VOLTAGE AT THE OPERATING POINT

Fig 22

$$\text{Load resistance (Rp)} = \frac{E\ max - E\ min}{I\ max. - I\ min}$$

The value of Rp may then be substituted in the following formula for calculating power output

$$\text{Power output} = \frac{[I\ max. - I\ min + 1.41\ (Ix - Iy)]^2\ Rp}{32}$$

For both of these formulas, if I is in amperes and E in volts, R_p is in ohms and power output is in watts

Calculations for distortion may be made by means of the following formulas The terms used have already been defined

$$\%\ \text{2nd harmonic distortion} = \frac{I\ max. + I\ min - 2\ Io}{I\ max - I\ min + 1.41\ (Ix - Iy)} \times 100$$

$$\%\ \text{3rd harmonic distortion} = \frac{I\ max. - I\ min. - 1.41\ (Ix - Iy)}{I\ max - I\ min. + 1.41\ (Ix - Iy)} \times 100$$

$$\%\ \text{total (2nd and 3rd) harmonic distortion} = \sqrt{(\%\ \text{2nd har dist.})^2 + (\%\ \text{3rd har dist.})^2}$$

The conversion curves given in Fig. 23 apply to radio tubes in general but are particularly useful for power tubes. These curves can be used for calculating approximate operating conditions for a plate voltage which is not included in the published data on operating conditions. For instance, suppose it is desired to operate two 6L6's in class A_1 push-pull, fixed bias, with a plate voltage of 200 volts. The nearest published operating conditions for this class of service are for a plate voltage of 250 volts. The operating conditions for the new plate voltage can be determined as follows: First compute the ratio of the new plate voltage to the plate voltage of the published data. In the example this ratio is 200/250 = 0.8. This figure is the Voltage Conversion Factor, F_e. Multiply by this factor to obtain the new values of grid bias and screen voltage. This gives a grid bias of $-16 \times 0.8 = -12.8$ volts, and a screen voltage of $250 \times 0.8 = 200$ volts for the new conditions

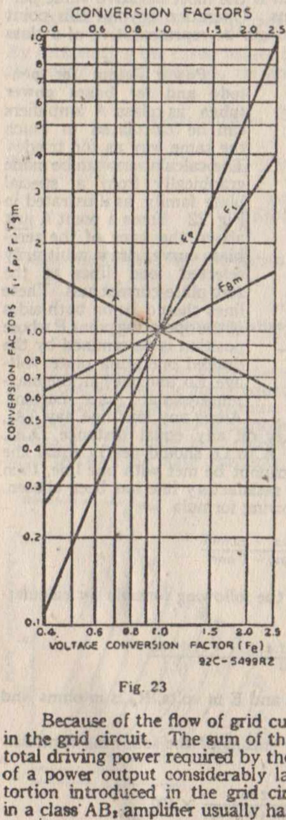


Fig. 23

To obtain the rest of the new conditions, multiply the published values by factors shown on the chart as corresponding to a voltage conversion factor of 0.8. In this chart,

- F_i applies to plate current and to screen current,
- F_p applies to power output,
- F_r applies to load resistance and plate resistance,
- F_{gm} applies to transconductance.

Thus, to find the power output for the new conditions, determine the value of F_p for a voltage conversion factor of 0.8. The chart shows that this value of F_p is 0.6. Multiplying the published value of power output by 0.6, the power output for the new conditions is $14.5 \times 0.6 = 8.7$ watts.

A class AB power amplifier employs two tubes connected in push-pull with a higher negative grid bias than is used in a class A stage. With this higher negative bias, the plate and screen voltages can usually be made higher than for class A because the increased negative bias holds plate current within the limit of the tube's plate dissipation rating. As a result of these higher voltages, more power output can be obtained from class AB operation.

Class AB amplifiers are subdivided into class AB_1 and class AB_2. In class AB_1 there is no flow of grid current. That is, the peak signal voltage applied to each grid is not greater than the negative grid-bias voltage. The grids therefore are not driven to a positive potential and do not draw grid current. In class AB_2, the peak signal voltage is greater than the bias so that the grids are driven positive and draw grid current.

Because of the flow of grid current in a class AB_2 stage there is a loss of power in the grid circuit. The sum of this loss and the loss in the input transformer is the total driving power required by the grid circuit. The driver stage should be capable of a power output considerably larger than this required power in order that distortion introduced in the grid circuit be kept low. The input transformer used in a class AB_2 amplifier usually has a step-down turns ratio.

Because of the large fluctuations of plate current in a class AB_2 stage, it is important that the power supply should have good regulation. Otherwise the fluctuations in plate current cause fluctuations in the voltage output of the power supply, with the result that power output is decreased and distortion is increased. To obtain satisfactory regulation it is usually advisable to use a choke-input filter.

It is sometimes advisable to use a mercury-vapor rectifier tube rather than a vacuum type because of the better regulation of the mercury-vapor type. In all cases, the resistance of the filter chokes and power transformer should be as low as possible.

A **class B power amplifier** employs two tubes connected in push-pull, so biased that plate current is almost zero when no signal voltage is applied to the grids. Because of this low value of no-signal plate current, class B amplification has the same advantage as class AB, that large power output can be obtained without excessive plate dissipation. The difference between class B and class AB is that, in class B, plate current is cut off for a larger portion of the negative grid swing.

There are several tube types designed especially for class B amplification. The characteristic common to all these types is high amplification factor. With this high amplification factor, plate current is small when grid voltage is zero. These tubes, therefore, can be operated in class B at a bias of zero volts so that a bias supply is not required. A number of the class B amplifier tube types consist of two triode units mounted in one tube. The two triode units can be connected in push-pull so that only one tube is required for a class B stage. Examples of class B twin triode types are the 6N7, 6A6, and 1G6-G.

Because a class B amplifier is usually operated at zero bias, each grid is at a positive potential during the positive half-cycle of its signal swing and consequently draws considerable grid current. There is, therefore, a loss of power in the grid circuit. This imposes the same requirement on the driver stage as in a class AB_2 stage, that is, the driver should be capable of considerably more power output than the power required for the class B grid circuit in order that distortion be low. The interstage transformer between the driver and class B stage usually has a step-down turns ratio.

The fluctuations in plate current in a class B stage are large so that it is important that the power supply have good regulation. The discussion of the power supply for a class AB_2 stage, therefore, also applies to the power supply for a class B amplifier.

An **inverse-feedback** circuit, sometimes called a **degenerative** circuit, is one in which a portion of the output voltage of a tube is applied to the input of the same or a preceding tube in opposite phase to the signal applied to the tube. Two important advantages of feedback are: (1) reduced distortion from each stage included in the feedback circuit and (2) reduction in the variations in gain due to changes in line voltage, possible differences between tubes of the same type, or variations in the values of circuit constants included in the feedback circuit.

Inverse feedback is used in audio amplifiers to reduce distortion in the output stage where the load impedance on the tube is a loudspeaker. Because the impedance of a loudspeaker is not constant for all audio frequencies, the load impedance on the output tube varies with frequency. When the output tube is a pentode or beam power tube having high plate resistance, this variation in plate load impedance can, if not corrected, produce considerable frequency distortion. Such frequency distortion can be reduced by means of inverse feedback. Inverse feedback circuits are of the **constant voltage** type and the **constant-current** type.

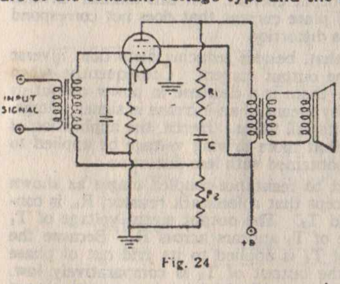


Fig. 24

The application of the **constant voltage** type of inverse feedback to a power output stage using a single beam power tube is illustrated by Fig 24. In this circuit, R_1, R_2, and C are connected across the output of the 6L6 as a voltage divider. The secondary of the grid-input transformer is returned to a point on this voltage divider. Condenser C blocks the d-c plate voltage from the grid. However, a portion of the tube's a-f output voltage, approximately equal to the output voltage multiplied by the fraction $R_2/(R_1 + R_2)$, is applied to the grid. There results a decrease in distortion which can be explained by the curves of Fig. 25.

Consider first the amplifier without the use of inverse feedback. Suppose that when a signal voltage e_s is applied to the grid the a-f plate current i'_p has an irregularity in its positive half-cycle. This irregularity represents a departure from the waveform of the input signal and is, therefore, distortion. For this plate-current waveform, the a-f plate voltage has a waveform shown by e_p. The plate-voltage waveform is inverted compared to the plate-current waveform because a plate-current increase produces an increase in the drop across the plate load. The voltage at the plate is the difference between the drop across the load and the supply voltage; thus, when plate current goes up, plate voltage goes down when plate current goes down, plate voltage goes up.

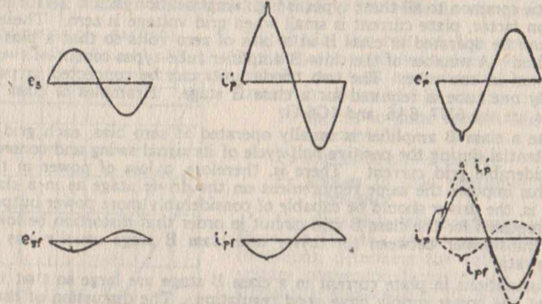


Fig. 25

Now suppose that inverse feedback is applied to the amplifier. The distortion irregularity in plate current is corrected in the following manner With an inverse feedback arrangement, the voltage fed back to the grid has the same waveform and phase as the plate voltage, but is smaller in magnitude. Hence, with a plate voltage of waveform shown by e_p, the feed-back voltage appearing on the grid is as shown by e'_{gf}. This voltage applied to the grid produces a component of plate current i'_{pf}. It is evident that the irregularity in the waveform of this component of plate current would act to cancel the original irregularity and thus reduce distortion.

After the correction of distortion has been applied by inverse feedback, the relations are as shown in the curve for i_p. The dotted curve shown by i_{pf} is the component of plate current due to the feedback voltage on the grid. The dotted curve shown by i'_p is the component of plate current due to the signal voltage on the grid. The algebraic sum of these two components gives the resultant plate current shown by the solid curve of i_p. Since i_p is the plate current that would flow without inverse feedback, it can be seen that the application of inverse feedback has reduced the irregularity in the output current. In this manner inverse feedback acts to correct any component of plate current that does not correspond to the input signal voltage, and thus reduces distortion

From the curve for i_p, it can be seen that, besides reducing distortion inverse feedback also reduces the amplitude of the output current. Consequently, when inverse feedback is applied to an amplifier there is a decrease in power output as well as a decrease in distortion. However, by means of an increase in signal voltage, the power output can be brought back to its full value. Hence, the application of inverse feedback to an amplifier requires that more driving voltage be applied to obtain full power output but this output is obtained with less distortion.

Inverse feedback may also be applied to resistance-coupled stages as shown in Fig. 26. The circuit is conventional except that a feedback resistor, R_3, is connected between the plates of tubes T_1 and T_2. The output signal voltage of T_1 and a portion of the output signal voltage of T_2 appears across R_1. Because the distortion generated in the plate circuit of T_2 is applied to its grid out of phase with the input signal, the distortion in the output of T_2 is comparatively low. With sufficient inverse feedback of the constant-voltage type in a power-output stage, it is not necessary to employ a network of resistance and capacitance in the output circuit to reduce response at high audio freqencies. Inverse feedback circuits can also be applied to push-pull class A and class AB_1 amplifiers. When the circuit in Fig. 24 is used in push-pull, the input transformer must have a separate secondary for each grid. Inverse feedback is not recommended for use in amplifiers drawing grid power because of the resistance introduced in the grid circuit.

Constant-current inverse feedback is usually obtained by omitting the by-pass condenser across a cathode resistor. This method decreases the gain and the distortion but increases the plate resistance of the tube. When the plate resistance of an output tube is increased, the output voltage rises at the resonant frequency of the loudspeaker and accentuates hang-over effects.

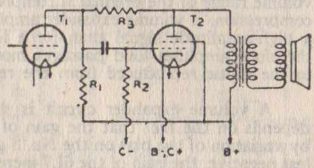


Fig. 26

Inverse feedback is not generally applied to a triode power amplifier such as the 2A3 because the variation in speaker impedance with frequency does not produce much distortion in a triode stage having low plate resistance. It is sometimes applied in a pentode stage but is not always convenient. As has been shown, when inverse feedback is used in an amplifier, the driving voltage must be increased in order to give full power output. When inverse feedback is used with a pentode, the total driving voltage required for full power output may be inconveniently large. Because a beam power tube gives full power output on a comparatively small driving voltage, inverse feedback is especially applicable to beam power tubes. By means of inverse feedback, the high efficiency and high power output of beam power tubes can be combined with freedom from the effects of varying speaker impedance

A corrective filter can be used to improve the frequency characteristic of an output stage, using a beam power tube or a pentode, when inverse feedback is not applicable. The filter consists of a resistor and a condenser connected in series across the primary of the output transformer Connected in this way, the filter is in parallel with the plate-load impedance reflected from the voice-coil by the output transformer. The magnitude of this reflected impedance increases with increasing frequency in the middle and upper audio range. The impedance of the filter, however, decreases with increasing frequency. It follows that by use of the proper values for the resistance and the capacitance in the filter, the effective load impedance on the output tubes can be made practically constant for all frequencies in the middle and upper audio range. The result is an improvement in the frequency characteristic of the output stage

The resistance to be used in the filter for a push-pull stage is 1.3 times the recommended plate-to-plate load resistance; or, for a single-tube stage, is 1.3 times the recommended plate load resistance The capacitance in the filter should have a value such that the voltage gain of the output stage at a frequency of 1000 cycles or higher is equal to the voltage gain at 400 cycles. A method of determining the proper value of capacitance for the filter is to make two measurements on the output voltage across the primary of the output transformer: first when a 400-cycle signal is applied to the input, and second, when a 1000-cycle signal of the same voltage as the 400-cycle signal is applied to the input. The correct value of capacitance is the one which gives equal output voltages for the two signal inputs In practice, this value is usually found to be on the order of 0.05 μf

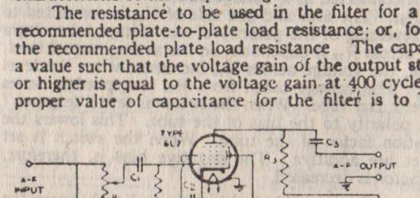


Fig. 27

A volume expander can be used in a phonograph amplifier to make more natural the reproduction of music which has a very large volume range. For instance, in the music of a symphony orchestra the sound intensity of the loud passages is very much higher than that of the soft passages. When this music is recorded, it is not feasible to make the ratio of maximum amplitude to minimum amplitude as large on the record as it is in the original music. The recording process is therefore monitored so that the volume range of the original is compressed on the record. To compensate for this compression, a volume-expander amplifier has a variable gain which is greater for a high-amplitude signal than for a low-amplitude signal. The volume expander therefore amplifies loud passages more than soft passages and thus can restore to the music reproduced from the record the volume range of the original.

A volume expander circuit is shown in Fig. 27. The action of this circuit depends on the fact that the gain of the 6L7 as an audio amplifier can be varied by variation of the bias on the No. 3 grid. When the bias on the No. 3 grid is made less negative, the gain of the 6L7 increases. In the circuit, the signal to be amplified is applied to the No. 1 grid of the 6L7 and is amplified by the 6L7. The signal is also applied to the grid of the 6C5, is amplified by the 6C5, and is rectified by the 6H6. The rectified voltage developed across R8, the load resistor of the 6H6, is applied as a positive bias voltage to the No. 3 grid of the 6L7. Then, when the amplitude of the signal input increases, the voltage across R8 increases, and the bias on the No. 3 grid of the 6L7 is made less negative. Because this increases the gain of the 6L7, the gain of the amplifier increases with increase in signal amplitude and thus produces volume expansion of the signal.

The No. 1 grid of the 6L7 is a variable-mu grid and therefore will produce distortion if the input signal voltage is too large. For that reason, the signal input to the 6L7 should not exceed a peak value of 1 volt. This value is of the same order as the voltage obtainable from the usual magnetic phonograph pick-up. The no-signal bias voltage on the No. 3 grid is controlled by adjustment of contact P. This contact should be adjusted initially to give a no-signal plate current of 0.15 milliampere in the 6L7. No further adjustment of contact P is required if the same 6L7 is always used. If it is desired to delay volume expansion until the signal input reaches a certain amplitude, the delay voltage can be inserted as a negative bias on the 6H6 plates at the point marked X in the diagram.

Another circuit using volume expansion is shown in CIRCUIT SECTION. This circuit can also be used to provide **volume compression** for microphone operation. Volume compression prevents overloading and blasting and compensates for differences in voice level produced by movements of the speaker at the microphone. In this circuit the 6H6 is connected as a voltage doubler. The d-c output is applied across potentiometer R_{26}. The arm and one side of R_{26} is connected to the d.p.d.t. switch S_2 to permit reversing of the polarity of the voltage taken from R_{26}. The amount of d-c voltage across R_{26} is dependent on the average signal level. When the level tends to increase, the voltage across R_{26} increases; when the level decreases, the voltage decreases. The voltage taken from R_{26} is applied in series with the control-bias of the master mixer tube. When the switch is set to "expand," the voltage becomes opposite in polarity to the bias of the tube. This lowers the bias and increases the amplification factor of the tube. When the switch is set to "compress," the two voltages are additive. The negative bias is, therefore, increased and the amplification factor is decreased.

A **phase inverter** is a circuit used to provide resistance coupling between the output of a single-tube stage and the input of a push-pull stage. The necessity for a phase inverter arises because the signal-voltage inputs to the grids of a push-pull stage must be 180 degrees out of phase and approximately equal in amplitude with respect to each other. Thus, when the signal voltage input to a push-pull stage swings the control grid of one tube in a positive direction, it should swing the other grid in a negative direction by a similar amount. With transformer coupling between stages, the out-of-phase input voltage to the push-pull stage is supplied by means of the center-tapped secondary. With resistance coupling, the out-of-phase input voltage is obtained by means of the inverter action of a tube.

Fig. 28 shows a push-pull power amplifier, resistance-coupled by means of a phase-inverter circuit to a single-stage triode T_1. Phase inversion in this circuit is provided by triode T_2. The output voltage of T_1 is applied to the grid of T_3. A portion of the output voltage of T_1 is also applied through the resistors R_3 and R_5 to the grid of T_2. The output voltage of T_2 is applied to the grid of T_4. When the output voltage of T_1 swings in the positive direction, the plate current of T_2 increases. This action increases the voltage drop across the plate resistor R_2 and swings the plate of T_2 in the negative direction. Thus, when the output voltage of T_1 swings positive, the output voltage of T_2 swings negative and is, therefore, 180° out of phase with the output voltage of T_1. In order to obtain equal voltages at E_a and E_b, the signal applied to the grid of T_2 should be less than the voltage at E_b in the ratio of the voltage gain of T_2. Under the conditions where a twin-type tube or two tubes having the same characteristics are used at T_1 and T_2, R_4 should be equal to the sum of R_3 and R_5. The ratio of R_5 to R_3 plus R_5 should be the same as the voltage gain ratio of T_2 in order to apply the correct value of signal voltage to T_2. The value of R_5 is, therefore, equal to R_4 divided by the voltage gain of T_2; R_3 is equal to R_4 minus R_5.

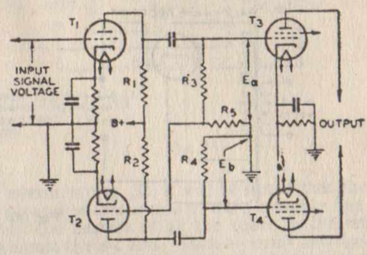
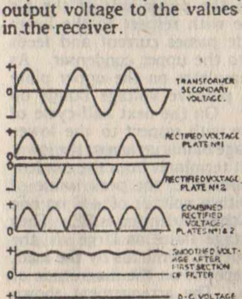


Fig. 28

Values of R_1, R_2, R_3 plus R_5, and R_4 may be taken from the chart in the RESISTANCE-COUPLED AMPLIFIER SECTION. In the practical application of this circuit, it is convenient to use a twin-triode tube combining T_1 and T_2.

RECTIFICATION

The rectifying action of a diode finds an important application in supplying a receiver with d-c power from an a-c line. A typical arrangement for this application includes a rectifier tube, a filter, and a voltage divider. The rectifying action of the tube is explained briefly under DIODES, page 312 The function of a filter is to smooth out the ripple of the tube output, as indicated in Fig 29. The action of the filter is explained on page 347 The voltage divider is used to cut down the output voltage to the values required by the plates, screens, and grids of the tubes in the receiver.



FULL-WAVE RECTIFICATION

Fig. 29

A half-wave rectifier and a full-wave rectifier circuit are shown in Fig. 30. In the half-wave circuit, current flows through the rectifier tube to the filter on every other half-cycle of the a-c input voltage when the plate is positive with respect to the cathode. In the full-wave circuit, current flows to the filter on every half-cycle, through plate No. 1 on one half-cycle when plate No. 1 is positive with respect to the cathode, and through plate No. 2 on the next half-cycle when plate No. 2 is positive with respect to the cathode. Because the current flow to the filter is more uniform in the full-wave circuit than in the half-wave circuit, the output of the full-wave circuit requires less filtering.

Parallel operation of rectifier tubes permits of obtaining correspondingly increased output current over that obtainable with the use of one tube. For example, when two full-wave rectifier tubes are connected in parallel, the plates of each tube are connected together and each tube acts as a half-wave rectifier. The allowable voltage and load conditions per tube are the same as for full-wave

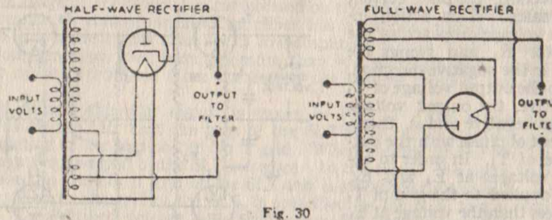
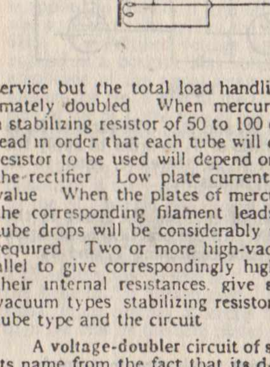


Fig. 30

service but the total load handling capability of the complete rectifier is approximately doubled. When mercury-vapor rectifier tubes are connected in parallel, a stabilizing resistor of 50 to 100 ohms should be connected in series with each plate lead in order that each tube will carry an equal share of the load. The value of the resistor to be used will depend on the amount of plate current that passes through the rectifier. Low plate current requires a high value, high plate current, a low value. When the plates of mercury-vapor rectifier tubes are connected in parallel, the corresponding filament leads should be similarly connected. Otherwise the tube drops will be considerably unbalanced and larger stabilizing resistors will be required. Two or more high-vacuum rectifier tubes can also be connected in parallel to give correspondingly higher output current and, as a result of paralleling their internal resistances, give somewhat increased voltage output. With high-vacuum types stabilizing resistors may or may not be necessary depending on the tube type and the circuit.

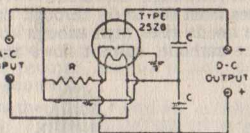
A voltage-doubler circuit of simple form is shown in Fig. 31. The circuit derives its name from the fact that its d-c voltage output can be as high as twice the peak value of a-c input. Basically, a voltage doubler is a rectifier circuit arranged so that the output voltages of two half-wave rectifiers are in series. The action of a voltage doubler is briefly as follows. On the positive half-cycle of the a-c input, that is, when the upper side of the a-c input line is positive with respect to the lower side, the upper diode passes current and feeds a positive charge into the upper condenser. As positive charge accumulates on the upper plate of the condenser, a positive voltage builds up across the condenser. On the next half-cycle of the a-c input, when the upper side of the line is negative with respect to the lower side, the lower diode passes current so that a negative voltage builds up across the lower condenser. As long as no current is drawn at the output terminals from the condensers, each condenser can charge up to a voltage of magnitude E, the peak value of the a-c input. It can be seen from the diagram that with a voltage of +E on one condenser and -E on the other, the total voltage across the condensers is 2E. Thus the voltage doubler supplies a no-load d-c output voltage twice as large as the peak a-c input voltage. When current is drawn at the output terminals by the load, the output voltage drops below 2E by an amount that depends on the magnitude of the load current and the capacitance of the condensers. The arrangement shown in Fig. 31 is called a full-wave voltage doubler because each rectifier passes current to the load on each half of the a-c input cycle.

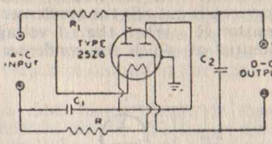


T_1, T_2: SEPARATE FILAMENT TRANSFORMER WINDINGS

Fig. 31

Two rectifier types especially designed for use as voltage doublers are the metal 25Z6 and the glass 25Z5. These tubes combine two separate diodes in one tube. As voltage doublers, the tubes are used in "transformerless" receivers. In these receivers, the heaters of all tubes in the set are connected in series with a voltage-dropping resistor across the line. The connections for the heater supply and the voltage-doubling circuit are shown in Figs. 32 and 33





R - HEATERS OF OTHER TUBES IN SERIES WITH VOLTAGE-DROPPING RESISTOR
R1 = PROTECTIVE RESISTOR
C, C1, C2 = CONDENSER

Fig 32 Fig 33

With the full-wave voltage-doubler circuit in Fig. 32, it will be noted that the d-c load circuit can not be connected to ground or to one side of the a-c supply line. This presents certain disadvantages when the heaters of all the tubes in the set are connected in series with a resistance across the a-c line. Such a circuit arrangement may cause hum because of the high a-c potential between the heaters and cathodes of the tubes. The circuit in Fig. 33 overcomes this difficulty by making one side of the a-c line common with the negative side of the d-c load circuit. In this circuit, one half of the tube is used to charge a condenser which, on the following half cycle, discharges in series with the line voltage through the other half of the tube. This circuit is called a half-wave voltage doubler because rectified current flows to the load only on alternate halves of the a-c input cycle. The voltage regulation of this arrangement is somewhat poorer than that of the full-wave voltage doubler.

DETECTION

When speech or music is transmitted from a radio station, the station radiates a radio-frequency wave whose amplitude varies in accordance with the audio-frequency signal being transmitted. The r-f wave is said to be modulated by the a-f wave. The effect of modulation on the waveform of the r-f wave is shown in Fig. 34.

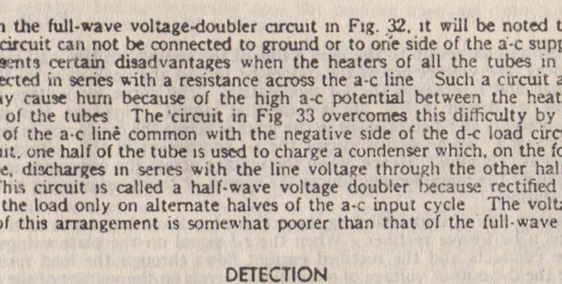


Fig 34

In the receiver it is desired to reproduce the original a-f modulating wave from the modulating r-f wave. In other words, it is desired to demodulate the r-f wave. The receiver stage which performs this demodulation is called the demodulator or detector stage. There are three different detector circuits in general use, the diode detector, the grid-bias detector, and the grid-leak detector. These detector circuits are alike in that they eliminate, either partially or completely, alternate half-cycles of the r-f wave. With the alternate half-cycles eliminated, the audio variations of the other half of the r-f wave can be amplified to drive a loudspeaker or headphones.

A diode-detector circuit is shown in Fig. 35. The action of this circuit when a modulated r-f wave is applied is illustrated by Fig. 36. The r-f voltage applied to the circuit is shown in light line; the output voltage across condenser C is shown in heavy line. Between points (a) and (b) on the first positive half-cycle of the applied r-f voltage, condenser C charges up to the peak value of the r-f voltage.

Then as the applied r-f voltage falls away from its peak value, the condenser holds the cathode at a potential more positive than the voltage applied to the anode. The condenser thus temporarily cuts off current through the diode. While the diode current is cut off, the condenser discharges from (b) to (c) through the diode load resistor R. When the r-f voltage on the anode rises high enough to exceed the potential at which the condenser holds the cathode, current flows again and

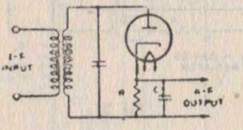


Fig. 35

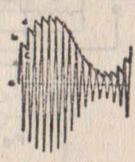


Fig. 36

the condenser charges up to the peak value of the second positive half-cycle at (d). In this way, the voltage across the condenser follows the peak value of the applied r-f voltage and reproduces the a-f modulation. The curve for voltage across the condenser, as drawn in Fig. 36, is somewhat jagged. However, this jaggedness, which represents an r-f component in the voltage across the condenser, is exaggerated in the drawing. In an actual circuit the r-f component of the voltage across the condenser is negligible. Hence, when the voltage across the condenser is amplified, the output of the amplifier reproduces the speech or music originating at the transmitting station.

Another way of understanding the action of a diode detector is to consider the circuit as a half-wave rectifier. When the r-f signal on the plate swings positive, the tube conducts and the rectified current flows through the load resistance R. Because the d-c output voltage of a rectifier depends on the voltage of the a-c input, the d-c voltage across C varies in accordance with the amplitude of the r-f carrier and thus reproduces the a-f signal. Condenser C should be large enough to smooth out r-f or i-f variations but should not be so large as to affect the audio variations. Two diodes can be connected in a circuit similar to a full-wave rectifier to give full-wave detection. However, in practice, the advantages of this connection generally do not justify the extra circuit complication.

The diode method of detection has the advantage over other methods in that it produces less distortion. The reason is that its dynamic characteristic can be made more linear than that of other detectors. It has the disadvantages that it does not amplify the signal, and that it draws current from the input circuit and therefore reduces the selectivity of the input circuit. However, because the diode method of detection produces less distortion and because it permits the use of simple avc circuits without the necessity for an additional voltage supply, the diode method of detection is most widely used in broadcast receivers.

A typical diode-detector circuit using a duplex-diode triode tube is shown in Fig. 37. Both diodes are connected together. R_1 is the diode load resistor. A

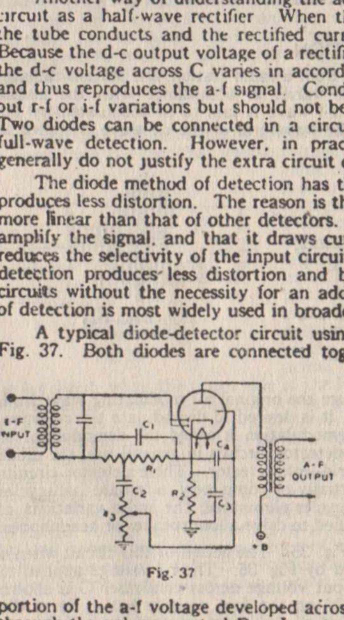


Fig. 37

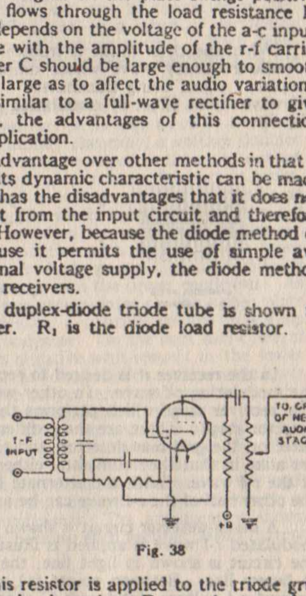


Fig. 38

portion of the a-f voltage developed across this resistor is applied to the triode grid through the volume control R_3. In a typical circuit, resistor R_1 may be tapped so that five-sixths of the total a-f voltage across R_1 is applied to the volume control

This tapped connection reduces the a-f voltage output of the detector circuit slightly but it reduces audio distortion and improves the r-f filtering. D-c bias for the triode section is provided by the cathode-bias resistor R_1 and the audio by-pass condenser C_3. The function of condenser C_2 is to block the d-c bias of the cathode from the grid. The function of condenser C_4 is to by-pass any r-f voltage on the grid to cathode. A duplex-diode pentode may also be used in this circuit. With a pentode, the a-f output should be resistance-coupled rather than transformer-coupled.

Another diode detector circuit, called a diode-biased circuit, is shown in Fig. 38. In this circuit, the triode grid is connected directly to a tap on the diode load resistor. When an r-f signal voltage is applied to the diode, the d-c voltage at the tap supplies bias to the triode grid. When the r-f signal is modulated, the a-f voltage at the tap is applied to the grid and is amplified by the triode. The advantage of this circuit over the self-biased arrangement shown in Fig. 37 is that the diode-biased circuit does not employ a condenser between the grid and the diode load resistor, and consequently does not produce as much distortion of a signal having a high percentage of modulation.

However, there are restrictions on the use of the diode-biased circuit. Because the bias voltage on the triode depends on the average amplitude of the r-f voltage applied to the diode, the average amplitude of the voltage applied to the diode should be constant for all values of signal strength at the antenna. Otherwise there will be different values of bias on the triode grid for different signal strengths and the triode will produce distortion. Since there is no bias applied to the diode-biased triode when no r-f voltage is applied to the diode, sufficient resistance should be included in the plate circuit of the triode to limit its zero-bias plate current to a safe value. These restrictions mean, in practice, that the receiver should have a separate-channel avc system. With such an avc system, the average amplitude of the signal voltage applied to the diode can be held within very close limits for all values of signal strength at the antenna. The tube used in a diode-biased circuit should be one which operates at a fairly large value of bias voltage. The variations in bias voltage are then a small percentage of the total bias and hence produce small distortion. Tubes taking a fairly large bias voltage are types such as the 6R7 or 1H6-G having a medium-mu triode. Tube types having a high-mu triode or a pentode should not be used in a diode-biased circuit.

A **grid-bias detector** circuit is shown in Fig. 39. In this circuit, the grid is biased almost to cut-off, i.e., operated so that the plate current with zero signal is practically zero. The bias voltage can be obtained from a cathode-bias resistor, a C battery or a bleeder tap. Because of the high negative bias, only the positive half cycles of the r-f signal are amplified by the tube. The signal is, therefore, detected in the plate circuit. The advantages of this method of detection are that it amplifies the signal, besides detecting it, and that it does not draw current from the input circuit and therefore does not lower the selectivity of the input circuit.

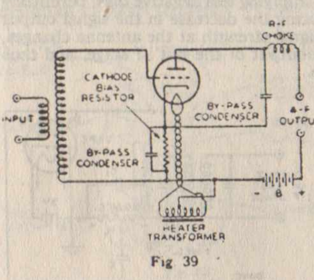


Fig. 39

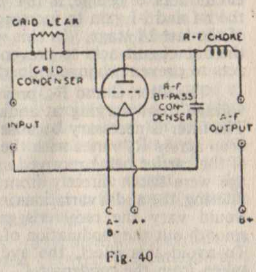


Fig. 40

The **grid-leak and condenser method**, illustrated by Fig. 40, is somewhat more sensitive than the grid-bias method and gives its best results on weak signals. In this circuit, there is no negative d-c bias voltage applied to the grid. Hence, on the positive half-cycles of the r-f signal, current flows from grid to cathode. The grid and cathode thus act as a diode detector, with the grid-leak resistor as the diode load resistor and the grid condenser as the r-f by-pass condenser. The voltage across the condenser then reproduces the a-f modulation in the same manner as has been explained for the diode detector. This voltage appears between the grid and cathode and is therefore amplified in the plate circuit. The output voltage thus reproduces the original a-f signal.

In this detector circuit, the use of a high-resistance grid leak increases selectivity and sensitivity. However, improved a-f response and stability are obtained with lower values of grid-leak resistance. This detector circuit has the advantage that it amplifies the signal but has the disadvantage that it draws current from the input circuit and therefore lowers the selectivity of the input circuit.

AUTOMATIC VOLUME CONTROL

The chief purposes of automatic volume control in a receiver are to prevent fluctuations in loudspeaker volume when the signal at the antenna is fading in and out, and to prevent an unpleasant blast of loud volume when the set is tuned from a weak signal, for which the volume control has been turned up high, to a strong signal. To accomplish these purposes, an automatic volume control circuit regulates the receiver's r-f and i-f gain so that this gain is less for a strong signal than for a weak signal. In this way, when the signal strength at the antenna changes, the avc circuit reduces the resultant change in the voltage output of the last i-f stage and consequently reduces the change in the speaker's output volume.

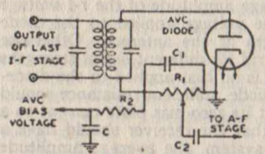


Fig. 41

The avc circuit reduces the r-f and i-f gain for a strong signal usually by increasing the negative bias of the r-f, i-f, and frequency-mixer stages when the signal increases. A simple avc circuit is shown in Fig. 41. On each positive half-cycle of the signal voltage, when the diode plate is positive with respect to the cathode, the diode passes current. Because of the flow of diode current through R_1, there is a voltage drop across R_1 which makes the left end of R_1 negative with respect to ground. This voltage drop across R_1 is applied, through the filter R_2 and C, as negative bias on the grids of the preceding stages. Then, when the signal strength at the antenna increases, the signal applied to the avc diode increases, the voltage drop across R_1 increases, the negative bias voltage applied to the r-f and i-f stages increases, and the gain of the r-f and i-f stages is decreased. Thus the increase in signal strength at the antenna does not produce as much increase in the output of the last i-f stage as it would produce without avc. When the signal strength at the antenna decreases from a previous steady value, the avc circuit acts, of course, in the reverse direction, applying less negative bias, permitting the r-f and i-f gain to increase, and thus reducing the decrease in the signal output of the last i-f stage. In this way, when the signal strength at the antenna changes, the avc circuit acts to prevent change in the output of the last i-f stage, and thus acts to prevent change in loudspeaker volume.

The filter, C and R_2, prevents the avc voltage from varying at audio frequency. The filter is necessary because the voltage drop across R_1 varies with the modulation of the carrier being received. If avc voltage were taken directly from R_1 without filtering, the audio variations in avc voltage would vary the receiver's gain so as to smooth out the modulation of the carrier. To avoid this effect, the avc voltage is taken from the condenser C. Because of the resistance R_2 in series with C, the condenser C can charge and discharge at only a comparatively slow rate. The avc voltage therefore cannot vary at frequencies

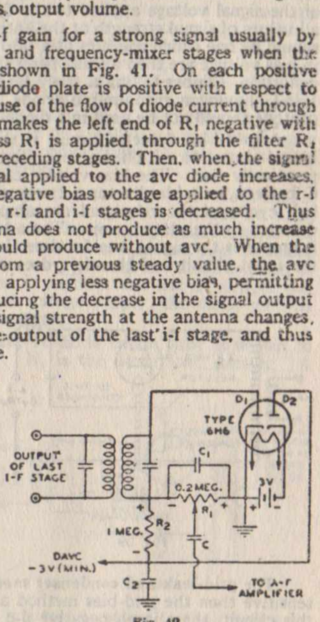


Fig. 42

as high as the audio range but can vary at frequencies high enough to compensate for most fading. Thus the filter permits the avc circuit to smooth out variations in signal due to fading, but prevents the circuit from smoothing out audio modulation.

It will be seen that an avc circuit and a diode detector circuit are much alike It is therefore convenient in a receiver to combine the detector and the avc diode in a single stage.

In the circuit shown in Fig. 41, a certain amount of avc negative bias is applied to the preceding stages on a weak signal. Since it may be desirable to maintain the receiver's r-f and i f gain at the maximum possible value for a weak signal, avc circuits are designed in some cases to apply no avc bias until the signal strength exceeds a certain value. These avc circuits are known as delayed avc, or. davc circuits. A davc circuit is shown in Fig. 42. In this circuit, the diode section D_1 of the 6H6 acts as detector and avc diode. R_1 is the diode load resistor and R_2 and C_1 are the avc filter. Because the cathode of diode D_2 is returned through a fixed supply of -3 volts to the cathode of D_1, a d-c current flows through R_1 and R_2 in series with D_2. The voltage drop caused by this current places the avc lead at approximately -3 volts (less the negligible drop through D_2). When the average amplitude of the rectified signal developed across R_1 does not exceed 3 volts, the avc lead remains at -3 volts. Hence, for signals not strong enough to develop 3 volts across R_1, the bias applied to the controlled tubes stays constant at a value giving high sensitivity. However, when the average amplitude of rectified signal voltage across R_1 exceeds 3 volts, the plate of diode D_2 becomes more negative than the cathode of D_2 and current flow in diode D_2 ceases. The potential of the avc lead is then controlled by the voltage developed across R_1. Therefore, with further increase in signal strength, the avc circuit applies an increasing avc bias voltage to the controlled stages. In this way, the circuit regulates the receiver's gain for strong signals, but permits the gain to stay constant at a maximum value for weak signals

It can be seen in Fig. 42 that a portion of the -3 volts delay voltage is applied to the plate of the detector diode D_1, this portion being approximately equal to $R_1/(R_1 + R_2)$ times -3 volts. Hence, with the circuit constants as shown, the detector plate is made negative with respect to its cathode by approximately one-half volt. However, this voltage does not interfere with detection because it is not large enough to prevent current flow in the tube.

TUNING INDICATION WITH ELECTRON-RAY TUBES

Electron-ray tubes are designed to indicate visually by means of a fluorescent target the effects of a change in controlling voltage. They are widely used as tuning indicators in radio receivers. Types such as the 6U5/6G5 and the 6N5 contain two main parts: (1) a triode which operates as a d-c amplifier and (2) an electron-ray indicator which is located in the bulb as shown in Fig. 43. The target is operated at a positive voltage and therefore attracts electrons from the cathode. When the electrons strike the target they produce a glow on the fluorescent coating of the target. Under these conditions, the target appears as a ring of light.

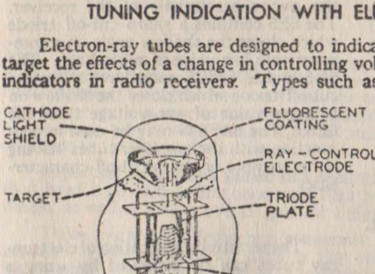


Fig. 43

A ray-control electrode is mounted between the cathode and target. When the potential of this electrode is less positive than the target, electrons flowing to the target are repelled by the electrostatic field of the electrode, and do not reach that portion of the target behind the electrode. Because the target does not glow where it is shielded from electrons, the control electrode casts a shadow on the glowing target. The extent of this shadow varies from approximately 100° of the target when the control electrode is much more negative than the target to 0° when the control electrode is at approximately the same potential as the target

In the application of the electron-ray tube, the potential of the control electrode is determined by the voltage on the grid of the triode section, as can be seen in Fig. 44. The flow of the triode plate current through resistor R produces a voltage drop which determines the potential of the control electrode. When the voltage of the triode grid changes in the positive direction, plate current increases, the potential of the control electrode goes down because of the increased drop across R, and the shadow angle widens. When the potential of the triode grid changes in the negative direction, the shadow angle narrows

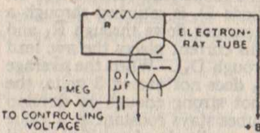


Fig. 44

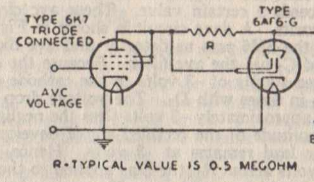


Fig. 45

Another type of indicator tube is the 6AF6-G This tube contains only an indicator unit but employs two ray-control electrodes mounted on opposite sides of the cathode and connected to individual base pins. It employs an external d-c amplifier. See Fig 45. Thus, two symmetrically opposite shadow angles may be obtained by connecting the two ray-control electrodes together or two unlike patterns may be obtained by individual connection of each ray-control electrode to its respective amplifier

In radio-receivers, avc voltage is applied to the grid of the d-c amplifier. Since avc voltage is at maximum when the set is tuned to give maximum response to a station, the shadow angle is at minimum when the receiver is tuned to resonance with the desired station. The choice between electron-ray tubes depends on the avc characteristic of the receiver. The 6E5 contains a sharp cut-off triode which closes the shadow angle on a comparatively low value of avc voltage. The 6N5 and 6U5/6G5 each have a remote cut-off triode which closes the shadow on a larger value of avc voltage than the 6E5. The 6AF6-G may be used in conjunction with d-c amplifier tubes having either remote or sharp cut-off characteristics

CIRCUIT FOR WIDE-ANGLE TUNING

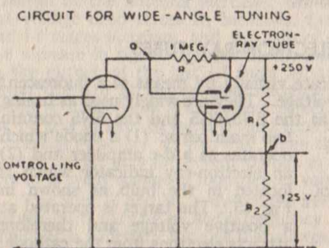


Fig 46

The sensitivity indication of electron-ray tubes can be increased by using a separate d-c amplifier to control the action of the ray-control electrode in the tuning indicator tube. This arrangement increases the maximum shadow angle from the usual 100° to approximately 180° A circuit for obtaining wide-angle tuning is shown in Fig 46

OSCILLATION

As an oscillator, a radio tube can be employed to generate a continuously alternating voltage. In present-day radio broadcast receivers, this application is limited practically to superheterodyne receivers for supplying the heterodyning frequency. Several circuits (represented in Figs. 47 and 48) may be utilized, but they all depend on feeding more energy from the plate circuit to the grid circuit than is required to equal the power loss in the grid circuit. Feed-back may be

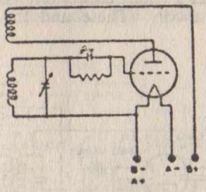


Fig. 47

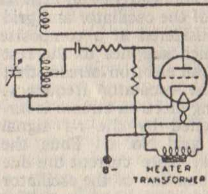
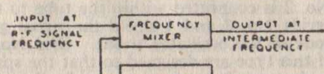


Fig. 48

produced by electrostatic or electromagnetic coupling between the grid and plate circuits. When sufficient energy is fed back to more than equal the loss in the grid circuit, the tube will oscillate. The action consists of regular surges of power between the plate and the grid circuit at a frequency dependent on the circuit constants of inductance and capacity. By proper choice of these values, the frequency may be adjusted over a very wide range.

FREQUENCY CONVERSION

Frequency conversion is used in superheterodyne receivers to change the frequency of the r-f signal to an intermediate frequency. To perform this change in frequency, a frequency-converting device consisting of an oscillator and a frequency mixer is employed. In such a device, shown diagrammatically in Fig. 49, two voltages of different frequency, the r-f signal voltage and the voltage generated by the oscillator, are applied to the input of the frequency mixer. These voltages beat, or heterodyne, within the mixer tube to produce a plate current having, in addition to the frequencies of the input voltages, numerous sum and difference frequencies. The output circuit of the mixer stage is provided with a tuned circuit which is adjusted to select only one beat frequency, i.e., the frequency equal to the difference between the signal frequency and the oscillator frequency. The selected output frequency is known as the intermediate frequency, or i.f. The output frequency of the mixer tube is kept constant for all values of signal frequency by tuning the oscillator to the proper frequency.



FREQUENCY CONVERTER

Fig. 49

Important advantages gained in a receiver by the conversion of signal frequency to a fixed intermediate frequency are high selectivity with few tuning stages and a high, as well as stable, overall gain for the receiver.

Three methods of frequency conversion for superheterodyne receivers are of interest. These methods are alike in that they employ a frequency-mixer tube in which plate current is varied at a combination of the signal frequency and the oscillator frequency. These variations in plate current produce across the tuned plate load a voltage of the desired intermediate frequency. The three methods differ in the types of tubes employed and in the means of supplying input voltages to the mixer tube.

A method widely used before the availability of tubes especially designed for frequency-conversion service, employs as mixer tube either a triode, a tetrode, or a pentode, in which oscillator voltage and signal voltage are applied to the same grid. In this method, coupling between the oscillator and mixer circuits is obtained by means of inductance or capacitance.

The second method employs a tube having an oscillator and frequency mixer combined in the same envelope. In one form of such a tube, coupling between the two units is obtained by means of the electron stream within the tube. One arrangement of the electrodes for this type is shown in Fig. 50. Since five grids are used, the tube is called a pentagrid converter. Grids No. 1, No. 2 and the cathode are connected to an external circuit to act as a triode oscillator. Grid No. 1 is the grid of the oscillator and grid No. 2 is the anode. These and the cathode can be considered as a composite cathode which supplies to the rest of the tube an electron stream that varies at the oscillator frequency. This varying electron stream is further controlled by the r-f signal voltage on grid No. 4. Thus, the variations in plate current are due to the combination of the oscillator and the signal frequencies. The purpose of grids No. 3 and No. 5, which are connected together within the tube, is to accelerate the electron stream and to shield grid No. 4 electrostatically from the other electrodes. The 6A8 is an example of a pentagrid-converter type.

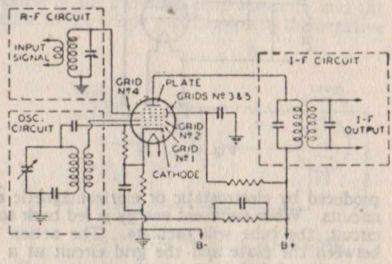


Fig. 50

Pentagrid-converter tubes of this design are good frequency-converting devices at medium frequencies but their performance is better at the lower frequencies than at the high ones. This is because the output of the oscillator drops off as the frequency is raised and because certain undesirable effects produced by interaction between oscillator and signal sections of the tube increase with frequency. To minimize these effects, several of the pentagrid converter tubes are designed so that no electrode functions alone as the oscillator anode. In these tubes, grid No. 1 functions as the oscillator grid, and grid No. 2 is connected within the tube to the screen (grid No. 4). The combined two grids No. 2 and 4 shield the signal grid (grid No. 3) and act as the composite anode of the oscillator triode. Grid No. 5 acts as the suppressor. Converter tubes of this type are designed so that the space charge around the cathode is unaffected by electrons from the signal grid. Furthermore, the electrostatic field of the signal grid also has little effect on the space charge. The result is that r-f voltage on the signal grid produces little effect on the cathode current. There is, therefore, little detuning of the oscillator by avc bias because changes in avc bias produce little change in oscillator transconductance or in the input capacitance of grid No. 1. Examples of the pentagrid converters discussed in this paragraph are the single-ended types 1R5 and 6SA7.

Another method of frequency conversion utilizes a separate oscillator having its grid connected to the No. 1 grid of a mixer hexode. A tube utilizing this construction is the 6K8 and a top view of its electrode arrangement is shown in Fig 51. The cathode, triode grid No. 1, and triode plate form the oscillator unit of the tube. The cathode, hexode mixer grid (grid No. 1), hexode double-screen (grids No. 2 and 4), hexode mixer grid (grid No. 3) and hexode plate constitute the mixer unit. The internal shields are connected to the shell of the tube and act as a suppressor for the hexode unit. The action of the 6K8 in converting a radio-frequency signal to an intermediate frequency depends on (1) the generation of a local frequency by the triode unit, (2) the transferring of this frequency to the hexode grid No. 1, and (3) the mixing in the hexode unit of this frequency with that of the r-f signal applied to the hexode grid No. 3. The 6K8 is not critical to changes in oscillator-plate voltage

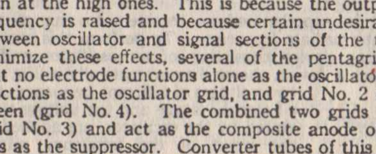


Fig. 51

or signal-grid bias and, therefore, finds important use in all-wave receivers to minimize frequency-shift effects at the higher frequencies.

The third method of frequency conversion employs a tube particularly designed for short-wave reception. This tube, called a pentagrid mixer, has two independent control grids and is used with a separate oscillator tube. R-F signal voltage is applied to one of the control grids and oscillator voltage is applied to the other. It follows, therefore, that the variations in plate current are due to the combination of the oscillator and signal frequencies. The arrangement of electrodes in a pentagrid-mixer tube is shown in Fig. 52. The tube contains a heater cathode, five grids, and a plate. Grids No. 1 and 3 are control grids. The r-f signal voltage is applied to grid No. 1. This grid has a remote cut-off characteristic and is suited for control by avc bias voltage. The oscillator voltage is applied to grid No. 3. This grid has a sharp cut-off characteristic and produces a comparatively large effect on plate current for a small amount of oscillator voltage. Grids No. 2 and 4 are connected together within the tube. They accelerate the electron stream and shield grid No. 3 electrostatically from the other electrodes. Grid No. 5, connected within the tube to the cathode, functions similarly to the suppressor in a pentode. The 6L7 and 6L7-G are pentagrid-mixer tubes.

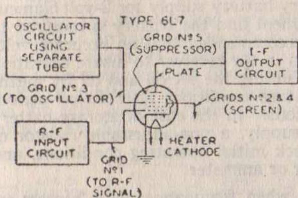


Fig. 52

Radio Tube Installation

The installation of radio tubes requires care if high-quality performance is to be obtained from the associated radio circuits. Installation suggestions and precautions which are generally common to all types of tubes are covered in this section. Careful observance of these suggestions will do much in helping the experimenter and radio technician to obtain the full performance capabilities of radio tubes and circuits.

FILAMENT AND HEATER POWER SUPPLY

The design of radio tubes allows for some variation in the voltage and current supplied to the filament or heater, but most satisfactory results are obtained from operation at the rated values. When the voltage is low, the temperature of the cathode is below normal, with the result that electron emission is limited. This may cause unsatisfactory operation and reduced tube life. On the other hand, high cathode voltage causes rapid evaporation of cathode material and shortens life. To insure proper tube operation, the filament or heater voltage should be checked at the socket terminals by means of an accurate voltmeter while the receiver is in operation. In the case of series operation of heaters or filaments, correct adjustment can be checked by means of an ammeter in the heater or filament circuit.

The filament or heater voltage supply may be a direct-current source (a battery or a d-c power line) or an alternating-current power line, depending on the type of service and type of tube. Frequently, a resistor (either variable or fixed) is used with a d-c supply to permit compensation for battery voltage variations or to adjust the tube voltage at the socket terminals to the correct value. Ordinarily, a step-down transformer is used with an a-c supply to provide the proper filament or heater voltage. Receivers intended for operation on both d-c and a-c power lines have the heaters connected in series with a suitable resistor and are supplied directly from the power line.

D-c filament or heater operation should be considered on the basis of the source of power In the case of the battery supply for the new 1.4-volt filament tubes, it is unnecessary to use a voltage-dropping resistor in series with the filament and a single dry-cell the filaments of these tubes are designed to operate satisfactorily over the range of voltage variations that normally occur during the life of a dry-cell. Likewise, no series resistor is required when the 2-volt filament type tubes are operated from a single storage cell or when the 6.3-volt series are operated from a 6-volt storage battery In the case of dry-battery supply for 2-volt filament tubes, a variable resistor in series with the filament and the battery is required to compensate for battery variations. It is also recommended that an accurate voltmeter or milliammeter be permanently installed in the receiver to insure operation of the tubes at their rated filament voltage. Turning the set on and off by means of the rheostat is advised to prevent over-voltage conditions after an off-period, for the voltage of dry-cells rises during off-periods. In the case of storage-battery supply, air-cell-battery supply, or d-c power supply, a non-adjustable resistor of suitable value may be used. It is well to check initial operating conditions, and thus the resistor value, by means of a voltmeter or ammeter

The **filament or heater resistor** required when filaments and/or heaters are operated in parallel can be determined easily by a simple formula derived from Ohm's law

$$\text{Required resistance (ohms)} = \frac{\text{supply volts} - \text{rated volts of tube type}}{\text{total rated filament current (amperes)}}$$

Thus, if a receiver using three 32's, two 30's, and two 31's is to be operated from dry batteries, the series resistor is equal to 3 volts (the voltage from two dry cells in series) minus 2 volts (voltage rating for these tubes) divided by 0.56 ampere (the sum of 5×0.060 ampere $+ 2 \times 0.130$ ampere), i.e., approximately 1.8 ohms. Since this resistor should be variable to allow adjustment for battery depreciation, it is advisable to obtain the next larger commercial size, although any value between 2 and 3 ohms will be quite satisfactory. Where much power is dissipated in the resistor, the wattage rating should be sufficiently large to prevent overheating. The power dissipation in watts is equal to the voltage drop in the resistor multiplied by the total filament current in amperes. Thus, for the example above $1 \times 0.56 = 0.56$ watt. In this case, the value is so small that any commercial rheostat with suitable resistance will be adequate.

For the case where the heaters and/or filaments of several tubes are operated in series, the resistor value is calculated by the following formula, also derived from Ohm's law

$$\text{Required resistance (ohms)} = \frac{\text{supply volts} - \text{total rated volts of tubes}}{\text{rated amperes of tubes}}$$

Thus, if a receiver having one 6SA7, one 6SK7, one 6B8, one 25A6, and one 25Z6 is to be operated from a 117-volt power line, the series resistor is equal to 117 volts (the supply voltage) minus 68.9 volts (the sum of 3×6.3 volts $+ 2 \times 25$ volts) divided by 0.3 ampere (current rating of these tubes), i.e., approximately 160 ohms. The wattage dissipation in the resistor will be 117 volts minus 68.9 volts times 0.3 ampere, or approximately 14.4 watts. A resistor having a wattage rating in excess of this value should be chosen.

It will be noted in the example for series operation that all tubes have the same current rating. If it is desired to connect in series tubes having different heater- or filament-current ratings, each tube of the lower rating should have a shunt resistor placed across its heater or filament terminals to pass the excess current. The value of this shunt resistor can be calculated from the following formula, where tube A is the tube in the series connection having the highest heater current rating and tube B is any tube having a heater current rating lower than tube A.

$$\text{Heater shunt resistance (ohms), tube B} = \frac{\text{heater volts, tube B}}{\text{rated heater amperes, tube A} - \text{rated heater amperes, tube B}}$$

For example, if a 6A6 having a 6.3-volt, 0.8-ampere heater is to be operated in a series-heater circuit employing several 6.3-volt tubes having heater ratings of 0.3

ampere the required shunt resistance for each of the latter types would be

$$\text{Heater shunt resistance} = \frac{6.3}{0.8 - 0.3} \text{ or } 12.6 \text{ ohms.}$$

The value of a series voltage-dropping resistor for a sequence of tubes having one or more shunt resistors should be calculated on the basis of the tube having the highest heater current rating.

When the series-heater connection is used in a-c/d-c receivers, it is usually advisable to arrange the heaters in the circuit so that the tubes most sensitive to hum disturbances are at or near the ground potential of the circuit. This arrangement reduces the amount of a-c voltage between the heaters and cathodes of these tubes and minimizes the hum output of the receiver. The order of heater connection, by tube function, from chassis to the rectifier-cathode side of the a-c line is shown in Fig. 53

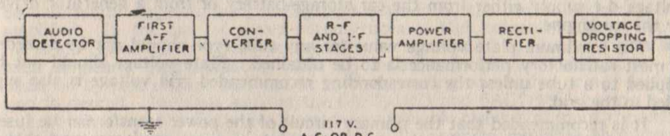


Fig. 53

A-c filament or heater operation should be considered on the basis of either a parallel or a series arrangement of filaments and/or heaters. In the case of the parallel arrangement, a step-down transformer is employed. Precautions should be taken to see that the line voltage is the same as that for which the primary of the transformer is designed. The line voltage may be determined by measurement with an a-c voltmeter (0-150 volts).

If the line voltage measures in excess of that for which the transformer is designed, a resistor should be placed in series with the primary to reduce the line voltage to the rated value of the transformer primary. Unless this is done, the excess input voltage will cause proportionally excessive voltage to be applied to the tubes. Any radio tube may be damaged or made inoperative by excessive operating voltages.

If the line voltage is consistently below that for which the primary of the transformer is designed, it may be necessary to install a booster transformer between the a-c outlet and the transformer primary. Before such a transformer is installed, the a-c line fluctuations should be very carefully noted. Some radio sets are equipped with a line-voltage switch which permits adjustment of the power transformer primary to the line voltage. When this switch is properly adjusted, the series-resistor or booster-transformer method of controlling line voltage is seldom required.

In the case of the series arrangements of filaments and/or heaters, a voltage-dropping resistance in series with the heaters and the supply line is usually required. This resistance should be of such value that, for normal line voltage, tubes will operate at their rated heater or filament current. The method for calculating the resistor value is given above.

HEATER-TO-CATHODE CONNECTION

The cathodes of heater-type tubes, when operated from a.c., should be connected either to the mid-tap on the heater-supply winding or to the mid-tap of a 50-ohm (approximate) resistor shunted across the winding. This practice follows the general recommendation that the potential difference between heater and cathode be kept low. In high-gain resistance-coupled circuits, it is suggested that the heater be made 10 volts positive with respect to the cathode in order to prevent emission from taking place from heater to cathode and producing hum. If a large resistor is used between heater and cathode, it should be by-passed by a suitable filter network or objectionable hum may develop. The hum is due to the fact that even a minute pulsating leakage current flowing between the heater and cathode will develop a small voltage across any resistance in the circuit. This hum voltage is amplified by succeeding stages. When 6.3-volt heater-cathode types are operated from a storage battery, the cathodes are connected either directly or through biasing resistors to the negative battery terminal. When a series-heater arrangement is used, the cathode circuits should be connected either directly or through biasing resistors to the negative side of the d-c plate supply, which is furnished either by the d-c power line or by the a-c power line through a rectifier.

PLATE VOLTAGE SUPPLY

The plate voltage for radio tubes is obtained from batteries, devices for rectifying a.c., direct-current power lines, and small local generators. Auto radios have caused the commercial development of a number of devices for obtaining a high-voltage d-c supply either from the car storage-battery or from a generator driven by the car engine.

The maximum plate voltage value for any tube type should not be exceeded if most satisfactory performance is to be obtained. Plate voltage should not be applied to a tube unless the corresponding recommended grid voltage is also supplied to the grid.

It is recommended that the primary circuit of the power transformer be fused to protect the rectifier tube(s), the power transformer, filter condenser, and chokes in case a rectifier tube fails.

GRID VOLTAGE SUPPLY

The recommended grid voltages for different operating conditions have been carefully determined to give the most satisfactory performance. Grid voltage may be obtained from a separate C-battery, a tap on the voltage divider of the high-voltage d-c supply, or from the voltage drop across a resistor in the cathode circuit. This last is called the "cathode-bias," or "self-bias" method. In any case, the object is to make the grid negative with respect to the cathode by the specified voltage. When a C battery is used, the negative terminal is connected to the grid return and the positive terminal is connected to the negative filament socket terminal, or to the cathode terminal if the tube is of the heater-cathode type. If the filament is supplied with alternating current, this connection is usually made to the center-tap of a low resistance (20-50 ohms) shunted across the filament terminals. This method reduces hum disturbances caused by the a-c supply. If bias voltages are obtained from the voltage divider of a high-voltage d-c supply, the grid return is connected to a more negative tap than the cathode.

The **cathode-biasing** method utilizes the voltage drop produced by the cathode current flowing through a resistor connected between the cathode and the negative terminal of the B-supply. See Fig. 54. The cathode current is, of course, equal

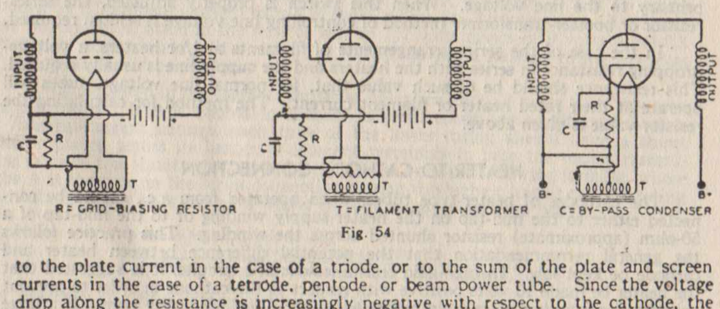


Fig. 54

to the plate current in the case of a triode, or to the sum of the plate and screen currents in the case of a tetrode, pentode, or beam power tube. Since the voltage drop along the resistance is increasingly negative with respect to the cathode, the required negative grid-bias voltage can be obtained by connecting the grid return to the negative end of the resistance.

The size of the resistance for cathode-biasing a single tube can be determined from the following formula:

$$\text{Resistance (ohms)} = \frac{\text{desired grid-bias voltage} \times 1000}{\text{rated cathode current in milliamperes}}$$

Thus, the resistance required to produce 9 volts bias for a triode which operates at 3 milliamperes plate current is $9 \times 1000/3 = 3000$ ohms. If the cathode current of more than one tube passes through the resistor, or if the tube or tubes employ more than three electrodes, the size of the resistor will be determined by the total current.

By-passing of the cathode-bias resistor depends on circuit design requirements. In r-f circuits the cathode resistor should always be by-passed. In a-f circuits the use of an unby-passed resistor will reduce distortion by introducing degeneration into the circuit. However, the use of an unby-passed resistor decreases power sensitivity. When by-passing is used, it is important that the by-pass condenser be sufficiently large to have negligible reactance at the lowest frequency to be amplified. In the case of power output tubes of high transconductance such as the beam power tubes, it may be necessary to shunt the bias resistor with a small mica condenser (approximately 0.001 μf) in order to prevent oscillations. The usual a-f by-pass may or may not be used, depending on whether or not degeneration is desired. In tubes such as the 6AB7/1853 and 6AC7/1852 having a very high value of transconductance, there are appreciable changes of input capacitance and input conductance with plate current. In order to minimize such changes when a tube of this type is used as an r-f or i-f amplifier, a portion of the cathode-bias resistor may be left unby-passed.

Grid-bias variation for the r-f and i-f amplifier stages is a convenient and frequently used method for controlling receiver volume. The variable voltage supplied to the grid may be obtained (1) from a variable cathode resistor as shown in Figs. 55 and 56; (2) from a bleeder circuit by means of a potentiometer as shown in Fig. 57 or (3) from a bleeder circuit in which the bleeder current is varied by a tube used for automatic volume control. The latter circuit is shown in Fig. 41. In all cases it is important that the control be arranged so that at no time will the bias be less than the recommended grid-bias voltage for the particular tubes used. This requirement can be met by providing a fixed stop on the potentiometer, by connecting a fixed resistance in series with the variable resistance, or by connecting a fixed cathode resistance in series with the variable resistance used for regulation.

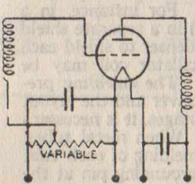


Fig. 55

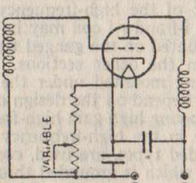


Fig. 56

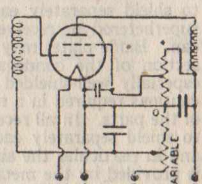


Fig. 57

Where receiver gain is controlled by grid-bias variation, it is advisable to have the control voltages extend over a wide range in order to minimize cross-modulation and modulation-distortion. A remote cut-off type of tube should, therefore, be used in the controlled stages

SCREEN VOLTAGE SUPPLY

The positive screen voltage for pentodes and beam power tubes may conveniently be obtained from a high-voltage supply through a series resistor because tubes having suppressor action provide high uniformity of the screen-current characteristic. Fig. 58 shows a pentode with its screen voltage supplied through a series resistor. The positive screen voltage for tetrodes (screen-grid tubes) should be obtained from a proper voltage tap or from a potentiometer connected across the B supply. It should not be obtained from a high-voltage supply through a series resistor because of the characteristic screen-current variations in tetrodes. Fig. 59 shows a tetrode with its screen voltage obtained from a potentiometer. It is important to note that the plate voltage for tetrodes or pentodes should be applied before or with the screen voltage. Otherwise, with voltage on the screen only the screen current may rise high enough to cause excessive screen dissipation.

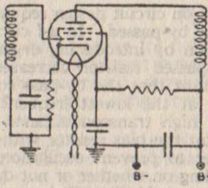


Fig. 58

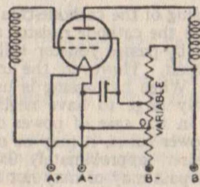


Fig. 59

Screen-voltage variation for the r-f amplifier stages has sometimes been used for volume control in older type receivers. Reduced screen voltage lowers the transconductance of the tube and results in decreased gain per stage. The voltage variation is obtained by means of a potentiometer shunted across the screen voltage supply. See Fig. 59. When the screen voltage is varied, it is essential that the screen voltage never exceed the rating of the tube. This requirement can be met by providing a fixed stop on the potentiometer.

SHIELDING

In high-frequency stages having high gain, the output circuit of each stage must be shielded from the input circuit of that stage. Each high-frequency stage also must be shielded from the other high-frequency stages. Unless shielding is employed, undesired feedback may occur and may produce many harmful effects on receiver performance. To prevent this feedback, it is a widely followed practice to shield separately each unit of the high-frequency stages. For instance, in a superheterodyne receiver, each i-f and r-f coil may be mounted in a separate shield can. Baffle plates may be mounted on the ganged tuning condenser to shield each section of the condenser from the other sections. The oscillator coil may be especially well-shielded by being mounted under the chassis. The shielding precautions required in a receiver depend on the design of the receiver and the layout of the parts. In all receivers having high-gain high-frequency stages, it is necessary to shield separately each tube in the high-frequency stages. When metal tubes and in particular the single-ended types, are used, complete shielding of each tube is provided by the metal shell which is grounded through its grounding pin at the socket terminal. The grounding connection should be short and heavy.

FILTERS

Feed-back effects also are caused in radio receivers by coupling between stages through common voltage-supply circuits. Filters find an important use in minimizing such effects. They should be placed in voltage-supply leads to each tube in order to return the signal current through a low-impedance path direct to the tube cathode rather than by way of the voltage-supply circuit. Fig. 60 illustrates several forms of filter circuits. Condenser C forms the low-impedance path, while the choke or resistor assists in diverting the signal through the condenser by offering a high-impedance to the power-supply circuit.

The choice between a resistor and a choke depends chiefly upon the permissible **d-c voltage** drop through the filter In circuits where the current is small (a few milliamperes) resistors are practical; where the current is large or regulation important, chokes are more suitable.

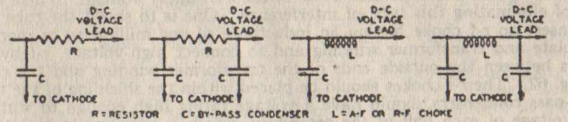


Fig. 60

The minimum practical size of the condensers may be estimated in most cases by the following rule: The impedance of the condenser at the lowest frequency amplified should not be more than one-fifth of the impedance of the filter choke or resistor at that frequency. Better results will be obtained in special cases if the ratio is not more than one-tenth. Radio-frequency circuits, particularly at high frequencies, require high-quality condensers. Mica condensers are preferable. Where stage shields are employed, filters should be placed within the shield.

Another important application of filters is to smooth the output of a rectifier tube. See RECTIFICATION. A smoothing filter usually consists of condensers and iron-core chokes. In any filter-design problem, the load impedance must be considered as an integral part of the filter because the load is an important factor in filter performance. Smoothing effect is obtained from the chokes because they are in series with the load and offer a high impedance to the ripple voltage. Smoothing effect is obtained from the condensers because they are in parallel with the load and store energy on the voltage peaks: this energy is released on the voltage dips and serves to maintain the voltage at the load substantially constant. Smoothing filters are classified as choke-input or condenser-input according to whether a choke or condenser is placed next to the rectifier tube. See Fig. 61.

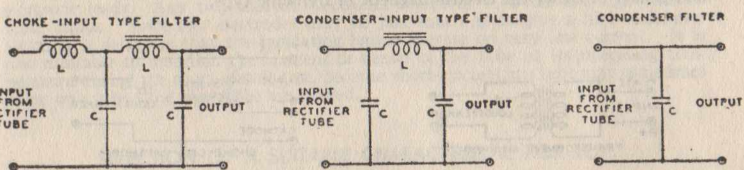


Fig. 61

If an input condenser is used, consideration must be given to the instantaneous peak value of the a-c input voltage. This peak value is about 1.4 times the RMS value as measured by an a-c voltmeter. Filter condensers, therefore, especially the input condenser should have a rating high enough to withstand the instantaneous peak value if breakdown is to be avoided. When the input-choke method is used, the available d-c output voltage will be somewhat lower than with the input-condenser method for a given a-c plate voltage. However, improved regulation together with lower peak current will be obtained.

Mercury-vapor and gas-filled rectifier tubes occasionally produce a form of local interference in radio receivers, through direct radiation or through the power line. This interference is generally identified in the receiver as a broadly tunable 120-cycle buzz (100 cycles for 50-cycle supply line, etc.). It is usually caused by the formation of a steep wave front when plate current within the tube begins to flow on the positive half of each cycle of the a-c supply voltage. There are several ways of eliminating this type of interference. One is to shield the tube. Another is to insert an r-f choke having an inductance of one millihenry or more between each plate and transformer winding and to connect high-voltage, r-f by-pass condensers between the outside ends of the transformer winding and the center tap. See Fig. 62. The r-f chokes should be placed within the shielding of the tube. The r-f by-pass condensers should have a voltage rating high enough to withstand the peak voltage of each half of the secondary, which is approximately 1.4 times the RMS value. Transformers having electrostatic shielding between primary and secondary are not likely to transmit r-f disturbances to the line. Often the interference may be eliminated simply by making the plate leads of the rectifier extremely short. In general, the particular method of interference elimination must be selected by experiment for each installation.

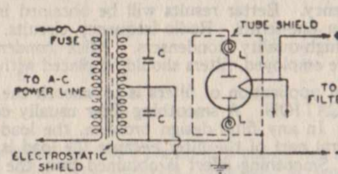


Fig. 62

OUTPUT-COUPLING DEVICES

An output-coupling device is used in the plate circuit of a power output tube to keep the comparatively high d-c plate current from the winding of an electromagnetic speaker and also to transfer power efficiently from the output stage to a loudspeaker of either the electro-magnetic or dynamic type.

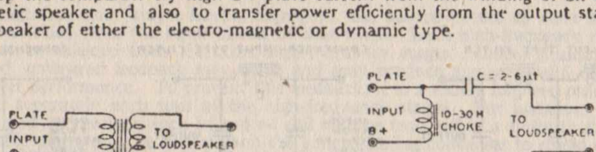


Fig. 63

Output-coupling devices are of two types, (1) choke-condenser and (2) transformer The choke-condenser type consists of an iron-core choke with an inductance of not less than 10 henrys which is placed in series with the plate and B-supply. The choke offers a very low resistance to the d-c plate current component of the signal voltage but opposes the flow of the fluctuating component. A by-pass condenser of 2 to 6 µf supplies a path to the speaker winding for the signal voltage. The transformer type is constructed with two separate windings a primary and a secondary wound on an iron core This construction permits of designing each winding to meet the requirements of its position in the circuit. Typical arrangements of each type of coupling device are shown in Fig. 63

Radio Tube Testing

The radio tube user — service man, experimenter, and non-technical radio listener — is interested in knowing the condition of his tubes, since they govern the performance of the device in which they are used. In order to determine the condition of a tube, some method of test is necessary. Because the operating capabilities and design features of a tube are indicated and described by its electrical characteristics, a tube is tested by measuring its characteristics and comparing them with representative values established as standard for that type. Tubes which read abnormally high with respect to the standard for the type are subject to criticism just the same as tubes which are too low.

Certain practical limitations are placed on the accuracy with which a tube test can be correlated with actual tube performance. These limitations make it unnecessary for the service man and dealer to employ complex and costly testing equipment having laboratory accuracy. Because the accuracy of the tube-testing device need be no greater than the accuracy of the correlation between test results and receiver performance, and since certain fundamental characteristics are virtually fixed by the manufacturing technique of leading tube manufacturers, it is possible to employ a relatively simple test in order to determine the serviceability of a tube.

In view of these factors, dealers and service men will find it economically expedient to obtain adequate accuracy and simplicity of operation by employing a device which indicates the status of a single characteristic. Whether the tube is satisfactory or unsatisfactory is judged from the test result of this single characteristic. Consequently, it is very desirable that the characteristic selected for the test be one which is truly representative of the tube's overall condition.

SHORT CIRCUIT TEST

The fundamental circuit of a short-circuit tester is shown in Fig. 64. While this circuit is suitable for tetrodes and types having less than four electrodes, tubes of more electrodes may be tested by adding more indicator lamps to the circuit. Voltages are applied between the various electrodes with lamps in series with the electrode leads. Any two shorted electrodes complete a circuit and light one or more lamps. Since two electrodes may be just touching to give a high-resistance short, it is desirable that the indicating lamps operate on very low current. It is also desirable to maintain the filament or heater of the tube at its operating temperature during the short-circuit test, because short-circuits in a tube may sometimes occur only when the electrodes are heated.

SELECTION OF A SUITABLE CHARACTERISTIC FOR TEST

Some characteristics of a tube are far more important in determining its operating worth than are others. The cost of building a device to measure any one of the more important characteristics may be considerably higher than that of a device which measures a less representative characteristic. Consequently, three methods of test will be discussed, ranging from relatively simple and inexpensive equipment to more elaborate, more accurate, and more costly devices.

An emission test is perhaps the simplest method of indicating a tube's condition. (Refer to DIODES, Page312for a discussion of electronic emission.) Since emission falls off as the tube wears out, low emission is indicative of the end of tube serviceability. However, the emission test is subject to limitations because it tests the tube under static conditions and does not take into account the actual operation of the tube. On the one hand, coated filaments, or cathodes, often develop active spots from which the emission is so great that the relatively small grid area adjacent to these spots cannot control the electron stream. Under these conditions, the total emission may indicate the tube to be normal although the tube is unsatisfactory. On the other hand, coated types of filaments are capable of such large emission that the tube will often operate satisfactorily after the emission has fallen far below the original value.

Fig. 65 shows the fundamental circuit diagram for an emission test. All of the electrodes of the tube, except the cathode, are connected to the plate. The filament, or heater, is operated at rated voltage; after the tube has reached constant temperature, a low positive voltage is applied to the plate and the electronic emission is read on the meter. Readings which are well below the average for a particular tube type indicate that the total number of available electrons has been so reduced that the tube is no longer able to function properly.

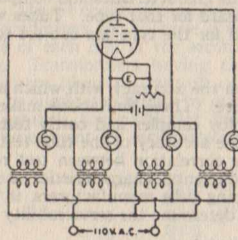


Fig. 64

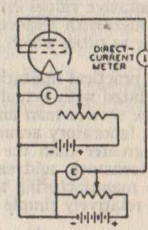


Fig. 65

A transconductance test takes into account a fundamental operating principle of the tube. (This will be seen from the definition of transconductance on page 11.) It follows that transconductance tests when properly made, permit better correlation between test results and actual performance than does a straight emission test.

There are two forms of transconductance test which can be utilized in a tube tester. In the first form (illustrated by Fig. 66 giving a fundamental circuit with a tetrode under test), appropriate operating voltages are applied to the electrodes of the tube. A plate current depending upon the electrode voltages, will then be indicated by the meter. If the bias on the grid is then shifted by the application of a different grid voltage, a new plate-current reading is obtained. The difference between the two plate-current readings is indicative of the transconductance of the tube. This method of transconductance testing is commonly called the "grid-shift" method, and depends on readings under static conditions. The fact that this form of test is made under static conditions imposes limitations not encountered in the second form of test made under dynamic conditions.

The dynamic transconductance test illustrated in Fig. 67 gives a fundamental circuit with a tetrode under test. This method is superior to the static transconductance test in that a-c voltage is applied to the grid. Thus, the tube is tested

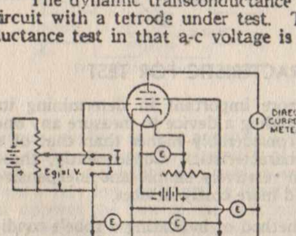


Fig. 66

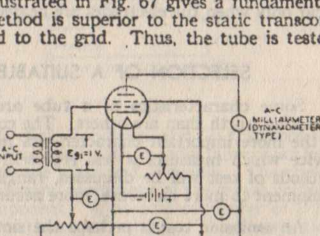


Fig. 67

under conditions which approximate actual operating conditions. The alternating component of the plate current is read by means of an a-c ammeter of the dynamometer type. The transconductance of the tube is equal to the a-c plate current divided by the input-signal voltage. If a one-volt RMS signal is applied to the grid, the plate-current-meter reading in milliamperes multiplied by one thousand is the value of transconductance in micromhos

The **power output test** probably gives the best correlation between test results and actual operating performance of a tube. In the case of voltage amplifiers, the power output is indicative of the amplification and output voltages obtainable from the tube. In the case of power output tubes, the performance of the tube is closely checked. Consequently, although more complicated to set up the power output test will give closer correlation with actual performance than any other single test

Fig. 68 shows the fundamental circuit of a power output test for class A operation of tubes. The diagram illustrates the method for a pentode. The a-c output voltage developed across the plate-load impedance (L) is indicated by the current meter. The current meter is isolated as far as the d-c plate current is concerned by the condenser (C). The power output can be calculated from the current reading and known load resistance. In this way, it is possible to determine the operating condition of the tube quite accurately.

Fig. 69 shows the fundamental circuit of a power output test for class B operation of tubes. With a-c voltage applied to the grid of the tube, the current in the plate circuit is read on a d-c milliammeter The power output of the tube is approximately equal to:

$$\text{Power output (watts)} = \frac{(\text{d-c current in amperes})^2 \times \text{load resistance in ohms}}{0.405}$$

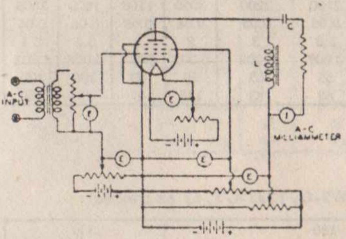


Fig. 68

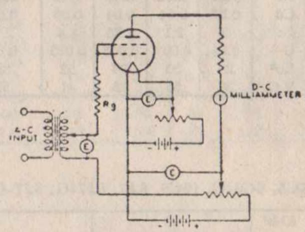


Fig. 69

ESSENTIAL TUBE TESTER REQUIREMENTS

1. It is desirable that the tester provide for a short-circuit test to be made prior to measurement of the tube's characteristics.

2. It is important that some means of controlling the voltages applied to the electrodes of the tube be provided. If the tester is a c operated, a line-voltage control will permit of supplying proper electrode voltages.

3. It is essential that the rated voltage applied to the filament or heater be maintained accurately.

4. It is suggested that the characteristics test follow one of the methods described. The method selected and the quality of the parts used in the test will depend upon the requirements of the user

TUBE TESTER LIMITATIONS

A tube testing device can only indicate the difference between a given tube's characteristics and those which are standard for that particular type. Since the operating conditions imposed upon a tube of a given type may vary within wide limits, it is impossible for a tube testing device to evaluate tubes in terms of performance capabilities for all applications. The tube tester, therefore, cannot be looked upon as a final authority in determining whether or not a tube is always satisfactory. Actual operating test in the equipment in which the tube is to be used will give the best possible indication of a tube's worth. Nevertheless, the tube tester is a most helpful device for indicating the serviceability of a tube.

RESISTANCE-COUPLED AMPLIFIER CHART

C = Blocking Condenser (μf)
C_c = Cathode By-Pass Condenser (μf)
C_d = Screen By-Pass Condenser (μf)
E_{bb} = Plate-Supply Voltage (Volts)
E_o = Voltage Output (Peak Volts)
R_c = Cathode Resistor (Ohms)
R_d = Screen Resistor (Megohms)
R_g = Grid Resistor (Megohms)
R_L = Plate Resistor (Megohms)
V.G. = Voltage Gain

2A6, 2B7: See 6SQ7 and 6B8, respectively.

6A6‡, 6B6-G, 6B7: See 6N7, 6SQ7, and 6B8, respectively.

6B8, 6B8-G, 12C8, 6B7, 2B7:

E_{bb}[1]	90			180					300		
R_L	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0.25	0.5
R_g[2]	0.25	0.5	1	0.25	0.25	0.5	1	1	0.25	0.5	1
R_d	0.5	1.1	2.8	0.5	1.18	1.2	1.5	2.8	0.55	1.2	2.9
R_c	2200	3500	6000	1200	1900	2100	2200	3500	1100	1600	2500
C_d	0.07	0.04	0.04	0.08	0.05	0.06	0.05	0.04	0.09	0.06	0.05
C_c	3	2.1	1.55	4.4	2.7	3.2	3	2	5	3.5	2.3
C	0.01	0.007	0.003	0.015	0.01	0.007	0.003	0.003	0.015	0.008	0.003
E_o[3]	28	33	29	52	39	55	53	55	89	100	120
V.G.[4]	33	55	85	41	55	69	83	115	47	79	150

6C5, 6C5-G, (6C6, 6J7, 6J7-G, 6J7-GT, 6W7-G, 12J7-GT, 57 as triodes):

E_{bb}[1]	90			180					300		
R_L	0.05	0.1	0.25	0.05	0.1			0.25	0.05	0.1	0.25
R_g[2]	0.1	0.25	0.5	0.1	0.1	0.25	0.5	0.5	0.1	0.25	0.5
R_c	3400	6400	14500	2700	3900	5300	6200	12300	2600	5300	12300
C_c	1.62	0.84	0.4	2.1	1.7	1.25	1.2	0.55	2.3	1.3	0.59
C	0.025	0.01	0.006	0.03	0.035	0.015	0.008	0.008	0.04	0.015	0.008
E_o[3]	17	22	23	45	41	54	55	52	70	84	85
V.G.[4]	9	11	12	11	12	12	13	13	11	13	14

6C6: As pentode, see 6J7; as triode, see 6C5.

6C8-G (one triode unit)‡‡:

E_{bb}[1]	90			180					300		
R_L	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0.25	0.5
R_g[2]	0.25	0.5	1	0.25	0.25	0.5	1	1	0.25	0.5	1
R_c	3700	7870	15000	3080	5170	6560	7550	12500	2840	6100	11500
C_c	1.48	0.81	0.43	1.84	1.25	0.95	0.85	0.5	2.01	0.96	0.48
C	0.0115	0.0065	0.0035	0.012	0.012	0.007	0.0035	0.004	0.013	0.0065	0.004
E_o[3]	17	19	20	40	35	45	50	44	73	80	83
V.G.[4]	20	23	24	22	24	25	26	26	23	26	27

‡‡ The cathodes of the two units have separate terminals

For other notes, see page 357

6F5, 6F5-G, 6F5-GT: See 6SF5.

6F8-G (one triode unit)‡‡, 6J5, 6J5-G, 6J5-GT, 12J5-GT:

Ebb[1]	90			180					300		
RL	0.05	0.1	0.25	0.05	0.1			0.25	0.05	0.1	0.25
Rg[2]	0.1	0.25	0.5	0.1	0.1	0.25	0.5	0.5	0.1	0.25	0.5
Rc	2070	3940	9760	1490	2330	2830	3230	7000	1270	2440	5770
Cc	2.66	1.29	0.55	2.86	2.19	1.35	1.15	0.62	2.96	1.42	0.64
C	0.029	0.012	0.007	0.032	0.038	0.012	0.006	0.007	0.034	0.0125	0.0075
Eo[3]	14	17	18	30	26	34	38	36	51	56	57
V.G.[4]	12	13	13	13	14	14	14	14	14	14	14

6J5, 6J5-G, 6J5-GT: See 6F8-G.

6J7, 6J7-G, 6J7-GT, 6W7-G, 12J7-GT, 6C6, 57: As triodes, see 6C5:

Ebb[1]	90			180					300		
RL	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0.25	0.5
Rg[2]	0.25	0.5	1	0.25	0.25	0.5	1	1	0.25	0.5	1
Rd	0.44	1.18	2.6	0.5	1.1	1.18	1.4	2.9	0.5	1.18	2.9
Rc	1100	2600	5500	750	1200	1600	2000	3100	450	1200	2200
Cd	0.05	0.03	0.05	0.05	0.04	0.04	0.04	0.025	0.07	0.04	0.04
Cc	5.3	3.2	2	6.7	5.2	4.3	3.8	2.5	8.3	5.4	4.1
C	0.01	0.005	0.0025	0.01	0.008	0.005	0.0035	0.0025	0.01	0.005	0.003
Eo[3]	22	32	29	52	41	60	60	56	81	104	97
V.G.[4]	55	85	120	69	93	118	140	165	82	140	350

6L5-G:

Ebb[1]	90			180					300		
RL	0.05	0.1	0.25	0.05	0.1			0.25	0.05	0.1	0.25
Rg[2]	0.1	0.25	0.5	0.1	0.1	0.25	0.5	0.5	0.1	0.25	0.5
Rc	2500	4620	10300	2240	3180	4200	4790	9290	2160	4140	9100
Cc	1.86	1.08	0.49	2.2	1.46	1.1	1	0.54	2.18	1.1	0.46
C	0.03	0.015	0.0085	0.03	0.03	0.0145	0.009	0.009	0.032	0.014	0.0075
Eo[3]	18	22	22	41	36	46	50	46	68	79	80
V.G.[4]	10[c]	12[c]	12[c]	11[c]	12[c]	12[c]	12[c]	12[c]	12[c]	13[c]	13[c]

6N7‡, 6N7-G‡, 6A6, 53:

Ebb[1]	90			180					300		
RL	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0.25	0.5
Rg[2]	0.25	0.5	1	0.25	0.25	0.5	1	1	0.25	0.5	1
Rc[6]	2250	4950	8500	1700	2950	3800	4300	6600	1500	3400	6100
C	0.01	0.006	0.003	0.015	0.015	0.007	0.0035	0.0035	0.015	0.0055	0.003
Eo[3]	19	20	23	46	40	50	57	54	83	87	94
V.G.[4]	19	22	23	21	23	24	24	25	22	24	24

‡‡ The cathodes of the two units have separate terminals.

For other notes, see page 357

6P5-G, 76, 56:

Ebb[1]	90			180					300		
R_L	0.25	0.1	0.25	0.05	0.1			0.25	0.05	0.1	0.25
Rg[2]	0.1	0.25	0.5	0.1	0.1	0.25	0.5	0.5	0.1	0.25	0.5
Rc	3200	6500	15100	3000	4500	6500	7600	14700	3100	6400	15200
Cc	1.6	0.82	0.36	1.9	1.45	0.97	0.8	0.45	2.2	1.2	0.5
C	0.03	0.015	0.007	0.035	0.035	0.015	0.008	0.007	0.045	0.02	0.009
Eo[3]	21	23	24	48	45	55	57	59	80	95	96
V.G.[4]	7.7	8.9	9.7	8.2	9.3	9.5	9.8	10	8.9	10	10

6Q7, 6Q7-G, 6Q7-GT, 12Q7-GT:

Ebb[1]	90			180					300		
R_L	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0.25	0.5
Rg[2]	0.25	0.5	1	0.25	0.25	0.5	1	1	0.25	0.5	1
Rc	4200	7600	12300	1900	3400	4000	4500	7100	1500	3000	5500
Cc	1.7	1.2	0.6	2.5	1.6	1.3	1.05	0.76	3.6	1.66	0.9
C	0.01	0.006	0.003	0.01	0.01	0.005	0.003	0.003	0.015	0.007	0.004
Eo[3]	8	11	13	26	25	31	37	36	52	52	60
V.G.[4]	28[b]	32	33	33	36	38	40	40	39	45	46

6R7, 6R7-G:

Ebb[1]	90			180					300		
R_L	0.05	0.1	0.25	0.05	0.1			0.25	0.05	0.1	0.25
Rg[2]	0.1	0.25	0.5	0.1	0.1	0.25	0.5	0.5	0.1	0.25	0.5
Rc	2600	4400	9800	2100	3000	4100	4600	8800	2000	3800	8400
Cc	1.7	0.9	0.42	1.9	1.3	0.9	0.8	0.4	2	1.1	0.5
C	0.03	0.01	0.007	0.03	0.03	0.01	0.006	0.006	0.03	0.015	0.007
Eo[3]	18	19	18	40	35	43	46	40	62	68	62
V.G.[4]	9	10	11	9	10	10	10	10	9	10	11

6S7, 6S7-G:

Ebb[1]	90			180					300		
R_L	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0.25	0.5
Rg[2]	0.25	0.5	1	0.25	0.25	0.5	1	1	0.25	0.5	1
Rd	0.65	1.6	3.5	0.68	1.6	1.8	1.9	3.6	0.67	1.95	3.9
Rc	900	1520	2800	540	850	890	950	1520	440	650	1080
Cd	0.061	0.044	0.03	0.07	0.05	0.044	0.046	0.037	0.071	0.057	0.041
Cc	5	3.23	1.95	6.9	4.6	4.7	4.4	3	8	5.8	3.9
C	0.01	0.0055	0.0026	0.01	0.0071	0.006	0.0037	0.003	0.01	0.005	0.0029
Eo[3]	21	18	15	43	33	40	44	38	75	66	66
V.G.[4]	47[c]	66[c]	84[c]	66[c]	79[c]	104[c]	118[c]	134[c]	78[c]	122[c]	162[c]

For notes, see page 357

6SC7 ‡, 12SC7 ‡:

Ebb[1]	90			180					300		
RL	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0.25	0.5
Rg[3]	0 25	0.5	1	0.25	0.25	0.5	1	1	0.25	0.5	1
Rc[6]	1960	3750	6300	1070	1850	2150	2400	3420	930	1680	2980
C	0.012	0.006	0.003	0.012	0.011	0 006	0.003	0.003	0 014	0.006	0 003
Eo[3]	5.9	8.6	10	24	21	28	32	32	50	55	62
V G[4]	23[b]	30	33	29	35	39	41	43	34	42	48

6SF5, 12SF5, 6F5, 6F5-G, 6F5-GT, 12F5-GT:

Ebb[1]	90			180					300		
RL	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0 25	0.5
Rg[3]	0.25	0.5	1	0 25	0.25	0.5	1	1	0.25	0.5	1
Rc	4800	8800	13500	2000	3500	4100	4500	6900	1600	3200	5400
Cc	2.1	1.18	0 67	3 3	2.3	1.8	1.7	0.9	3.7	2 1	1.2
C	0.01	0.005	0.003	0.015	0.01	0 006	0.004	0.003	0.01	0.007	0.004
Eo[3]	5	7	10	23	21	26	32	33	43	54	62
V.G.[4]	34[b]	43[c]	46	44	48	53	57	63	49	63	70

6SJ7, 12SJ7:

Ebb[1]	90			180					300		
RL	0.1	0 25	0.5	0.1	0.25			0.5	0.1	0 25	0.5
Rg[3]	0.25	0.5	1	0.25	0.25	0.5	1	1	0 25	0.5	1
Rd	0.29	0.92	1.7	0.31	0.83	0.94	0.94	2.2	0 37	1.10	2.2
Rc	880	1700	3800	800	1050	1060	1100	2180	530	860	1410
Cd	0.085	0.045	0.03	0.09	0.06	0.06	0.07	0.04	0 09	0.06	0 05
Cc	7.4	4.5	2.4	8	6.8	6.6	6.1	3.8	10.9	7.4	5.8
C	0 016	0.005	0.002	0.015	0.001	0.004	0.003	0.002	0.016	0 004	0.002
Eo[3]	23	18	22	60	38	47	54	44	96	88	79
V.G[4]	68	93	119	82	109	131	161	192	98	167	238

6SQ7, 12SQ7, 2A6, 6B6-G, 75:

Ebb[1]	90			180					300		
RL	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0.25	0.5
Rg[3]	0.25	0.5	1	0.25	0.25	0.5	1	1	0.25	0.5	1
Rc	6600	11000	16600	2900	4300	4800	5300	8000	2200	3900	6100
Cc	1.7	1.07	0.7	2.9	2.1	1.8	1.5	1.1	3.5	2	1.3
C	0.01	0.006	0.003	0.015	0 015	0.007	0.004	0.004	0.015	0.007	0.004
Eo[3]	5	7	10	22	21	28	33	33	41	51	62
V G[4]	20[b]	40[c]	44	36	43	50	53	57	39	53	60

For notes, see page 357

6T7-G:

Ebb[1]	90			180					300		
RL	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0.25	0.5
Rg[2]	0.25	0.5	1	0.25	0.25	0.5	1	1	0.25	0.5	1
Rc	4750	8300	14200	2830	4410	5220	5920	9440	2400	4580	8200
Cc	1.5	1	0.6	2.25	1.5	1.25	1.11	0.74	2.55	1.35	0.82
C	0.012	0.0075	0.0045	0.0135	0.012	0.008	0.005	0.0045	0.0135	0.0075	0.0055
Eo[3]	7.8	10	12	29	27	34	39	39	58	69	77
V.G.[4]	24[b]	30[c]	33[c]	28[c]	34[c]	36[c]	38[c]	41[c]	32[c]	40[c]	43[c]

6W7-G: See 6J7 and 6C5.

6Z7-G‡:

Ebb[1]	90			180					300		
RL	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0.25	0.5
Rg[2]	0.25	0.5	1	0.25	0.25	0.5	1	1	0.25	0.5	1
Rc*	1760	3390	6050	1100	1820	2110	2400	3890	950	1680	3110
Cc	2.02	1.1	0.61	2.6	1.71	1.38	1.1	0.703	2.63	1.46	0.72
C	0.0115	0.006	0.003	0.0115	0.012	0.007	0.0035	0.0035	0.012	0.006	0.0035
Eo[3]	11	15	18	28	28	34	41	38	52	59	70
V.G.[4]	25	30	33	31	35	38	39	40	34	40	44

12C8, 12F5-GT, 12J5-GT: See 6B8, 6SF5, and 6F8-G, respectively.
12J7-GT, 12Q7-GT: See 6J7 and 6C5, and 6Q7, respectively.
12SC7, 12SF5, 12SJ7, 12SQ7: See 6SC7, 6SF5, 6SJ7, and 6SQ7, respectively.
53, 55, 56: See 6N7, 85, and 6P5-G, respectively.
57, 75, 76: See 6J7 and 6C5, 6SQ7, and 6P5-G, respectively.
79‡:

Ebb[1]	90			180					300		
RL	0.1	0.25	0.5	0.1	0.25			0.5	0.1	0.25	0.5
Rg[2]	0.25	0.5	1	0.25	0.25	0.5	1	1	0.25	0.5	1
Rc*	2200	4250	6850	1250	2050	2450	2750	4100	1000	2050	3600
C	0.015	0.006	0.004	0.02	0.02	0.01	0.005	0.0035	0.01	0.0055	0.003
Eo[3]	8.4	9.7	12	27	26	34	40	39	57	66	75
V.G.[4]	29[c]	33	38	31	37	41	42	44	34	42	46

85, 55:

Ebb[1]	90			180					300		
RL	0.05	0.1	0.25	0.05	0.1			0.25	0.05	0.1	0.25
Rg[2]	0.1	0.25	0.5	0.1	0.1	0.25	0.5	0.5	0.1	0.25	0.5
Rc	4600	9000	20500	4100	6200	8700	10000	20000	4100	8300	19400
Cc	1.1	0.55	0.25	1.6	0.9	0.7	0.57	0.29	1.5	0.54	0.22
C	0.03	0.015	0.007	0.045	0.04	0.015	0.008	0.008	0.045	0.015	0.006
Eo[3]	19	22	23	44	37	47	50	48	74	82	84
V.G.[4]	4.9	5.4	5.5	5.2	5.3	5.5	5.5	5.7	5.5	5.7	5.7

For notes, see page 357

Voltage at plate equals Plate-Supply Voltage minus voltage drop in R_L and R_c. For other supply voltages differing by as much as 50% from those listed, the values of resistors, condensers and gain are approximately correct. The value of voltage output, however, for any of these other supply voltages equals the listed voltage output multiplied by the new plate-supply voltage divided by the plate-supply voltage corresponding to the listed voltage output.

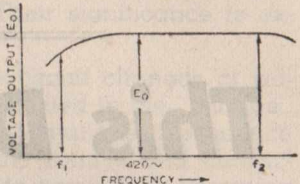
For following stage (see Circuit Diagrams). [3] Voltage across Rg at grid-current point

Voltage Gain at 5 volts (RMS) output unless index letter indicates otherwise.
[b] At 3 volts (RMS) output. [c] At 4 volts (RMS) output.

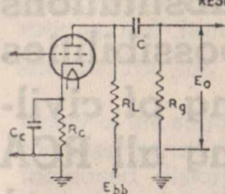
* Values are for phase-inverter service: See NOTES under RESISTANCE-COUPLED PHASE-INVERTER diagram.

‡ The cathodes of the two units have a common terminal.

In the discussions which follow, f_2 is the frequency at which the high-frequency response begins to fall off. f_1 is the frequency at which the low-frequency response drops below a satisfactory value, as discussed below. Decoupling filters are not necessary for two stages or less. The highest permissible value of Rg should always be used. A variation of 10% in values of resistors and condensers has only slight effect on performance.



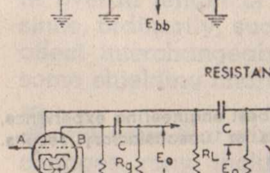
RESISTANCE-COUPLED TRIODE AMPLIFIER



Condensers C and Cc have been chosen to give output voltages equal to 0.8 Eo for f_1 of 100 cycles. For any other value of f_1, multiply values of C and Cc by $100/f_1$. In the case of condenser Cc, the values shown in the table are for an amplifier with d-c heater excitation; when a.c. is used, depending on the character of the associated circuit, the gain, and the value of f_1, it may be necessary to increase the value of Cc to minimize hum disturbances. It may also be desirable to have a d-c potential difference of approximately 10 volts between heater and cathode.

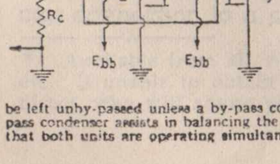
The voltage output at f_1 of n like stages equals $(0.8\ Eo)^n$. For an amplifier of typical construction, the value of f_2 is well above the audio-frequency range for any value of R_L.

RESISTANCE-COUPLED PENTODE AMPLIFIER



Condensers C, Cc, and Cd have been chosen to give output voltages equal to 0.7 Eo for f_1 of 100 cycles. For any other value of f_1 multiply values of C, Cc, and Cd by $100/f_1$. In the case of condenser Cc, the values shown in the table are for an amplifier with d-c heater excitation; when a.c. is used, depending on the character of the associated circuits, the gain, and the value of f_1, it may be necessary to increase the value of Cc to minimize hum disturbances. It may also be desirable to have a d-c potential difference of approximately 10 volts between heater and cathode. The voltage output at f_1 for n like stages equals $(0.7\ Eo)^n$. For an amplifier of typical construction, approximate values of f_2 for different values of R_L are: 0.1 meg., 20000 cps; 0.25 meg., 10000 cps; 0.5 meg., 5000 cps.

RESISTANCE-COUPLED PHASE INVERTER



Information given for triode amplifiers, in general, applies also to this case. Condensers C have been chosen to give output voltages equal to 0.9 Eo for f_1 of 100 cycles. For other values, multiply values of C by $100/f_1$.

The signal input is supplied to grid of triode unit A. Grid of triode unit B obtains its signal from a tap (P) on the grid resistor (Rg) in the output circuit of unit A. The tap is chosen so as to make the voltage output of the unit B equal to that of unit A. Its location is determined by the voltage gain values given in the chart. For example, if V.G. is 20 (from the chart), P is chosen so as to supply 1/20 of the voltage across Rg to the grid of unit B.

For phase-inverter service, the cathode resistor may be left unby-passed unless a by-pass condenser is necessary to minimize hum; omission of the by-pass condenser assists in balancing the output voltages. The value of Rc is specified on the basis that both units are operating simultaneously at the same values of plate load and plate voltage

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This Directory

lists over 2000 tube substitutions having replacement possibilities for emergency servicing of civilian receivers. Including all RCA Receiving Tubes and arranged for easy reference, the list will greatly assist radio service men in quickly selecting a suitable substitute type.

Information contained herein is based on our best engineering experience, but no responsibility is accepted for errors or unsatisfactory results.

EXPLANATION OF NUMBERS INDICATING CHANGES

In making such substitutions, it may be necessary to make certain basic changes in every receiver. Such changes are indicated by numbers shown in the "change" column of the list. Their significance is explained below.

Some substitutions will require circuit changes or adjustments additional to those indicated in the "change" column. Before making any substitutions, the service man should, therefore, check the ratings and characteristics of the proposed substitute against the operating conditions of the circuit. Convenient reference for tube ratings and characteristics is *Bernards' Radio Valve Manual (No. 30). Price 3/6* *

Many of the suggested substitutions may cause lowered receiver sensitivity and lowered power output with increased distortion, but such substitutions may be desirable on the basis that they provide the only method by which broadcast receivers can be put in useable condition under existing circumstances.

1 signifies that **space limitations** must be considered, because the substitute type is appreciably larger in size than the type to be replaced. Small differences in overall length or diameter have been disregarded since, ordinarily, such differences do not in themselves affect interchangeability. They may, however, affect some shielding changes.

2 indicates that **wiring changes** will be required. Such changes may include any of the following items: (1) lengthening of top-cap lead; (2) changing from top-cap connection to a socket-terminal connection, or vice

* Available from all Wireless Dealers, Newsagents, Bookstalls, etc. If unable to obtain please get in touch with the Publishers direct, who will advise you of your nearest supplier.

versa (if change is from single-ended metal type to a top-cap type, it may be necessary to use a suitably shielded lead to the top-cap); or (3) rewiring of socket (except for filament- or heater-circuit changes which are considered under "change number" 3). CAUTION: When wiring changes are made, it may also be necessary to remove wiring connections utilizing spare terminals of the socket. Special attention should also be given to the pin No. 1 connection of octal-base types, because in different circuits this pin may be used to ground the shield, left floating, or made a high-potential common tie. The particular arrangement used in the receiver and its relation to the substitute tube will determine what has to be changed in order that proper connections for the substitute type can be made.

3 indicates that **filament- or heater-circuit changes** will be required to provide the proper voltage or current for the substitute type. When heaters are connected in parallel, a substitute type with lower heater voltage than the type to be replaced may be used if a series resistor of proper value is inserted in one of the heater leads. When heaters are operated in series, a substitute type with different heater rating than the type to be replaced may be used by adding series and/or shunt resistors to the heater string. Sample calculations of series- and shunt-resistor values are shown.

When shunt or series resistors are added to the heater circuit, leave ample space around them for adequate ventilation. The practice of using shunt resistors is suggested only as an emergency measure, because the heater-string current during the warm-up period does not always divide proportionately between the heater and its shunt resistor. As a result, the heater may be temporarily but seriously overloaded.

4 indicates that **socket changes** will be required unless suitable adaptors can be procured. The use of adaptors may be restricted in some receivers by lack of space or other considerations such as alignment difficulties caused by capacitances added to the input and output circuits by the adaptor.

Supplemental Notes

In making substitutions for Power Output Types, the service man may find that the load resistance for the tube to be replaced is not suitable for use with the substitute type. When it is impractical to change the load resistance to the required value, some benefit may be obtained by adjusting the grid bias to give lowest distortion, but in so doing, care should be taken to not exceed the dissipation ratings of the tube. Also, if the substitute type has greater power-handling capability than the tube to be replaced, the current drain of the substitute tube must be kept within the current-delivering ability of the power supply in the receiver.

When substitutions are to be made for R-F Amplifier, I-F Amplifier, Converter, Oscillator, and Mixer Types, the substitute type may have a lower or a higher value of transconductance than that of the type to be replaced. If the substitute type has a lower value, it may cause some loss in receiver sensitivity and possibly impaired frequency conversion. In areas relatively close to broadcast stations, satisfactory reception should be obtained, but in remote areas, the diminished receiver sensitivity may be unsatisfactory. If the substitute type has a higher value of transconductance than the type to be replaced, oscillation difficulties may be experienced. These can sometimes be corrected by additional shielding, filtering, or reduction in the screen voltage. In all such substitutions, realignment of the receiver is recommended.

Substitutions for Audio Voltage Amplifier Types can generally be made with satisfactory results because a wide variation in gain is usually permissible. If necessary, the gain obtained with the substitute type can be changed by choosing the right combination of B-supply voltage, bias, grid resistor, and plate load.

TUBE SUBSTITUTION DIRECTORY

To Replace These RCA Types	Use These RCA Types	With Changes Indicated Below
0Z4	0Z4-G	
	6X5	1, 2, 3
	6X5-GT/G	1, 2, 3
	7Y4	1, 2, 3, 4
	See	Key 2, 4
0Z4-G	0Z4	
	6X5	1, 2, 3
	6X5-GT/G	1, 2, 3
	7Y4	1, 2, 3, 4
	See	Key 2, 4
1A3	See	Key 6
1A4-P	1D5-GP	4
	1D5-GT	4
	34	1
	See	Key 42-44, 50
1A5-GT/G	1LA4	4
	1N6-G	1, 2
	See	Key 12, 14, 16
1A6	1C6	3
	1C7-G	3, 4
	1D7-G	4
	See	Key 20
1A7-GT/G	1B7-GT	3
	1LA6	2, 4
	1R5	2, 4
	See	Key 20
1B4-P	1E5-GP	4
	15	3, 4
	32	1
	See	Key 42-44, 50
1B5	1H6-G	4
	See	Key 32
1B7-GT	1A7-GT/G	3
	1LA6	2, 3, 4
	1R5	2, 3, 4
	See	Key 20
1C5-GT/G	1D8-GT	2
	1LB4	3, 4
	1Q5-GT/G	
	1S4	4
	1T5-GT	3
	3Q4	3, 4
	3Q5-GT/G	3
	3S4	3, 4
	See	Key 12, 14, 16, 17
1C6	1A6	3
	1C7-G	4
	1D7-G	3, 4
	See	Key 20
1C7-G	1A6	3, 4
	1C6	4
	1D7-G	3
	See	Key 20
1D5-GP	1A4-P	4
	1D5-GT	
	34	1, 4
	See	Key 42-44, 50
1D5-GT	1A4-P	4
	1D5-GP	
	34	1, 4
	See	Key 42-44, 50
1D7-G	1A6	4
	1C6	3, 4
1D7-G—Continued	1C7-G	3
	See	Key 20
1D8-GT	See	Key 17, 31
1E5-GP	1B4-P	4
	15	3, 4
	32	1, 4
	See	Key 42-44, 50
1E7-G	See	Key 19
1F4	1E7-G	3, 4
	1F5-G	4
	1G5-G	4
	1J5-G	4
	See	Key 14, 19
1F5-G	1E7-G	2, 3
	1F4	4
	1G5-G	
	1J5-G	
	See	Key 14, 19
1F6	1F7-G	4
	See	Key 53
1F7-G	1F6	4
	See	Key 53
1G4-GT/G	See	Key 28, 31, 38, 39
1G5-G	1E7-G	2, 3
	1F4	4
	1F5-G	
	1J5-G	
	See	Key 14
1G6-GT/G	See	Key 10
1H4-G	30	4
	See	Key 28
1H5-GT/G	1LH4	2, 4
	See	Key 39
1H6-G	1B5	4
	See	Key 32
1J5-G	1E7-G	2, 3
	1F4	4
	1F5-G	
	1G5-G	
	See	Key 14
1J6-G	19	3, 4
	See	Key 10, 19
1L4	1LN5	1, 4
	1N5-GT/G	1, 2, 4
	1S5	2
	3A8-GT	1, 2, 3, 4
	See	Key 44, 50-52
1LA4	1A5-GT/G	4
	1N6-G	1, 4
	See	Key 12, 14, 16
1LA6	1A7-GT/G	2, 4
	1B7-GT	2, 3, 4
	1R5	4
	See	Key 20
1LB4	1C5-GT/G	3, 4
	1D8-GT	3, 4
	1Q5-GT/G	3, 4
	1S4	3, 4
	1T5-GT	4
	3Q4	3, 4
1LB4—Continued	3Q5-GT/G	3, 4
	3S4	3, 4
	See	Key 12, 14, 17
1LH4	1H5-GT/G	2, 4
	See	Key 39
1LN5	1L4	4
	1N5-GT/G	2, 3, 4
	1S5	4
	3A8-GT	2, 3, 4
	See	Key 44, 50-52
1N5-GT/G	1L4	2, 4
	1LN5	2, 4
	1S5	2, 4
	3A8-GT	2, 3
	See	Key 44, 50-52
1N6-G	See	Key 16
1P5-GT	1T4	2, 4
	See	Key 44, 50-52
1Q5-GT/G	1C5-GT/G	
	1D8-GT	2
	1LB4	3, 4
	1S4	4
	1T5-GT	3
	3Q4	3, 4
	3Q5-GT/G	3
	3S4	3, 4
	See	Key 12, 14, 17
1R5	1A7-GT/G	1, 2, 4
	1B7-GT	1, 2, 3, 4
	1LA6	1, 4
	See	Key 20
1S4	1C5-GT/G	1, 4
	1D8-GT	1, 4
	1LB4	1, 3, 4
	1Q5-GT/G	1, 4
	1T5-GT	1, 3, 4
	3Q4	3
	3Q5-GT/G	1, 3, 4
	3S4	3
	See	Key 12, 14, 17
1S5	3A8-GT	1, 2, 3, 4
	See	Key 51, 52
1T4	1P5-GT	1, 2, 4
	See	Key 44, 50-52
1T5-GT	1C5-GT/G	3
	1D8-GT	2, 3
	1LB4	4
	1Q5-GT/G	3
	1S4	3, 4
	3Q4	3, 4
	3Q5-GT/G	3
	3S4	3, 4
	See	Key 12, 14, 17
1-v	See	Key 1, 2
2A3	45	
	See	Key 8
2A5	46	1, 4
	47	1, 4
	59	1, 3, 4
	See	Key 14
2A6	See	Key 32, 40

1. Space limitations.
2. Wiring changes.
3. Filament voltage and/or current changes.
4. Socket change.

To Replace These RCA Types	Use These RCA Types	With Changes Indicated Below
2A7	See	Key 20
2B7	See	Key 49
2E5	See	Key 26
3A8-GT	See	Key 38, 51
3Q4	1C5-GT/G	1, 3, 4
	1D8-GT	1, 3, 4
	1LB4	1, 3, 4
	1Q5-GT/G	1, 3, 4
	1S4	3
	1T5-GT	1, 3, 4
	3Q5-GT/G	1, 4
	3S4	
	See	Key 12, 14, 17
3Q5-GT/G	1C5-GT/G	3
	1D8-GT	2, 3
	1LB4	3, 4
	1Q5-GT/G	3
	1S4	3, 4
	1T5-GT	3
	3Q4	4
	3S4	4
	See	Key 12, 14, 17
3S4	1C5-GT/G	1, 3, 4
	1D8-GT	1, 3, 4
	1LB4	1, 3, 4
	1Q5-GT/G	1, 3, 4
	1S4	3
	1T5-GT	1, 3, 4
	3Q4	
	3Q5-GT/G	1, 4
	See	Key 12, 14, 17
5T4	5U4-G	1, 3
	5X4-G	1, 2, 3
	5Z3	1, 3, 4
	See	Key 2
5U4-G	5T4	
	5X4-G	2
	5Z3	4
	See	Key 2
5V4-G	5T4	
	5U4-G	1, 3
	5X4-G	1, 2, 3
	5Z3	1,
	83-v	4
	See	Key 2
5W4	5T4	1, 3
	5U4-G	1, 3
	5V4-G	1, 3
	5W4-GT/G	
	5X4-G	1, 2, 3
	5Y3-GT/G	3
	5Y4-G	1, 2, 3
	5Z3	1, 3, 4
	5Z4	3
	80	1, 3, 4
	83-v	1, 3, 4
	See	Key 2
5W4-GT/G	5T4	1, 3
	5U4-G	1, 3
	5V4-G	1, 3
	5W4	
	5X4-G	1, 2, 3
	5Y3-GT/G	3
	5Y4-G	1, 2, 3
	5Z3	1, 3, 4
	5Z4	3
	80	1, 3, 4
	83-v	1, 3, 4
	See	Key 2
5X4-G	5T4	2
	5U4-G	2
	5Z3	4
	See	Key 2
5Y3-GT/G	5T4	1
	5U4-G	1, 3
	5V4-G	1
	5X4-G	1, 2, 3
	5Y4-G	1, 2
	5Z3	1, 3, 4
	5Z4	
	80	1, 4
	83-v	1, 4
	See	Key 2
5Y4-G	5T4	2
	5U4-G	1, 2, 3
	5V4-G	2
	5X4-G	1, 3
	5Y3-GT/G	2
	5Z3	1, 3, 4
	5Z4	2
	80	4
	83-v	4
	See	Key 2
5Z3	5T4	4
	5U4-G	4
	5X4-G	4
	See	Key 2
5Z4	5T4	1
	5U4-G	1, 3
	5V4-G	1
	5X4-G	1, 2, 3
	5Y3-GT/G	
	5Y4-G	1, 2
	5Z3	1, 3, 4
	80	1, 4
	83-v	1, 4
	See	Key 2
6A3	2A3	3
	6B4-G	4
	45	3
	See	Key 8
6A4	6G6-G	3, 4
	6K6-GT/G	3, 4
	6V6	3, 4
	6V6-GT/G	3, 4
	7B5	3, 4
	7C5	3, 4
	38	2
	41	3, 4
	89	2, 3, 4
	See	Key 12, 14
6A6	6N7	4
	6N7-GT/G	4
	6Y7-G	4
	6Z7-G	4
	53	3
	79	2, 4
	See	Key 10
6A7	2A7	3
	6A7S	
	6A8	2, 4
	6A8-G	4
	6A8-GT	2, 4
	6D8-G	3, 4
	7A8	2, 3, 4
	7B8	2, 4
	12A8-GT	2, 3, 4
	12A8-GT/G	2, 3, 4
6A7S	2A7	3
	6A7	
6A7S—Continued		
	6A8	2, 4
	6A8-G	4
	6A8-GT	2, 4
	6D8-G	3, 4
	7A8	2, 3, 4
	7B8	2, 4
	12A8-GT/G	2, 3, 4
	See	Key 20-24
6A8	2A7	1, 2, 3, 4
	6A7	1, 2, 4
	6A7S	1, 2, 4
	6A8-G	1, 2
	6A8-GT	
	6D8-G	1, 2, 3
	7A8	2, 3, 4
	7B8	2, 4
	12A8-GT/G	3
	See	Key 20-24
6A8-GT	2A7	1, 2, 3, 4
	6A7	1, 2, 4
	6A7S	1, 2, 4
	6A8	
	6A8-G	1, 2
	6D8-G	1, 2, 3
	7A8	2, 3, 4
	7B8	2, 4
	12A8-GT/G	3
	See	Key 20-24
6AB5/6N5	6U5/6G5	3
	See	Key 25, 26
6AB7	6SG7	2
	7H7	4
	See	Key 44, 48, 50
6AC5-GT/G	25AC5-GT/G	3
	See	Key 10
6AC7	6AG5	4
	6SH7	2
	7G7	4
	See	Key 44, 48, 50
6AD6-G	6AF6-G	
	See	Key 27
6AD7-G	See	Key 15
6AE5-GT/G*	6C5	
	6C5-GT/G	
	6F8-G	1, 2, 3
	6J5	
	6J5-GT/G	
	6L5-G	1, 3
	6P5-GT/G	
	6SN7-GT	2, 3
	7A4	4
	12J5-GT	3
	12SN7-GT	2, 3
	27	1, 3, 4
	37	1, 4
	56	1, 3, 4
	76	1, 4
	See	Key 28-41
6AE6-G	See	Key 35
6AE7-GT	See	Key 34
6AF6-G	6AD6-G	1
	See	Key 27
6AG5	6AC7	1, 3, 4
	6SH7	1, 4
	7G7	1, 3, 4
	12SH7	1, 3, 4
	See	Key 44, 48, 50
6AG7	See	Key 14

*Pentodes under Type 6C6 may also be used as a substitute for this type when they are connected as triodes (screen and suppressor tied to plate).

1. Space limitations.
2. Wiring changes.
3. Filament voltage and/or current changes.
4. Socket change.

To Replace These RCA Types	Use These RCA Types	With Changes Indicated Below
6B4-G	2A3	3, 4
	6A3	4
	45	3, 4
	See	Key 8
6B5	6N6-G	4
	See	Key 11, 12, 14
6B6-G	2A6	3, 4
	6Q7	2
	6Q7-G	
	6Q7-GT	2
	6SQ7	2
	6SQ7-GT/G	2
	6T7-G	3
	7B6	2, 4
	7C6	2, 3, 4
	12Q7-GT/G	2, 3
	12SQ7	2, 3
	12SQ7-GT/G	2, 3
	75	4
	See	Key 32, 40
6B7	2B7	3
	6B7S	
	6B8	2, 4
	6B8-G	4
	12C8	2, 3, 4
	See	Key 49
6B7S	2B7	3
	6B7	
	6B8	2, 4
	6B8-G	4
	12C8	2, 3, 4
	See	Key 49
6B8	2B7	1, 2, 3, 4
	6B7	1, 2, 4
	6B7S	1, 2, 4
	6B8-G	1, 2
	12C8	3
	See	Key 49
6B8-G	2B7	3, 4
	6B7	4
	6B7S	4
	6B8	2
	12C8	2, 3
	See	Key 49
6C5*	6AE5-GT/G	
	6C5-GT/G	
	6F8-G	1, 2, 3
	6J5	
	6J5-GT/G	
	6L5-G	1, 3
	6P5-GT/G	
	6SN7-GT	2, 3
	7A4	4
	12J5-GT	3
	12SN7-GT	2, 3
	27	1, 3, 4
	37	1, 4
	56	1, 3, 4
	76	1, 4
	See	Key 28-41
6C5-GT/G*	6AE5-GT/G	
	6C5	
	6F8-G	1, 2, 3
	6J5	
	6J5-GT/G	
	6L5-G	1, 3
	6P5-GT/G	
	6SN7-GT	2, 3
	7A4	4
	12J5-GT	3
	12SN7-GT	2, 3
	27	1, 3, 4
6C5-GT/G*—Continued		
	37	1, 4
	56	1, 3, 4
	76	1, 4
	See	Key 28-41
6C6	6D7	4
	6J7	2, 4
	6J7-G	4
	6J7-GT	2, 4
	6SJ7	2, 4
	6SJ7-GT	2, 4
	6W7-G	3, 4
	7C7	2, 3, 4
	12J7-GT/G	2, 3, 4
	12SJ7	2, 3, 4
	12SJ7-GT	2, 3, 4
	57	3
	77	
	See	Key 44-50
6C7	6R7	2, 4
	6R7-GT/G	2, 4
	6SR7	2, 4
	6ST7	2, 3, 4
	6V7-G	4
	7E6	2, 4
	12SR7	2, 3, 4
	55	3, 4
	85	4
	See	Key 32, 40
6C8-G	6F8-G	3
	6SN7-GT	2, 3
	12AH7-GT	2, 3
	12SN7-GT	2, 3
	See	Key 10, 33, 41
6D6	6E7	4
	6K7	2, 4
	6K7-G	4
	6K7-GT	2, 4
	6S7	2, 3, 4
	6S7-G	3, 4
	6SK7	2, 4
	6SK7-GT/G	2, 4
	6SS7	2, 3, 4
	6U7-G	4
	7A7	2, 4
	7B7	2, 3, 4
	12K7-GT/G	2, 3, 4
	12SK7	2, 3, 4
	12SK7-GT/G	2, 3, 4
	14A7	2, 3, 4
	39/44	4
	58	3
	78	
	See	Key 44-50
6D7	6C6	4
	6J7	2, 4
	6J7-G	4
	6J7-GT	2, 4
	6SJ7	2, 4
	6SJ7-GT	2, 4
	6W7-G	3, 4
	7C7	2, 3, 4
	12J7-GT/G	2, 3, 4
	12SJ7	2, 3, 4
	12SJ7-GT/G	2, 3, 4
	57	3, 4
	77	4
	See	Key 44-50
6D8-G	2A7	3, 4
	6A7	3, 4
	6A7S	3, 4
	6A8	2, 3
6D8-G—Continued		
	6A8-G	3
	6A8-GT	2, 3
	7A8	2, 4
	7B8	2, 3, 4
	12A8-GT/G	2, 3
	See	Key 20-24
6E5	2E5	3
	See	Key 25, 26
6E6	See	Key 9, 10
6E7	6D6	4
	6K7	2, 4
	6K7-G	4
	6K7-GT	2, 4
	6S7	2, 3, 4
	6S7-G	3, 4
	6SK7	2, 4
	6SK7-GT/G	2, 4
	6SS7	2, 3, 4
	6U7-G	4
	7A7	2, 4
	7B7	2, 3, 4
	12K7-GT/G	2, 3, 4
	12SK7	2, 3, 4
	12SK7-GT/G	2, 3, 4
	14A7	2, 3, 4
	39/44	4
	58	3, 4
	78	4
	See	Key 44-50
6F5	6F5-GT/G	
	6SF5	2
	6SF5-GT	2
	6K5-GT/G	2
	7B4	2, 4
	12F5-GT	3
	12SF5	2, 3
	12SF5-GT	2, 3
	See	Key 28-41
6F5-GT/G	6F5	
	6SF5	2
	6SF5-GT	2
	6K5-GT/G	2
	7B4	2, 4
	12F5-GT	3
	12SF5	2, 3
	12SF5-GT	2, 3
	See	Key 28-41
6F6	6AD7-G	1, 2, 3
	6F6-G	1
	6K6-GT/G	
	6L6	1, 3
	6L6-G	1, 3
	6V6	
	6V6-GT/G	
	7B5	4
	7C5	4
	12A5	1, 4
	38	1, 2, 4
	41	1, 4
	42	1, 4
	89	1, 2, 4
	See	Key 12, 14, 15
6F6-G	6AD7-G	2, 3
	6F6	
	6K6-GT/G	
	6L6	3
	6L6-G	1, 3
	6V6	
	6V6-GT/G	
	7B5	4

* Pentodes under Type 6C6 may also be used as a substitute for this type when they are connected as triodes (screen and suppressor tied to plate).

1. Space limitations. 2. Wiring changes. 3. Filament voltage and/or current changes. 4. Socket change.

To Replace These RCA Types	Use These RCA Types	With Changes Indicated Below
6F8-G—Continued		
	7C5	4
	12A5	4
	38	2, 4
	41	4
	42	4
	89	2, 4
	See	Key 12, 14, 15
6F7	6P7-G	4
	See	Key 29, 45
6F8-G	6C8-G	
	6SN7-GT	2
	12AH7-GT	2, 3
	12SN7-GT	2, 3
	See	Key 33, 41
6G6-G	6A4	1, 3, 4
	6K6-GT/G	3
	6V6	3
	6V6-GT/G	3
	7B5	3, 4
	7C5	3, 4
	38	2, 3, 4
	41	3, 4
	89	2, 3, 4
	See	Key 12, 14
6H6	6H6-GT/G	1
	7A6	1, 3, 4
	12H6	3
	See	Key 7
6H6-GT/G	6H6	
	7A6	3, 4
	12H6	3
	See pp. 14-	Key 6
6J5*	6AE5-GT/G	
	6C5	
	6C5-GT/G	
	6F8-G	1, 2, 3
	6J5-GT/G	
	6L5-G	1, 3
	6P5-GT/G	
	6SN7-GT	2, 3
	7A4	4
	12J5-GT	3
	12SN7-GT	2, 3
	27	1, 3, 4
	37	1, 4
	56	1, 3, 4
	76	1, 4
	See	Key 28-41
6J5-GT/G*	6AE5-GT/G	
	6C5	
	6C5-GT/G	
	6F8-G	1, 2, 3
	6J5	
	6L5-G	1, 3
	6P5-GT/G	
	6SN7-GT	2, 3
	7A4	4
	12J5-GT	3
	12SN7-GT	2, 3
	27	1, 3, 4
	37	1, 4
	56	1, 3, 4
	76	1, 4
	See	Key 28-41
6J7	6C6	1, 2, 4
	6D7	1, 2, 4
	6J7-G	1, 2
	6J7-GT	
	6SJ7	2
	6SJ7-GT	2
6J7—Continued		
	6W7-G	1, 2, 3
	7C7	2, 3, 4
	12J7-GT/G	3
	12SJ7	2, 3
	12SJ7-GT	2, 3
	57	1, 2, 3, 4
	77	1, 2, 4
	See	Key 44-50
6J7-G	6C6	4
	6D7	4
	6J7	2
	6J7-GT	2
	6SJ7	2
	6SJ7-GT	2
	6W7-G	3
	7C7	2, 3, 4
	12J7-GT/G	2, 3
	12SJ7	2, 3
	12SJ7-GT	2, 3
	57	3, 4
	77	4
	See	Key 44-50
6J7-GT	6C6	1, 2, 4
	6D7	1, 2, 4
	6J7	
	6J7-G	1, 2
	6SJ7	2
	6SJ7-GT	2
	6W7-G	1, 2, 3
	7C7	2, 3, 4
	12J7-GT/G	3
	12SJ7	2, 3
	12SJ7-GT	2, 3
	57	1, 2, 3, 4
	77	1, 2, 4
	See	Key 44-50
6J8-G	7J7	2, 4
	See	Key 20-24
6K5-GT/G	6F5	2
	6F5-GT/G	2
	6SF5	2
	6SF5-GT/G	2
	7B4	2, 4
	12F5-GT	2, 3
	12SF5	2, 3
	12SF5-GT	2, 3
	See	Key 28-41
6K6-GT/G	6AD7-G	1, 2, 3
	6F6	3
	6F6-G	1, 3
	6L6	1, 3
	6L6-G	1, 3
	6V6	
	6V6-GT/G	
	7B5	4
	7C5	4
	38	1, 2, 4
	41	1, 4
	42	1, 3, 4
	89	1, 2, 4
	See	Key 12, 14, 15
6K7	6D6	1, 2, 4
	6E7	1, 2, 4
	6K7-G	1, 2
	6K7-GT	
	6S7	3
	6S7-G	1, 2, 3
	6SK7	2
	6SK7-GT/G	2
	6SS7	2, 3
	6U7-G	1, 2
6K7—Continued		
	7A7	2, 4
	7B7	2, 3, 4
	12K7-GT/G	3
	12SK7	2, 3
	12SK7-GT/G	2, 3
	14A7	2, 3, 4
	39/44	1, 2, 4
	58	1, 2, 3, 4
	78	1, 2, 4
	See	Key 44-50
6K7-G	6D6	4
	6E7	4
	6K7	2
	6K7-GT	2
	6S7	2, 3
	6S7-G	3
	6SK7	2
	6SK7-GT/G	2
	6SS7	2, 3
	6U7-G	
	7A7	2, 4
	7B7	2, 3, 4
	12K7-GT/G	2, 3
	12SK7	2, 3
	12SK7-GT/G	2, 3
	14A7/12B7	2, 3, 4
	39/44	4
	58	3, 4
	78	4
	See	Key 44-50
6K7-GT	6D6	1, 2, 4
	6E7	1, 2, 4
	6K7	
	6K7-G	1, 2
	6S7	3
	6S7-G	1, 2, 3
	6SK7	2
	6SK7-GT/G	2
	6SS7	2, 3
	6U7-G	1, 2
	7A7	2, 4
	7B7	2, 3, 4
	12K7-GT/G	3
	12SK7	2, 3
	12SK7-GT/G	2, 3
	14A7/12B7	2, 3, 4
	39/44	1, 2, 4
	58	1, 2, 3, 4
	78	1, 2, 4
	See	Key 44-50
6K8	6K8-G	1, 2
	6K8-GT	
	12K8	3
	See	Key 20-24
6K8-G	6K8	2
	6K8-GT	2
	12K8	2, 3
	See	Key 20-24
6K8-GT	6K8	
	6K8-G	1, 2
	12K8	3
	See	Key 20-24
6L5-G*	6AE5-GT/G	3
	6C5	3
	6C5-GT/G	3
	6F8-G	2, 3
	6J5	3
	6J5-GT/G	3
	6P5-GT/G	3
	6SN7-GT	2, 3
	7A4	3, 4
	12J5-GT	3

*Pentodes under Type 6C6 may also be used as a substitute for this type when they are connected as triodes (screen and suppressor tied to plate).

1. Space limitations 2. Wiring changes. 3. Filament voltage and/or current changes. 4. Socket change.

To Replace These RCA Types	Use These RCA Types	With Changes Indicated Below
6L5-G*—Continued		
	12SN7-GT	2, 3
	27	3, 4
	37	3, 4
	56	3, 4
	76	3, 4
	See	Key 28-41
6L6	6L6-G	1
	See	Key 12, 14, 15
6L6-G	6L6	
	See	Key 12, 14, 15
6L7	6L7-G	1, 2
	See	Key 20-24
6L7-G	6L7	2
	See	Key 20-24
6N6-G	5B5	4
	See	Key 11, 12, 14
6N7 or **6N7-GT/G**	6A6	1, 4
	6N7, 6N7-GT/G	
	6Y7-G	1
	6Z7-G	1
	53	1, 3, 4
	79	1, 2, 4
	See	Key 10
6P5-GT/G*	6AE5-GT/G	
	6C5	
	6C5-GT/G	
	6F8-G	1, 2, 3
	6J5	
	6J5-GT/G	
	6L5-G	1, 3
	6SN7-GT	2, 3
	7A4	4
	12J5-GT	3
	12SN7-GT	2, 3
	27	1, 3, 4
	37	1, 4
	56	1, 3, 4
	76	1, 4
	See	Key 28-41
6P7-G	6F7	4
	See	Key 29, 45
6Q7	2A6	1, 2, 3, 4
	6B6-G	1, 2
	6Q7-G	1, 2
	6Q7-GT	
	6SQ7	2
	6SQ7-GT/G	2
	6T7-G	1, 2, 3
	7B6	2, 4
	7C6	2, 3, 4
	12Q7-GT/G	3
	12SQ7	2, 3
	12SQ7-GT/G	2, 3
	75	1, 2, 4
	See	Key 32, 40
6Q7-G	2A6	3, 4
	6B6-G	
	6Q7	2
	6Q7 GT	2
	6SQ7	2
	6SQ7-GT/G	2
	6T7-G	3
	7B6	2, 4
	7C6	2, 3, 4
	12Q7-GT/G	2, 3
	12SQ7	2, 3
	12SQ7-GT/G	2, 3
	75	4
	See	Key 32, 40
6Q7-GT	2A6	1, 2, 3, 4
	6B6-G	1, 2
	6Q7	
	6Q7-G	1, 2
	6SQ7	2
	6SQ7-GT/G	2
	6T7-G	1, 2, 3
	7B6	2, 4
	7C6	2, 3, 4
	12Q7-GT/G	3
	12SQ7	2, 3
	12SQ7-GT/G	2, 3
	75	1, 2, 4
	See	Key 32, 40
6R7	6C7	1, 2, 4
	6R7-GT/G	
	6SR7	2
	6ST7	2, 3
	6V7-G	1, 2
	7E6	2, 4
	12SR7	2, 3
	55	1, 2, 3, 4
	85	1, 2, 4
	See	Key 32, 40
6R7-GT/G	6C7	1, 2, 4
	6R7	
	6SR7	2
	6ST7	2, 3
	6V7-G	1, 2
	7E6	2, 4
	12SR7	2, 3
	55	1, 2, 3, 4
	85	1, 2, 4
	See	Key 32, 40
6S7	6D6	1, 2, 3, 4
	6E7	1, 2, 3, 4
	6K7	3
	6K7-G	1, 2, 3
	6K7-GT	3
	6S7-G	1, 2
	6SK7	2, 3
	6SK7-GT/G	2, 3
	6SS7	2
	6U7-G	1, 2, 3
	7A7	2, 3, 4
	7B7	2, 4
	12K7-GT/G	3
	12SK7	2, 3
	12SK7-GT/G	2, 3
	14A7/12B7	2, 3, 4
	39/44	1, 2, 3, 4
	58	1, 2, 3, 4
	78	1, 2, 3, 4
	See	Key 44-50
6S7-G	6D6	3, 4
	6E7	3, 4
	6K7	2, 3
	6K7-G	3
	6K7-GT	2, 3
	6S7	2
	6SK7	2, 3
	6SK7-GT/G	2, 3
	6SS7	2
	6U7-G	3
	7A7	2, 3, 4
	7B7	2, 4
	12K7-GT/G	2, 3
	12SK7	2, 3
	12SK7-GT/G	2, 3
	14A7/12B7	2, 3, 4
	39/44	3, 4
	58	3, 4
6S7-G—Continued		
	78	3, 4
	See	Key 44-50
6SA7	6SA7-GT/G	
	7Q7	4
	12SA7	3
	12SA7-GT/G	3
	See	Key 20-24
6SA7-GT/G	6SA7	
	7Q7	4
	12SA7	3
	12SA7-GT/G	3
	See	Key 20-24
6SC7	6SL7-GT	2
	7F7	4
	12SC7	3
	12SL7-GT	2, 3
	See	Key 33, 41
6SF5	6F5	2
	6F5-GT/G	2
	6SF5-GT	
	6K5-GT/G	2
	7B4	4
	12F5-GT	2, 3
	12SF5	3
	12SF5-GT	3
	See	Key 28-41
6SF5-GT	6F5	2
	6F5-GT/G	2
	6SF5	
	6K5-GT/G	2
	7B4	4
	12F5-GT	2, 3
	12SF5	3
	12SF5-GT	3
	See	Key 28-41
6SF7	12SF7	3
	See	Key 46
6SG7	6AB7	2, 3
	7H7	4
	12SG7	3
	See	Key 44-50
6SH7	6AC7	2, 3
	6AG5	4
	7G7	3, 4
	12SH7	3
	See	Key 44-50
6SJ7	6C6	1, 2, 4
	6D7	1, 2, 4
	6J7	2
	6J7-G	1, 2
	6J7-GT	2
	6SJ7-GT	
	6W7-G	1, 2, 3
	7C7	3, 4
	12J7-GT/G	2, 3
	12SJ7	3
	12SJ7-GT	3
	57	1, 2, 3, 4
	77	1, 2, 4
	See	Key 44-50
6SJ7-GT	6C6	1, 2, 4
	6D7	1, 2, 4
	6J7	2
	6J7-G	1, 2
	6J7-GT	2
	6SJ7	
	6W7-G	1, 2, 3
	7C7	3, 4
	12J7-GT/G	2, 3
	12SJ7	3

*Pentodes under Type 6C6 may also be used as a substitute for this type when they are connected as triodes (screen and suppressor tied to plate).

1. Space limitations.
2. Wiring changes.
3. Filament voltage and/or current changes.
4. Socket change.

To Replace These RCA Types	Use These RCA Types	With Changes Indicated Below
6SJ7-GT—Continued		
	12SJ7-GT	3
	57	1, 2, 3, 4
	77	1, 2, 4
	See	Key 44-50
6SK7	6D6	1, 2, 4
	6E7	1, 2, 4
	6K7	2
	6K7-G	1, 2
	6K7-GT	2
	6S7	2, 3
	6S7-G	1, 2, 3
	6SK7-GT/G	
	6SS7	3
	6U7-G	1, 2
	7A7	4
	7B7	3, 4
	12K7-GT/G	2, 3
	12SK7	3
	12SK7-GT/G	3
	14A7/12B7	3, 4
	39/44	1, 2, 4
	58	1, 2, 3, 4
	78	1, 2, 4
	See	Key 44-50
6SK7-GT/G	6D6	1, 2, 4
	6E7	1, 2, 4
	6K7	2
	6K7-G	1, 2
	6K7-GT	2
	6S7	2, 3
	6S7-G	1, 2, 3
	6SK7	
	6SS7	3
	6U7-G	1, 2
	7A7	4
	7B7	3, 4
	12K7-GT/G	2, 3
	12SK7	3
	12SK7-GT/G	3
	14A7/12B7	3, 4
	39/44	1, 2, 4
	58	1, 2, 3, 4
	78	1, 2, 4
	See	Key 44-50
6SL7-GT	7F7	4
	12SL7-GT	3
	See	Key 33, 41
6SN7-GT	6C8-G	1, 2
	6F8-G	1, 2
	12AH7-GT	2, 3
	12SN7-GT	3
	See	Key 33, 41
6SQ7	2A6	1, 2, 3, 4
	6B6-G	1, 2
	6Q7	2
	6Q7-G	1, 2
	6Q7-GT	2
	6SQ7-GT/G	
	6T7-G	1, 2, 3
	7B6	4
	7C6	3, 4
	12Q7-GT/G	2, 3
	12SQ7	3
	12SQ7-GT/G	3
	75	1, 2, 4
	See	Key 32, 40
6SQ7-GT/G	2A6	1, 2, 3, 4
	6B6-G	1, 2
	6Q7	2
	6Q7-G	1, 2
	6Q7-GT	2
6SQ7-GT/G—Continued		
	6SQ7	
	6T7-G	1, 2, 3
	7B6	4
	7C6	3, 4
	12Q7-GT/G	2, 3
	12SQ7	3
	12SQ7-GT/G	3
	75	1, 2, 4
	See	Key 32, 40
6SR7	6C7	1, 2, 4
	6R7	2
	6R7-GT/G	2
	6ST7	3
	6V7-G	1, 2
	7E6	4
	12SR7	3
	55	1, 2, 3, 4
	85	1, 2, 4
	See	Key 32, 40
6SS7	6D6	1, 2, 3, 4
	6E7	1, 2, 3, 4
	6K7	2, 3
	6K7-G	1, 2, 3
	6K7-GT	2, 3
	6S7	2
	6S7-G	1, 2
	6SK7	3
	6SK7-GT/G	3
	6U7-G	1, 2, 3
	7A7	3, 4
	7B7	4
	12K7-GT/G	2, 3
	12SK7	3
	12SK7-GT/G	3
	14A7/12B7	3, 4
	39/44	1, 2, 3, 4
	58	1, 2, 3, 4
	78	1, 2, 3, 4
	See	Key 44-50
6ST7	6C7	1, 2, 3, 4
	6R7	2, 3
	6R7-GT/G	2, 3
	6SR7	3
	6V7-G	1, 2, 3
	7E6	3, 4
	12SR7	3
	55	1, 2, 3, 4
	85	1, 2, 3, 4
	See	Key 32, 40
6T7-G	2A6	3, 4
	6B6-G	3
	6Q7	2, 3
	6Q7-G	3
	6Q7-GT	2, 3
	6SQ7	2, 3
	6SQ7-GT/G	2, 3
	7B6	2, 3, 4
	7C6	2, 4
	12Q7-GT/G	2, 3
	12SQ7	2, 3
	12SQ7-GT/G	2, 3
	75	3, 4
	See	Key 32, 40
6U5/6G5	6AB5/6N5	3
	See	Key 25, 26
6U7-G	6D6	4
	6E7	4
	6K7	2
	6K7-G	
	6K7-GT	2
6U7-G—Continued		
	6S7	2, 3
	6S7-G	3
	6SK7	2
	6SK7-GT/G	2
	6SS7	2, 3
	7A7	2, 4
	7B7	2, 3, 4
	12K7-GT/G	2, 3
	12SK7	2, 3
	12SK7-GT/G	2, 3
	14A7/12B7	2, 3, 4
	39/44	4
	58	3, 4
	78	4
	See	Key 44-50
6V6	6AD7-G	1, 2, 3
	6F6	3
	6F6-G	1, 3
	6K6-GT/G	
	6L6	1, 3
	6L6-G	1, 3
	6V6-GT/G	
	6Y6-G	1, 3
	7B5	4
	7C5	4
	12A5	1, 3, 4
	38	1, 2, 4
	41	1, 4
	42	1, 3, 4
	89	1, 2, 4
	See	Key 12, 14, 15
6V6-GT/G	6AD7-G	1, 2, 3
	6F6	3
	6F6-G	1, 3
	6K6-GT/G	
	6L6	1, 3
	6L6-G	1, 3
	6V6	
	6Y6-G	1, 3
	7B5	4
	7C5	4
	12A5	1, 3, 4
	38	1, 2, 4
	41	1, 4
	42	1, 3, 4
	89	1, 2, 4
	See	Key 12, 14, 15
6V7-G	6C7	4
	6R7	2
	6R7-GT/G	2
	6SR7	2
	6ST7	2, 3
	7E6	2, 4
	12SR7	2, 3
	55	3, 4
	85	4
	See	Key 32, 40
6W7-G	6C6	3, 4
	6D7	3, 4
	6J7	2, 3
	6J7-G	3
	6J7-GT	2, 3
	6SJ7	2, 3
	6SJ7-GT	2, 3
	7C7	2, 4
	12J7-GT/G	2, 3
	12SJ7	2, 3
	12SJ7-GT	2, 3
	57	3, 4
	77	3, 4
	See	Key 44-50

1. Space limitations.
2. Wiring changes.
3. Filament voltage and/or current changes.
4. Socket change.

To Replace These RCA Types	Use These RCA Types	With Changes Indicated Below
6X5	6X5-GT/G	
	84/6Z4	1, 4
	See	Key 2
6X5-GT/G	6X5	
	84/6Z4	1, 4
	See	Key 2
6Y5	6X5	4
	6X5-GT/G	4
	6Z5	2
	7Y4	4
	84/6Z4	4
	See	Key 2
6Y6-G	6L6	
	6L6-G	1
	6V6	
	6V6-GT/G	
	7C5	4
	12A5	4
	See	Key 12, 14, 15
6Y7-G	6A6	1, 3, 4
	6N7	3
	6N7-GT/G	3
	6Z7-G	
	53	1, 3, 4
	79	2, 4
	See	Key 10
6Z5	6X5	4
	6X5-GT/G	4
	7Y4	4
	84/6Z4	4
	See	Key 2
6Z7-G	6A6	1, 3, 4
	6N7	3
	6N7-GT/G	3
	6Y7-G	3
	53	1, 3, 4
	79	2, 3, 4
	See	Key 10
6ZY5-G	6X5	3
	6X5-GT/G	3
	6Y5	3, 4
	6Z5	3, 4
	7Y4	3, 4
	84/6Z4	3, 4
	See	Key 2
7A4*	6AE5-GT/G	4
	6C5	4
	6C5-GT/G	4
	6F8-G	1, 3, 4
	6J5	4
	6J5-GT/G	4
	6L5-G	1, 3, 4
	6P5-GT/G	4
	6SN7-GT	3, 4
	12J5-GT	3, 4
	12SN7-GT	3, 4
	27	1, 3, 4
	37	1, 4
	56	1, 3, 4
	76	1, 4
	See	Key 28-41
7A5	6L6	1, 3, 4
	6L6-G	1, 3, 4
	6V6	4
	6V6-GT/G	4
	6Y6-G	1, 3, 4
	7C5	
	12A5	1, 4
	See	Key 12, 14, 15
7A6	6H6	3, 4
	6H6-GT/G	3, 4
7A6—Continued	12H6	3, 4
	See	Key 7
7A7	6D6	1, 2, 4
	6E7	1, 2, 4
	6K7	2, 4
	6K7-G	1, 2, 4
	6K7-GT	2, 4
	6S7	2, 3, 4
	6S7-G	1, 2, 3, 4
	6SK7	4
	6SK7-GT/G	4
	6SS7	3, 4
	6U7-G	1, 2, 4
	7B7	3
	12K7-GT/G	2, 3, 4
	12SK7	3, 4
	12SK7-GT/G	3, 4
	14A7/12B7	3
	39/44	1, 2, 4
	58	1, 2, 3, 4
	78	1, 2, 4
	See	Key 44-50
7A8	2A7	1, 2, 3, 4
	6A7	1, 2, 3, 4
	6A7S	1, 2, 3, 4
	6A8	2, 3, 4
	6A8-G	1, 2, 3, 4
	6A8-GT	2, 3, 4
	6D8-G	1, 2, 4
	7B8	3
	12A8-GT/G	2, 3, 4
	See	Key 20-24
7B4	6F5	2, 4
	6F5-GT/G	2, 4
	6SF5	4
	6SF5-GT	4
	6K5-GT/G	2, 4
	12F5-GT	2, 3, 4
	12SF5	3, 4
	12SF5-GT	3, 4
	See	Key 28-41
7B5	6AD7-G	1, 3, 4
	6F6	3, 4
	6F6-G	1, 3, 4
	6K6-GT/G	4
	6L6	1, 3, 4
	6L6-G	1, 3, 4
	6V6	4
	6V6-GT/G	4
	7C5	
	38	1, 2, 4
	41	1, 4
	42	1, 3, 4
	89	1, 2, 4
	See	Key 12, 14, 15
7B6	2A6	1, 2, 3, 4
	6B6-G	1, 2, 4
	6Q7	2, 4
	6Q7-G	1, 2, 4
	6Q7-GT	2, 4
	6SQ7	4
	6SQ7-GT/G	4
	6T7-G	1, 2, 3, 4
	7C6	3
	12Q7-GT/G	2, 3, 4
	12SQ7	3, 4
	12SQ7-GT/G	3, 4
	75	1, 2, 4
	See	Key 32, 40
7B7	6D6	1, 2, 3, 4
	6E7	1, 2, 3, 4
7B7—Continued	6K7	2, 3, 4
	6K7-G	1, 2, 3, 4
	6K7-GT	2, 3, 4
	6S7	2, 4
	6S7-G	1, 2, 4
	6SK7	3, 4
	6SK7-GT/G	3, 4
	6SS7	4
	6U7-G	1, 2, 3, 4
	7A7	3
	12K7-GT/G	2, 3, 4
	12SK7	3, 4
	12SK7-GT/G	3, 4
	14A7/12B7	3
	39/44	1, 2, 3, 4
	58	1, 2, 3, 4
	78	1, 2, 3, 4
	See	Key 44-50
7B8	2A7	1, 2, 3, 4
	6A7	1, 2, 4
	6A7S	1, 2, 4
	6A8	2, 4
	6A8-G	1, 2, 4
	6A8-GT	2, 4
	6D8-G	1, 2, 3, 4
	7A8	3
	12A8-GT/G	2, 3, 4
	See	Key 20-24
7C5	6AD7-G	1, 3, 4
	6F6	3, 4
	6F6-G	1, 3, 4
	6K6-GT/G	4
	6L6	1, 3, 4
	6L6-G	1, 3, 4
	6V6	4
	6V6-GT/G	4
	6Y6-G	1, 3, 4
	7B5	
	12A5	1, 3, 4
	38	1, 2, 4
	41	1, 4
	42	1, 3, 4
	89	1, 2, 4
	See	Key 12, 14, 15
7C6	2A6	1, 2, 3, 4
	6B6-G	1, 2, 3, 4
	6Q7	2, 3, 4
	6Q7-G	1, 2, 3, 4
	6Q7-GT	2, 3, 4
	6SQ7	3, 4
	6SQ7-GT/G	3, 4
	6T7-G	1, 2, 4
	7B6	3
	12Q7-GT/G	2, 3, 4
	12SQ7	3, 4
	12SQ7-GT/G	3, 4
	75	1, 2, 3, 4
	See	Key 32, 40
7C7	6C6	1, 2, 3, 4
	6D7	1, 2, 3, 4
	6J7	2, 3, 4
	6J7-G	1, 2, 3, 4
	6J7-GT	2, 3, 4
	6SJ7	3, 4
	6SJ7-GT	3, 4
	6W7-G	1, 2, 4
	12J7-GT/G	2, 3, 4
	12SJ7	3, 4
	12SJ7-GT	3, 4
	57	1, 2, 3, 4
	77	1, 2, 3, 4
	See	Key 44-50

*Pentodes under Type 6C6 may also be used as a substitute for this type when they are connected as triodes (screen and suppressor tied to plate).

1. Space limitations
2. Wiring changes.
3. Filament voltage and/or current changes.
4. Socket change.

To Replace These RCA Types	Use These RCA Types	With Changes Indicated Below
7E6	6C7	1, 2, 4
	6R7	2, 4
	6R7-GT/G	2, 4
	6SR7	4
	6ST7	3, 4
	6V7-G	1, 2, 4
	12SR7	3, 4
	55	1, 2, 3, 4
	85	1, 2, 4
	See	Key 32, 40
7E7	See	Key 47, 48
7F7	6SL7-GT	4
	12SL7-GT	3, 4
	See	Key 33, 41
7G7	6AC7	4
	6AG5	4
	6SH7	4
	See	Key 44-50
7H7	6AB7	3, 4
	6SG7	4
	12SG7	3, 4
	See	Key 44-50
7J7	6J8-G	1, 2, 4
	See	Key 20-24
7Q7	6SA7	4
	6SA7-GT/G	4
	See	Key 20-24
7Y4	6X5	3, 4
	6X5-GT/G	3, 4
	6Z5	1, 3, 4
	84/6Z4	1, 4
	See	Key 2
12A5	6L6	3, 4
	6L6-G	1, 3, 4
	6V6	4
	6V6-GT/G	4
	6Y6-G	1, 3, 4
	7C5	4
	See	Key 12, 14, 15
12A7	25A7-GT/G	2, 3, 4
	See	Key 18
12A8-GT/G	6A7	1, 2, 3, 4
	6A7S	1, 2, 3, 4
	6A8	3
	6A8-G	1, 2, 3
	6A8-GT	3
	6D8-G	1, 2, 3
	7A8	2, 3, 4
	7B8	2, 3, 4
	See	Key 20-24
12AH7-GT	6C8-G	1, 2, 3
	6F8-G	1, 2, 3
	6SN7-GT	2, 3
	12SN7-GT	2, 3
	See	Key 33, 41
12B8-GT	25B8-GT	3
	See	Key 45
12C8	6B8	3
	6B7	1, 2, 3, 4
	6B7S	1, 2, 3, 4
	6B8-G	1, 2, 3
	See	Key 49
12F5-GT	6F5	3
	6F5-GT/G	3
	6K5-GT/G	2, 3
	6SF5	2, 3
	6SF5-GT	2, 3
	7B4	2, 3, 4
	12SF5	2
12F5-GT—Continued	12SF5-GT	2
	See	Key 28-41
12H6	6H6	3
	6H6-GT/G	1, 3
	7A6	1, 3, 4
	See	Key 7
12J5-GT*	6AE5-GT/G	3
	6C5	3
	6C5-GT/G	3
	6F8-G	1, 2, 3
	6J5	3
	6J5-GT/G	3
	6L5-G	1, 3
	6P5-GT/G	3
	6SN7-GT	2, 3
	7A4	3, 4
	12SN7-GT	2, 3
	37	1, 3, 4
	76	1, 3, 4
	See	Key 28-41
12J7-GT/G	6C6	1, 2, 3, 4
	6D7	1, 2, 3, 4
	6J7-G	1, 2, 3
	6J7-GT	3
	6SJ7	2, 3
	6SJ7-GT	2, 3
	6W7-G	1, 2, 3
	7C7	2, 3, 4
	12SJ7	2
	12SJ7-GT	2
	77	1, 2, 3, 4
	See	Key 44-50
12K7-GT/G	6D6	1, 2, 3, 4
	6E7	1, 2, 3, 4
	6K7	3
	6K7-G	1, 2, 3
	6K7-GT	3
	6S7	3
	6S7-G	1, 2, 3
	6SK7	2, 3
	6SK7-GT/G	2, 3
	6SS7	2, 3
	6U7-G	1, 2, 3
	7A7	2, 3, 4
	7B7	2, 3, 4
	12SK7	2
	12SK7-GT/G	2
	14A7/12B7	2, 4
	39/44	1, 2, 3, 4
	78	1, 2, 3, 4
	See	Key 44-50
12K8	6K8	3
	6K8-G	1, 2, 3
	6K8-GT	3
	See	Key 20-24
12Q7-GT/G	6B6-G	1, 2, 3
	6Q7	3
	6Q7-G	1, 2, 3
	6Q7-GT	3
	6SQ7	2, 3
	6SQ7-GT/G	2, 3
	6T7-G	1, 2, 3
	7B6	2, 3, 4
	7C6	2, 3, 4
	12SQ7	2
	12SQ7-GT/G	2
	75	1, 2, 3, 4
	See	Key 32, 40
12SA7	6SA7	3
	6SA7-GT/G	3
12SA7—Continued	7Q7	3, 4
	See	Key 20-24
12SA7-GT/G	6SA7	3
	6SA7-GT/G	3
	7Q7	3, 4
	See	Key 20-24
12SC7	6SC7	3
	6SL7-GT	2, 3
	7F7	3, 4
	12SL7-GT	2
	See	Key 33, 41
12SF5	6F5	2, 3
	6F5-GT/G	2, 3
	6K5-GT/G	2, 3
	6SF5	3
	6SF5-GT	3
	7B4	3, 4
	12F5-GT	2
	12SF5-GT	
	See	Key 28-41
12SF5-GT	6F5	2, 3
	6F5-GT/G	2, 3
	6K5-GT/G	2, 3
	6SF5	3
	6SF5-GT	3
	7B4	3, 4
	12F5-GT	2
	12SF5	
	See	Key 28-41
12SF7	6SF7	3
	See	Key 46
12SG7	6AB7	2, 3
	6SG7	3
	7H7	3, 4
	See	Key 44-50
12SH7	6AC7	2, 3
	6AG5	3, 4
	6SH7	3
	7G7	3, 4
	See	Key 44-50
12SJ7	6C6	1, 2, 3, 4
	6D7	1, 2, 3, 4
	6J7-G	1, 2, 3
	6J7-GT	2, 3
	6SJ7	3
	6SJ7-GT	3
	6W7-G	1, 2, 3
	7C7	3, 4
	12J7-GT/G	2
	12SJ7-GT	
	77	1, 2, 3, 4
	See	Key 44-50
12SJ7-GT	6C6	1, 2, 3, 4
	6D7	1, 2, 3, 4
	6J7-G	1, 2, 3
	6J7-GT	2, 3
	6SJ7	3
	6SJ7-GT	3
	6W7-G	1, 2, 3
	7C7	3, 4
	12J7-GT/G	2
	12SJ7	
	77	1, 2, 3, 4
	See	Key 44-50
12SK7	6D6	1, 2, 3, 4
	6E7	1, 2, 3, 4
	6K7	2, 3
	6K7-G	1, 2, 3
	6K7-GT	2, 3

*Pentodes under Type 6C6 may also be used as a substitute for this type when they are connected as triodes (screen and suppressor tied to plate).

1. Space limitations.
2. Wiring changes.
3. Filament voltage and/or current changes.
4. Socket change.

To Replace These RCA Types	Use These RCA Types	With Changes Indicated Below
12SK7—Continued		
	6S7	2, 3
	6S7-G	1, 2, 3
	6SK7	3
	6SK7-GT/G	3
	6SS7	3
	6U7-G	1, 2, 3
	7A7	3, 4
	7B7	3, 4
	12K7-GT/G	2
	12SK7-GT/G	
	14A7/12B7	4
	39/44	1, 2, 3, 4
	78	1, 2, 3, 4
	See	Key 44-50
12SK7-GT/G	6D6	1, 2, 3, 4
	6E7	1, 2, 3, 4
	6K7	2, 3
	6K7-G	1, 2, 3
	6K7-GT	2, 3
	6S7	2, 3
	6S7-G	1, 2, 3
	6SK7	3
	6SK7-GT/G	3
	6SS7	3
	6U7-G	1, 2, 3
	7A7	3, 4
	7B7	3, 4
	12K7-GT/G	2
	12SK7	
	14A7/12B7	4
	39/44	1, 2, 3, 4
	78	1, 2, 3, 4
	See	Key 44-50
12SL7-GT	6SL7-GT	3
	7F7	3, 4
	See	Key 33, 41
12SN7-GT	6C8-G	1, 2, 3
	6F8-G	1, 2, 3
	6SN7-GT	3
	12AH7-GT	2, 3
	See	Key 33, 41
12SQ7	6B6-G	1, 2, 3
	6Q7	2, 3
	6Q7-G	1, 2, 3
	6Q7-GT	2, 3
	6SQ7	3
	6SQ7-GT/G	3
	6T7-G	1, 2, 3
	7B6	3, 4
	7C6	3, 4
	12Q7-GT/G	2
	12SQ7-GT/G	
	75	1, 2, 3, 4
	See	Key 32, 40
12SQ7-GT/G	6B6-G	1, 2, 3
	6Q7	2, 3
	6Q7-G	1, 2, 3
	6Q7-GT	2, 3
	6SQ7	3
	6SQ7-GT/G	3
	6T7-G	1, 2, 3
	7B6	3, 4
	7C6	3, 4
	12Q7-GT/G	2
	12SQ7-GT/G	
	75	1, 2, 3, 4
	See	Key 32, 40
12SR7	6C7	1, 2, 3, 4
	6R7	2, 3
	6R7-GT/G	2, 3
	6SR7	3
12SR7—Continued		
	6ST7	3
	6V7-G	1, 2, 3
	7E6	3, 4
	85	1, 2, 3, 4
	See	Key 32, 40
12Z3	1-v	3
	35Z3	3, 4
	35Z4-GT	3, 4
	35Z5-GT/G	3, 4
	45Z3	3, 4
	45Z5-GT	3, 4
	See	Key 1
14A7/12B7	6D6	1, 2, 3, 4
	6E7	1, 2, 3, 4
	6K7	2, 3, 4
	6K7-G	1, 2, 3, 4
	6K7-GT	2, 3, 4
	6S7	2, 3, 4
	6S7-G	1, 2, 3, 4
	6SK7	3, 4
	6SK7-GT/G	3, 4
	6SS7	3, 4
	6U7-G	1, 2, 3, 4
	7A7	3
	7B7	3
	12K7-GT/G	2, 4
	12SK7	4
	12SK7-GT/G	4
	39/44	1, 2, 3, 4
	78	1, 2, 3, 4
	See	Key 44-50
15	1B4-P	3, 4
	1E5-GP	3, 4
	32	1, 3, 4
	See	Key 44, 50
19	1J6-G	3, 4
	See	Key 10
24-A	35	
	See	Key 42-44, 50
25A6	12A5	1, 3, 4
	25A6-GT/G	
	25B6-G	1
	25C6-G	1
	25L6	
	25L6-GT/G	
	35A5	3, 4
	35L6-GT/G	3
	43	1, 4
	50L6-GT	3
	See	Key 12, 14
25A6-GT/G	12A5	1, 3, 4
	25A6	
	25B6-G	1
	25C6-G	1
	25L6	
	25L6-GT/G	
	35A5	3, 4
	35L6-GT/G	3
	43	1, 4
	50L6-GT	3
	See	Key 12, 14
25A7-GT/G	32L7-GT	3
	70L7-GT	2, 3
	117L7/M7-GT	2, 3
	117N7-GT	2, 3
	117P7-GT	2, 3
	See	Key 13, 18
25AC5-GT/G	6AC5-GT/G	3
	See	Key 10
25B5	25N6-G	4
	See	Key 11
25B6-G	12A5	3, 4
	25A6	
	25A6-GT/G	
	25C6-G	
	25L6	
	25L6-GT/G	
	35A5	3, 4
	35L6-GT/G	3
	43	4
	50L6-GT	3
	See	Key 12, 14
25B8-GT	12B8-GT	3
	See	Key 45
25C6-G	12A5	3, 4
	25A6	
	25A6-GT/G	
	25B6-G	
	25L6	
	25L6-GT/G	
	35A5	3, 4
	35L6-GT/G	3
	43	4
	50L6-GT	3
	See	Key 12, 14
25L6	12A5	1, 3, 4
	25A6	
	25A6-GT/G	
	25B6-G	1
	25C6-G	1
	25L6-GT/G	
	35A5	3, 4
	35L6-GT/G	3
	43	1, 4
	50L6-GT	3
	See	Key 12, 14
25L6-GT/G	12A5	1, 3, 4
	25A6	
	25A6-GT/G	
	25B6-G	1
	25C6-G	1
	25L6	
	35A5	3, 4
	35L6-GT/G	3
	43	1, 4
	50L6-GT	3
	See	Key 12, 14
25N6-G	25B5	4
	See	Key 11
25Y5	25Z5	
	25Z6	4
	25Z6-GT/G	4
	50Y6-GT/G	3, 4
	50Z7-G	3, 4
	117Z6-GT/G	3, 4
	See	Key 5
25Z5	25Y5	
	25Z6	4
	25Z6-GT/G	4
	50Y6-GT/G	3, 4
	50Z7-G	3, 4
	117Z6-GT/G	3, 4
	See	Key 5
25Z6	25Y5	1, 4
	25Z5	1, 4
	25Z6-GT/G	
	50Y6-GT/G	3
	50Z7-G	1, 2, 3
	117Z6-GT/G	3
	See	Key 5

1. Space limitations.
2. Wiring changes.
3. Filament voltage and/or current changes.
4. Socket change.

To Replace These RCA Types	Use These RCA Types	With Changes Indicated Below
25Z6-GT/G	25Y5	1, 4
	25Z5	1, 4
	25Z6	
	50Y6-GT/G	3
	50Z7-G	1, 2, 3
	117Z6-GT/G	3
	See	Key 5
27	56	
	See	Key 28-41
30	1H4-G	4
	See	Key 28, 32
31	See	Key 8
32	1B4-P	
	1E5-GP	4
	15	3, 4
	See	Key 42-44, 50
32L7-GT	25A7-GT/G	3
	70L7-GT	2, 3
	117L7/M7-GT	2, 3
	117N7-GT	2, 3
	117P7-GT	2, 3
	See	Key 13, 18
33	See	Key 14, 19
34	1A4-P	
	1D5-GP	4
	1D5-GT	4
	See	Key 42-44, 50
35	24-A	
	See	Key 42-44, 50
35A5	12A5	1, 3, 4
	25A6	3, 4
	25A6-GT/G	3, 4
	25B6-G	1, 3, 4
	25C6-G	1, 3, 4
	25L6	3, 4
	25L6-GT/G	3, 4
	35L6-GT/G	4
	43	1, 3, 4
	50L6-GT	3, 4
	See	Key 12, 14
35L6-GT/G	12A5	1, 3, 4
	25A6	3
	25A6-GT/G	3
	25B6-G	1, 3
	25C6-G	1, 3
	25L6	3
	25L6-GT/G	3
	35A5	4
	43	1, 3, 4
	50L6-GT	3
	See	Key 12, 14
35Z3	12Z3	1, 3, 4
	35Z4-GT	4
	35Z5-GT/G	4
	45Z3	3, 4
	45Z5-GT	3, 4
	See	Key 1, 5
35Z4-GT	12Z3	1, 3, 4
	35Z3	4
	35Z5-GT/G	2
	45Z3	3, 4
	45Z5-GT	2, 3
	See	Key 1, 5
35Z5-GT/G	12Z3	1, 3, 4
	35Z3	4
	35Z4-GT	2
	45Z3	3, 4
	45Z5-GT	3
	See	Key 1, 5
36	See	Key 43, 50
37*	6AE5-GT/G	4
	6C5	4
	6C5-GT/G	4
	6F8-G	3, 4
	6J5	4
	6J5-GT/G	4
	6L5-G	3, 4
	6P5-GT/G	4
	6SN7-GT	3, 4
	7A4	4
	12J5-GT	3, 4
	12SN7-GT	3, 4
	27	3
	56	3
	76	
	See	Key 28-41
38	6AD7-G	1, 2, 3, 4
	6F6	2, 3, 4
	6F6-G	1, 2, 3, 4
	6G6-G	2, 3, 4
	6K6-GT/G	2, 3, 4
	6V6	2, 3, 4
	6V6-GT/G	2, 3, 4
	7B5	2, 3, 4
	7C5	2, 3, 4
	41	2, 3, 4
	42	1, 2, 3, 4
	89	3, 4
	See	Key 12, 14, 15
39/44	6D6	4
	6E7	4
	6K7	2, 4
	6K7-G	4
	6K7-GT	2, 4
	6S7	2, 3, 4
	6S7-G	3, 4
	6SK7	2, 4
	6SK7-GT/G	2, 4
	6SS7	2, 3, 4
	6U7-G	4
	7A7	2, 4
	7B7	2, 3, 4
	12K7-GT/G	2, 3, 4
	12SK7	2, 3, 4
	12SK7-GT/G	2, 3, 4
	14A7/12B7	2, 3, 4
	58	3, 4
	78	4
	See	Key 44-50
41	6AD7-G	1, 3, 4
	6F6	3, 4
	6F6-G	1, 3, 4
	6K6-GT/G	4
	6L6	3, 4
	6L6-G	1, 3, 4
	6V6	4
	6V6-GT/G	4
	7B5	4
	7C5	4
	38	2, 4
	42	1, 3
	89	2
	See	Key 12, 14, 15
42	6AD7-G	3, 4
	6F6	4
	6F6-G	4
	6K6-GT/G	4
	6L6	3, 4
	6L6-G	3, 4
	6V6	4
	6V6-GT/G	4
	7B5	4
	7C5	4
42—Continued	12A5	4
	38	2, 4
	41	
	89	2
	See	Key 12, 14, 15
43	12A5	3, 4
	25A6	4
	25A6-GT/G	4
	25B6-G	4
	25C6-G	4
	25L6	4
	25L6-GT/G	4
	35A5	3, 4
	35L6-GT/G	3, 4
	50L6-GT	3, 4
	See	Key 12, 14
45	2A3	1, 3
	See	Key 8
45Z3	35Z3	1, 3, 4
	35Z4-GT	1, 3, 4
	35Z5-GT/G	1, 3, 4
	45Z5-GT	1, 3, 4
	See	Key 1
45Z5-GT	12Z3	1, 3, 4
	35Z3	3, 4
	35Z4-GT	2, 3
	35Z5-GT/G	3
	45Z3	3, 4
	See	Key 1
46	2A5	4
	47	2
	59	3, 4
	See	Key 10-14
47	2A5	4
	46	2
	59	3, 4
	See	Key 10, 14
49	See	Key 10
50L6-GT	12A5	1, 3, 4
	25A6	3
	25A6-GT/G	3
	25B6-G	1, 3
	25C6-G	1, 3
	25L6	3
	25L6-GT/G	3
	35A5	3, 4
	35L6-GT/G	3
	43	1, 3, 4
	See	Key 12, 14
50Y6-GT/G	25Y5	1, 3, 4
	25Z5	1, 3, 4
	25Z6	3
	25Z6-GT/G	3
	50Z7-G	1, 2
	117Z6-GT/G	3
	See	Key 5
50Z7-G	25Y5	3, 4
	25Z5	3, 4
	25Z6	2, 3
	25Z6-GT/G	2, 3
	50Y6-GT/G	2
	117Z6-GT/G	2, 3
	See	Key 5
53	6A6	3
	6N7	3, 4
	6N7-GT/G	3, 4
	6Y7-G	3, 4
	6Z7-G	3, 4
	79	2, 3, 4
	See	Key 10

*Pentodes under Type 6C6 may also be used as a substitute for this type when they are connected as triodes (screen and suppressor tied to plate).

1. Space limitations.
2. Wiring changes.
3. Filament voltage and/or current changes.
4. Socket change.

To Replace These RCA Types	Use These RCA Types	With Changes Indicated Below
55	See	Key 32, 40
56	27	3
	See	Key 28-41
57	See	Key 44-50
58	See	Key 44-50
59	2A5	4
	46	4
	47	4
	See	Key 10, 14
70L7-GT	25A7-GT/G	2, 3
	32L7-GT	2, 3
	117L7/M7-GT	2, 3
	117N7-GT	2, 3
	117P7-GT	2, 3
	See	Key 13, 18
75	2A6	3
	6B6-G	4
	6Q7	2, 4
	6Q7-G	4
	6Q7-GT	2, 4
	6SQ7	2, 4
	6SQ7-GT/G	2, 4
	6T7-G	3, 4
	7B6	2, 4
	7C6	2, 3, 4
	12Q7-GT/G	2, 3, 4
	12SQ7	2, 3, 4
	12SQ7-GT/G	2, 3, 4
	See	Key 32, 40
76*	6AE5-GT/G	4
	6C5	4
	6C5-GT/G	4
	6F8-G	3, 4
	6J5	4
	6J5-GT/G	4
	6L5-G	3, 4
	6P5-GT/G	4
	6SN7-GT	3, 4
	7A4	4
	12J5-GT	3, 4
	12SN7-GT	3, 4
	27	3
	37	
	56	3
	See	Key 28-41
77	6C6	
	6D7	4
	6J7	2, 4
	6J7-G	4
	6J7-GT	2, 4
	6SJ7	2, 4
	6SJ7-GT	2, 4
	6W7-G	3, 4
	7C7	2, 3, 4
	12J7-GT/G	2, 3, 4
	12SJ7	2, 3, 4
	12SJ7-GT	2, 3, 4
	See	Key 44-50
78	6D6	
	6E7	4
	6K7	2, 4
	6K7-G	4
	6K7-GT	2, 4
	6S7	2, 3, 4
	6S7-G	3, 4
	6SK7	2, 4
	6SK7-GT/G	2, 4
	6SS7	2, 3, 4
	6U7-G	4
	7A7	2, 4
78. —Continued		
	7B7	2, 3, 4
	12K7-GT/G	2, 3, 4
	12SK7	2, 3, 4
	12SK7-GT/G	2, 3, 4
	14A7/12B7	2, 3, 4
	39/44	4
	58	3
	See	Key 44-50
79	6A6	1, 2, 3, 4
	6N7	2, 3, 4
	6N7-GT/G	2, 3, 4
	6Y7-G	2, 4
	6Z7-G	2, 4
	53	1, 2, 3, 4
	See	Key 10
80	5T4	4
	5U4-G	1, 3, 4
	5V4-G	4
	5W4	4
	5W4-GT/G	4
	5X4-G	1, 3, 4
	5Y3-GT/G	4
	5Y4-G	4
	5Z3	1, 3
	5Z4	4
	83-v	
	See	Key 2
82	See	Key 3
83	See	Key 3
83-v	5T4	4
	5U4-G	1, 3, 4
	5V4-G	4
	5X4-G	1, 3, 4
	5Z3	1, 3
	See	Key 2
84	6X5	3, 4
	6X5-GT/G	3, 4
	6Y5	3, 4
	6Z5	3, 4
	6ZY5-G	4
	7Y4	4
	See	Key 2
85	6C7	4
	6R7	4
	6R7-GT/G	4
	6SR7	4
	6ST7	3, 4
	6V7-G	4
	7E6	4
	12SR7	3, 4
	55	3
	See	Key 32, 40
89	See	Key 14
117L7/M7-GT	25A7-GT/G	2, 3
	32L7-GT	2, 3
	70L7-GT	2, 3
	117N7-GT	2
	117P7-GT	2
	See	Key 13, 18
117N7-GT	25A7-GT/G	2, 3
	32L7-GT	2, 3
	70L7-GT	2, 3
	117L7/M7-GT	2
	117P7-GT	
	See	Key 13, 18
117P7-GT/G	25A7-GT/G	2, 3
	32L7-GT	2, 3
	70L7-GT	2, 3
117P7-GT/G—Continued		
	117L7/M7-GT	2
	117N7-GT	
	See	Key 13, 18
117Z6-GT/G	25Y5	1, 3, 4
	25Z5	1, 3, 4
	25Z6	3
	25Z6-GT/G	3
	50Y6-GT/G	3
	50Z7-G	1, 2, 3
	See	Key 5
183/483	See	Key 8
485	See	Key 28

For explanation of : Keys 1 - 53 , see next page.

*Pentodes under Type 6C6 may also be used as a substitute for this type when they are connected as triodes (screen and suppressor tied to plate).

1. Space limitations.
2. Wiring changes.
3. Filament voltage and/or current changes.
4. Socket change.

CLASSIFICATION CHART
OF RECEIVING TUBES

This chart classifies RCA Receiving Tubes according to their functions and their cathode voltages. It is so arranged as to permit quick determination by the equipment designer or tube user of the type designations of tubes applicable to specific design requirements. Types having similar characteristics and in the same cathode-voltage group are bracketed.

Cathode Volts			1.4	2.0	2.5—5.0	6.3	12.6—117	Key No.
RECTIFIERS *(For rectifiers with amplifier units, see POWER AMPLIFIERS).*								
Half-Wave	high-vacuum					1-v	12Z3 35Z3 [35Z4-GT 35Z5-GT/G] 45Z5-GT 45Z3	1
Full-Wave	high-vacuum				5T4 [5U4-G 5X4-G 5Z3] [5W4 5W4-GT/G] [5Y3-GT/G 5Y4-G 80] 5Z4 [5V4-G 83-v]	[6X5, 6X5-GT/G, 84/6Z4] 6Y5 6Z5 6ZY5-G 7Y4	6Z5	2
	mercury-vapor				82 83			3
	gas		Cold-Cathode Types 0Z4, 0Z4-G					4
Doubler	high-vacuum						25Y5 [25Z5 25Z6 25Z6-GT/G] 50Y6-GT/G 50Z7-G 117Z6-GT/G	5
DIODE DETECTORS *(For diode detectors with amplifier units, see VOLTAGE AMPLIFIERS and also POWER AMPLIFIERS).*								
One Diode			1A3					6
Two Diodes						[6H6, 6H6-GT/G] 7A6	12H6	7
POWER AMPLIFIERS with and without Rectifiers, Diode Detectors, and Voltage Amplifiers								
Triodes	low-mu	single unit		31	2A3 45 183/483	[6A3 6B4-G]		8
		twin unit				6E6		9
	high-mu	single unit		49	46	6AC5-GT/G	25AC5-GT/G	10
		twin unit	1G6-GT/G	[1J6-G 19]	53	[6N7, 6A6 6N7-GT/G] 6Z7-G [6Y7-G 79]		
	direct-coupled arrangement					[6B5 6N6-G]	[25B5 25N6-G]	11
Beam Tubes	single unit		[1Q5-GT/G 3Q5-GT/G*] 1T5-GT			[6L6 6L6-G] [6V6 6V6-GT/G] 6Y6-G 7A5 7C5	25C6-G [25L6 25L6-GT/G] 35A5 35L6-GT/G 50L6-GT	12
	with rectifier						32L7-GT 70L7-GT [117L/M7-GT 117P7-GT] 117N7-GT	13
Pentodes	single unit		1A5-GT/G [1S4, 3S4*] 1C5-GT/G 1LA4 1LB4, 3Q4*	[1F4 1F5-G] 1G5-G 1J5-G 33	2A5 47 59	[6F6, 6F6-G, 42] 6A4 7B5 6G6-G 12A5 38 6AG7 89 [6K6-GT/G, 41]	12A5 [25A6 25A6-GT/G 43] 25B6-G	14
	with medium-mu triode					6AD7-G		15
	with diode		1N6-G					16
	with diode & triode		1D8-GT					17
	with rectifier						12A7 25A7-GT/G	18
	twin unit			1E7-G★				19

* Filament arranged for either 1.4 or 2.8-volt operation. ★ Two 1F5-G's in one bulb.

CLASSIFICATION CHART OF RCA RECEIVING TUBES

		Cathode Volts	1.4	2.0	2.5—5.0	6.3	12.6—117	Key No.
CONVERTERS & MIXERS *(For other types used as Mixers, see VOLTAGE AMPLIFIERS).*								
Converters	pentagrid		1A7-GT/G 1B7-GT 1LA6 1R5	[1C6, 1C7-G] [1A6, 1D7-G]	2A7	[6A8, 6A8-G, 6A8-GT, 6A7, 6A7S, 6D8-G] 7B8 7Q7 [6SA7, 6SA7-GT/G]	12A8-GT/G [12SA7, 12SA7-GT/G]	20
	triode-hexode					[6K8, 6K8-G, 6K8-GT]	12K8	21
	triode-heptode					6J8-G 7J7		22
	octode					7A8		23
Mixers	pentagrid					[6L7, 6L7-G]		24
ELECTRON-RAY TUBES								
Single	with remote cut-off triode					6AB5/6N5 6U5/6G5		25
	with sharp cut-off triode				2E5	6E5		26
Twin	without triode					6AD6-G 6AF6-G		27
VOLTAGE AMPLIFIERS with and without Diode Detectors, TRIODE, TETRODE & PENTODE DETECTORS, OSCILLATORS								
Triodes	medium-mu	single unit	1G4-GT/G	[1H4-G, 30]	27 56 485	[6C5, 6C5-GT/G] [6J5, 6J5-GT/G] [6P5-GT/G, 76] 7A4 37 6L5-G 6AE5-GT/G	12J5-GT	28
		with r-f pentode				[6F7, 6P7-G]		29
		with power pentode				6AD7-G		30
		with power pentode & diode	1D8-GT					31
		with two diodes		[1B5, 1H6-G]	55	[6R7, 6R7-GT/G, 6SR7, 6ST7] 6C7 7E6 [85, 6V7-G]	12SR7	32
		twin unit				6C8-G [6F8-G, 6SN7-GT]■	12AH7-GT 12SN7-GT	33
		twin input				6AE7-GT		34
		twin plate				6AE6-G		35
	high-mu	single unit				[6F5, 6F5-GT/G, 6SF5, 6SF5-GT] 7B4 6K5-GT/G	[12SF5, 12SF5-GT, 12F5-GT]	36
		with r-f pentode					12B8-GT 25B8-GT	37
		with diode & r-f pentode	3A8-GT*					38
		with diode	1H5-GT/G 1LH4					39
		with two diodes			2A6	6T7-G, 7B6, 7C6 [6B6-G, 6SQ7, 6SQ7-GT/G, 75] [6Q7, 6Q7-G, 6Q7-GT]	[12Q7-GT/G, 12SQ7, 12SQ7-GT/G]	40
		twin unit				6SC7 7F7 6SL7-GT	12SC7 12SL7-GT	41
Tetrodes	remote cut-off			1D5-GT	35			42
	sharp cut-off			32	24-A	36		43
Pentodes	remote cut-off	single unit	1T4 1P5-GT	34 [1D5-GP, 1A4-P]	58	[6K7, 6K7-G, 6K7-GT, 78] 6AB7 [6SK7, 6SK7-GT/G] 7A7 7B7 7H7 39/44 6SS7 [6D6, 6E7, 6U7-G, 6S7, 6S7-G]	[12SK7, 12SK7-GT/G] 12K7-GT/G 14A7/12B7	44
		with triode				[6F7, 6P7-G]	12B8-GT 25B8-GT	45
		with diode				6SF7	12SF7	46
		with two diodes				7E7		47
	semi-remote cut-off	single unit				6SG7	12SG7	48
		with two diodes			2B7	[6B8, 6B8-G, 6B7, 6B7S]	12C8	49
	sharp cut-off	single unit	1N5-GT/G 1L4 1LN5	[1E5-GP, 1B4-P] 15	57	[6J7, 6J7-G, 6J7-GT, 6C6, 6D7, 6W7-G, 77] [6SJ7, 6SJ7-GT] 6SH7 7C7 7G7 6AC7 6AG5	12SH7 [12SJ7, 12SJ7-GT] 12J7-GT/G	50
		with triode & diode	3A8-GT*					51
		with diode	1S5					52
		with two diodes		[1F6, 1F7-G]				53

* Filament arranged for either 1.4 or 2.8-volt operation.

■ Two 6J5-GT/G's in one bulb.

TYPICAL CALCULATIONS

for Adding Series & Shunt Resistors to a Heater String

In order to determine the proper value of series and shunt resistors in heater strings, use is made of the following formulas in which $E =$ voltage in volts, $I =$ current in amperes, $R =$ resistance in ohms, and $W =$ power in watts.

$$R = \frac{E}{I} \text{ (which may also be written as } E = I\,R \text{ or as } I = \frac{E}{R}\text{)}$$

$$W = E\,I \text{ (which may also be written as } W = I^2 R \text{ or as } W = \frac{E^2}{R}\text{)}$$

When the calculated value of resistance is not available in standard fixed-resistor sizes, it is suggested that an adjustable resistor be used in order to obtain the proper value. The wattage rating of either shunt or series resistors should be chosen at about twice the calculated value in order to provide an adequate safety factor under conditions of free circulation of air. A higher factor of safety may be required in compact receivers where air circulation is poor.

As a guide for calculating series- and shunt-resistor values, several examples applying to tube substitutions in 150-milliampere and 300-milliampere heater strings follow.

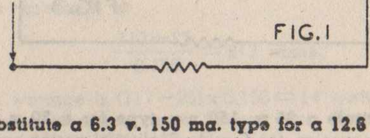

FIG. 1

FIG. 1—To substitute a 6.3 v. 150 ma. type for a 12.6 v. 150 ma. type, calculate value of the resistor to be added in series with the 6.3-volt heater. Using the formula $R = E/I$, we have

$$\frac{12.6 - 6.3}{0.150} = 42 \text{ ohms.}$$

The calculated wattage is $W = E\ I$ or $6.3 \times 0.150 = 1$ watt, but to provide an adequate factor of safety use at least a 2-watt size.

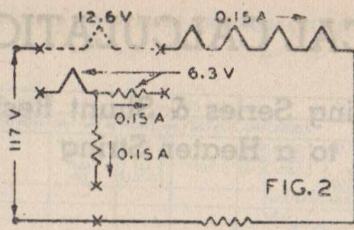

FIG. 2—To substitute a 6.3 v. 300 ma. type for a 12.6 v. 150 ma. type in string position as indicated, calculate value of resistor R which must shunt **all components** in the heater string except the substitute type. Using the formula R = E/I, we have

$$\frac{117-6.3}{0.150} = 738 \text{ ohms.}$$

The calculated wattage is W = E I or $(117-6.3) \times 0.150 = 17$ watts, but to provide an adequate factor of safety use a 50-watt size. The resistance to be added in series with the 6.3-volt heater is

$$\frac{12.6-6.3}{0.150} = 42 \text{ ohms,}$$

and the calculated wattage is $6.3 \times 0.150 = 1$ watt, but to provide an adequate factor of safety use at least a 2-watt size.

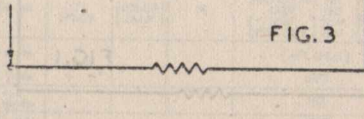

FIG. 3—To substitute a 35 v. 150 n.a. type for a 50 v. 150 ma. type, proceed as in discussion for Fig. 1. Value of series resistor is

$$\frac{50-35}{0.150} = 100 \text{ ohms,}$$

and the calculated wattage is $(50-35) \times 0.150 = 2.3$ watts, but to provide an adequate factor of safety use at least a 5-watt size.

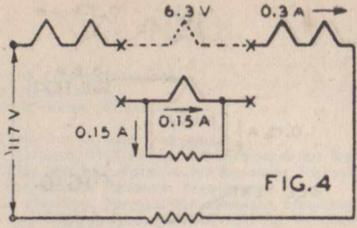

FIG. 4—To substitute a 6.3 v. 150 ma. type for a 6.3 v. 300 ma. type, calculate value of shunt resistor to be added across the 0.150-ampere heater. Using the formula $R = E/I$, we have

$$\frac{6.3}{0.150} = 42 \text{ ohms.}$$

The calculated wattage is $W = E/I$ or $6.3 \times 0.150 = 1$ watt, but to provide an adequate factor of safety use at least a 2-watt size.

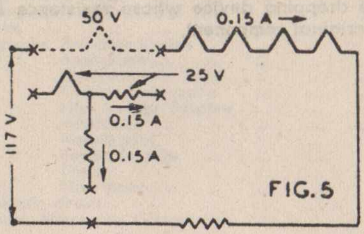

FIG. 5—To substitute a 25 v. 300 ma. type for a 50 v. 150 ma. type in string position as indicated, proceed as in discussion for Fig. 2. Value of shunt resistor R is

$$\frac{117-25}{0.150} = 613 \text{ ohms.}$$

The calculated wattage is $(117-25) \times 0.150 = 14$ watts, but to provide an adequate factor of safety use a 50-watt size. The resistance to be added in series with the 25-volt heater is

$$\frac{50-25}{0.150} = 166 \text{ ohms,}$$

and the calculated wattage is $25 \times 0.150 = 3.8$ watts, but to provide an adequate factor of safety use a 10-watt size.

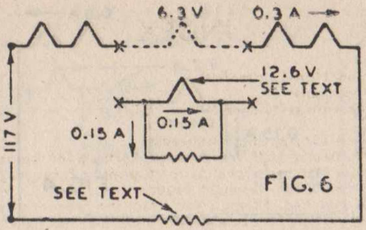

FIG. 6—To substitute a 12.6 v. 150 ma. type for a 6.3 v. 300 ma. type, proceed as in discussion for Fig. 4. Value of shunt resistor is

$$\frac{12.6}{0.150} = 84 \text{ ohms},$$

and the calculated wattage is $12.6 \times 0.150 = 2$ watts, but to provide an adequate factor of safety use a 5-watt size. Since the substitute type increases the total voltage drop of the string by 6.3 volts, it will be necessary to decrease the voltage drop, and hence the resistance, through the line-voltage dropping device (such as line cord or ballast tube) by 6.3 volts, or $6.3/0.3 = 21$ ohms. To effect this decrease, the practical solution will usually be found in the use of a new line-voltage dropping device whose resistance is 21 ohms less than that of the original component.

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