OHMS LAW FORMULAS FOR DC CIRCUITS

$$I = \frac{E}{R} = \frac{W}{E} = \sqrt{\frac{W}{R}}$$

$$R = \frac{E}{I} = \frac{W}{I^2} = \frac{E^2}{W}$$

$$E = IR = \frac{W}{I} = \sqrt{WR}$$

$$W = EI = I^2R = \frac{E^2}{R}$$

LESSON 13 R

RESISTANCE IN RADIO CIRCUIT SYSTEMS

RADIO-TELEVISION TRAINING SCHOOL, INC. ESTABLISHED 1922 LOS ANGELES

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RESISTANCE IN RADIO CIRCUIT SYSTEMS

INTRODUCTION. Resistance in a radio circuit may be good or bad, depending upon where in the circuit it occurs and in what amount. Definite values of resistance are necessary in some circuits to cause them to perform properly; while even very small amounts in others will greatly impair their operation and change the operating characteristics entirely.

Resistance nearly always involves a dissipation or waste of power. In some cases this dissipation is necessary for the good performance of the circuit system, and in others it is detrimental. The problem then appears to be one of determining when and where resistance is necessary and how much, and when it is unwanted or harmful.

NATURE OF ELECTRICAL RESISTANCE

Resistance is the opposition or electrical friction that a conductor offers to the flow of current through it. This resistance is a definite property of the particular kind of matter of which the object is composed, and under similar conditions of temperature, pressure, etc., it is always the same. The resistance of an object is independent of the current that may be flowing through it, except that the current heats the conductor, and if the temperature rise is appreciable, the resistance value may also change.

There is no perfect electrical conductor, but all objects offer resistance to the flow of current, some more than others, depending upon the material of which the object is made. Those that offer little resistance are called conductors and are said to have good conductivity. The metals in general are good conductors, and of the common metals copper is the best. It is for that reason that copper wire is used in making circuit connections, winding coils, etc., for on account of its low resistance it permits the easy passage of current and introduces no appreciable losses.

Objects that offer high resistance are said to have low or poor conductivity, and such materials are used in making resistance elements, or "resistors" as they are called in radio-electrical language. Some high resistance materials used in this manner are carbon, metal alloys, etc. Resistors of various sizes are used to regulate or retard the flow of current, and very high resistors are used to confine electrical currents to certain sections of a circuit. Conductivity is the reciprocal of resistance, and as the one decreases, the other increases in the same ratio.

UNITS OF MEASURING ELECTRICAL RESISTANCE

Electrical resistance is measured in a unit called the ohm, which can be defined as the resistance of an object through which an electromotive force of one volt can send a current of one ampere. This definition however, is merely a restatement of Ohm's Law. From a scientific standpoint the standard ohm is defined as the resistance equal to that of a column of mercury at 0° Centigrade, 106.3 centimeters long, and with a cross-section of one square millimeter. This definition specifies the material, length, cross-section and temperature. For laboratory work and other practical purposes various resistance standards are available, generally in the form of coils wound with German silver or manganin wire, both high resistance alloys.

When very large values of resistance are to be expressed and the use of the ohm as a unit involves a number with too many digits, the megohm is used, a megohm being equal to one million ohms. For very small values of resistance the microhm is used. The microhm is one millionth of an ohm.

1 megohm equals 1,000,000 ohms.

1 ohm equals 1,000,000 microhms or .000001 megohm.

1 microhm equals .000001 ohm.

To change:

Ohms to megohms multiply by .000001.

ohms	to microhms	multiply by	1,000,000.
megohms	" ohms	"	1,000,000.
microhms	" ohms	"	.000001.

Thus, 250,000 ohms are equal to .25 megohm, or 5 megohms are equal to 5,000,000 ohms, etc.

OHM'S LAW REVIEWED

Ohm's law is a statement of the mathematical relation existing between the three factors that are operative in every electric circuit, namely, pressure, current flow and resistance. The law says: In any circuit the current flow expressed in amperes is equal to the applied pressure in volts divided by the resistance in ohms. Stated in formula form it can be written in the following three ways:

$$(1)\ \text{Amperes} = \frac{\text{Volts}}{\text{Ohms}} \qquad (2)\ \text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$$

$$(3)\ \text{Volts} = \text{Amperes} \times \text{Ohms}.$$

Thus, if the value of any two factors are known, the third can be determined by employing one of the above three forms.

Ohm's Law can be applied either to an entire circuit or only to a portion or section of it. If the entire circuit is being dealt with, the total applied voltage must be considered, the total current flowing, and the resistance of the entire circuit system. If only a section of the circuit is being considered, then the voltage across only that portion of the circuit enters into the calculations, as well as the resistance of that section and the current flow through it. The law as stated here applies only to direct current circuit systems. In alternating current circuits the inductance and capacity effects must also receive consideration, and Ohm's Law then takes on a slightly modified form as will be explained later.

Illustrative Example No. 1. How much current can an electromotive force of 30 volts send through the filament of a type 48 tube which has a resistance of 75 ohms?

$$\text{Current} = \frac{\text{Volts}}{\text{Ohms}} = \frac{30}{75} = .4 \text{ Ampere.}$$

Illustrative Example No. 2. What is the resistance of the filament of a type 43 tube if a pressure of 25 volts is needed to send a current of .3 ampere through it?

$$\text{Resistance} = \frac{\text{Volts}}{\text{Amperes}} = \frac{25}{.3} = 83.3 \text{ ohms.}$$

Illustrative Example No. 3. What is the D.C. voltage drop across a 30-millihenry filter choke that has a resistance of 250 ohms, if the current flow through it is 80 milliamperes (.080 ampere)?

$$\text{Voltage} = \text{Amperes} \times \text{Ohms} = .08 \times 250 = 20 \text{ volts}$$

The important point to observe in these calculations is that the values must always be expressed in volts, amperes, and ohms. If the data is given in microvolts, milliamperes and megohms; for example, these must always be reduced or changed to volts, amperes and ohms, or the results will not come out with the correct decimal values.

THE CIRCULAR MIL

In wire measurements it is common practice to express the diameter of wires in "mils" and the cross-section area in "circular mils". A mil is one thousandth of an inch, and hence a wire one inch thick is said to have a diameter of 1000 mils. A one-half inch wire has a diameter of 500 mils, etc.

A circular mil is the area of a circle which is one-thousandth inch in diameter. The use of such a unit greatly simplifies wire calculations, for since the areas of circles are proportional to the squares of their diameters, the area of any round section expressed in circular mils is equal merely to the square of its diameter in mils.

Thus, a wire which has a diameter of ten-thousandths of an inch or 10 mils has a cross-section area of 10 x 10 or 100 circular mils. Circular mils must not be confused with square mils, for a square mil is a unit of square measure and is equal to the area of a square surface 1 mil on an edge.

In the wire table in Fig. 1 are given the specifications of copper wire of various sizes.

PROPERTIES OF COPPER WIRE.

United States Units—Brown & Sharpe Gauge.

Numbers.	Diameter in mils.	Area in circular mils.	Weight in Pounds.		Resistance at 20°C—68°F.	
			1000 feet.	Mile.	1000 feet.	Mile.
0000	460.0	211600.	640.5	3 382.	.0490	.259
000	409.6	167 806.	507.9	2682.	.0618	.326
00	364.8	133077.	402.8	2127.	.0779	.411
0	324.9	105535.	319.5	1 687.	.0983	.519
1	289.3	83 692.7	253.3	1 338.	.1239	.654
2	257.6	66 371.3	200.9	1 061.	.1563	.825
3	229.4	52634.8	159.3	841.2	.1970	1.040
4	204.3	41 741.3	126.4	667.1	.2485	1.312
5	161.9	33102.4	100.2	529.1	.3133	1.654
6	162.0	26251.4	79.46	419.6	.3951	2.086
7	144.3	20 818.3	63.02	332.7	.4982	2.630
8	128.5	16 509.7	49.97	263.9	.6282	3.317
9	114.4	13092.6	39.63	209.3	.7921	4.182
10	101.9	10 383.0	31.43	165.9	.9989	5.274
11	90.74	8234.11	24.92	131.6	1.260	6.650
12	80.81	6 529.95	19.77	104.4	1.588	8.386
13	71.96	5178.48	15.68	82.77	2.003	10.57
14	64.08	4 106.72	12.43	65.64	2.525	13.33
15	57.07	3256.78	9.858	52.05	3.184	16.81
16	50.82	2582.74	7.818	41.28	4.016	21.20
17	45.26	2048.21	6.200	32.74	5.064	26.74
18	40.30	1624.30	4.917	25.96	6.385	33.71
19	35.89	1288.13	3.899	20.59	8.051	42.51
20	31.96	1021.53	3.099	16.33	10.15	53.61
21	28.46	810.114	2.452	12.95	12.80	67.60
22	25.35	642.450	1.945	10.27	16.14	85.24
23	22.57	509.486	1.542	8.143	20.36	107.5
24	20.10	404.041	1.223	6.458	25.67	135.5
25	17.90	320.419	.9699	5.121	32.37	170.9
26	15.94	254.104	.7692	4.061	40.81	215.5
27	14.20	201.513	.6100	3.221	51.47	271.7
28	12.64	159.807	.4837	2.554	64.90	342.7
29	11.26	126.733	.3836	2.026	81.84	432.1
30	10.03	100.504	.3042	1.606	103.2	544.9
31	8.928	79.7031	.2413	1.274	130.1	687.0
32	7.950	63.2075	.1913	1.010	164.1	866.4
33	7.080	50.1258	.1517	.801	206.9	1092.4
34	6.305	39.7516	.1203	.635	260.9	1377.6
35	5.615	31.5244	.0954	.504	329.0	1 737.1
36	5.000	25.0000	.0757	.400	414.6	2190.4
37	4.453	19.8259	.0600	.317	523.1	2 762.0
38	3.965	15.7227	.0476	.251	659.6	3482.9
39	3.531	12.4686	.0377	.199	831.8	4391.8
40	3.145	9.88807	.0299	.158	1049.0	5 538.0

Fig. 1. Wire Table

In the first column is given the number of the wire, in the second column the diameter of the wire in mils, and in the third column the cross-section area in circular mils. For example, No. 14 wire such as is commonly used for electric light wiring has a diameter of 64.08 mils and a cross-section area of 4106.72 circular mils. No. 22 wire which is used a great deal in winding radio coils, has a diameter of 25.35 mils and a cross-section area of 642.45 circular mils. In every case it will be noticed the area in circular mils is always equal to the square of the diameter expressed in mils.

SPECIFIC RESISTANCE OR RESISTIVITY

All materials offer resistance to the flow of current, some more and some less. That is, there is no perfect conductor nor perfect resistor, the entire property of resistance or conductance is relative. However, to make it possible to calculate absolute resistance values, the specific resistance or resistivity of various materials has been determined. By the specific resistance of a substance is meant the resistance per unit cross-section. In practical engineering calculations the foot is used as the unit of length and the circular mil as the unit of cross-section. In other words, the specific resistance of a substance is its resistance per mil-foot. In engineering tables the specific resistance values of different materials are given at either 0° Centrigrade (32° Fahrenheit) or at 21° Centrigrade which is 69.8° Fahrenheit ordinary room temperature.

In the following table in column (1) are given the specific resistance values in ohms per mil-foot of the common metals at room temperatures; that is, 21°C. In column (2) are given the relative conductivities of these same materials expressed in percent of the conductivity of copper which is used as the standard of comparison.

Material	(1)	(2)
Silver	9.7	108.6
Copper(annealed)	10.4	100
Copper (hard drawn) ..	10.7	97.8
Aluminum............	18.7	59.8

(Continued on Page 7)

Zinc	38.0	27.7
Iron Wire	65.2	16.2
Nickel	85.1	12.9
Steel Wire	90.2	11.6
Brass (soft)	46.9	22.2
Phosphor-bronze	51.7	18.8
German Silver......................	128.9	7.5

HOW TO CALCULATE THE RESISTANCE OF A CONDUCTOR

The resistance of a conductor depends upon three factors: First, the length of the conductor; second, the cross section area; and third, the material of which the conductor is made. The resistance depends directly upon the length of the conductor; that is, the greater the length, the greater the resistance. But the resistance varies inversely as the cross-section area; that is, as the cross-section area becomes smaller, the resistance becomes larger proportionately, and vice-versa. As stated, the resistance depends upon the material of the conductor; that is, a copper wire of a given length and thickness has less resistance than an iron wire, etc.

If the dimensions of a conductor are known and the material of which it is made, the resistance "R" can then be calculated with the aid of the following formula:

$$R = r \times \frac{L}{A}$$

where r is the specific resistance as given in the table in the previous section, "L" is the length of the conductor expressed in feet, and "A" is the cross-section area expressed in circular mils.

Illustrative Example No. 4. What is the resistance of 150 feet of No. 18 copper wire, such as is commonly used for door bells, etc?

$$R = \frac{r \times L}{A} = \frac{10.4 \times 150}{1624.3} = .96 \text{ Ohm}$$

Illustrative Example No. 5. If 2000 feet of No. 38 wire are needed for winding an audio choke, what will be the resistance of the winding?

$$R = \frac{r \times L}{A} = \frac{10.4 \times 2000}{15.7} = 1325 \text{ Ohms}$$

In such calculations as these the specific resistance values are obtained from the table in the preceding section and the diameters and areas of the wires from the wire table in Fig. 1.

HOW CHANGES IN TEMPERATURE AFFECT RESISTANCE

The exact resistance of pure metal conductors depends upon the temperature, and increases as the temperature rises and decreases as the temperature drops. That is why in Specific Resistance tables the temperature is always mentioned. For ordinary practical purposes the room temperature (70°F) resistance is generally sufficiently accurate, but where greater accuracy is necessary the change in resistance due to temperature conditions must be taken into consideration.

Experimental observations have shown that the rate of increase in resistance with rise in temperature is nearly the same for all the more common metals. The increase in resistance per ohm per degree rise in temperature is called the Temperature Coefficient; and if temperatures are measured on the Fahrenheit scale, this coefficient has a numerical value of approximately .0023. (Coefficient means multiplying factor.) In other words, a 1-ohm resistor raised 1 degree in temperature will increase in resistance by .0023 ohm.

To calculate the resistance of a conductor at a given higher temperature, the above facts have been put into the following formula form:

$$R2 = R1 + (R1 \times t \times c)$$

where R2 is the unknown resistance at the higher temperature, R1 is the known resistance, "t" is the number of degrees change in temperature, and "C" is the temperature coefficient or .0023.

Illustrative Example No. 6. The resistance of a filter choke wound with copper wire is 1325 ohms at room temperature (70°F.). What will its resistance be at 150°F?

Rise in temperature is 150 - 70 or 80 degrees

Upon substituting these values in the above formula it becomes:

$$R2 = 1325 + (1325 \times 80 \times .0023)$$
$$R2 = 1325 + 243.8$$
$$= 1568.8 \text{ Ohms}$$

The quantity in parenthesis, or 243.8, represents the increase in resistance and that added on to the initial resistance gives the high temperature resistance.

Pyrometers or electric thermometers operate on this principle of the increase in resistance of special heating elements with rise in temperature. The heating element is connected in series with a source of voltage and a current indicating meter. With a constant voltage the current varies with the resistance, and hence if properly calibrated the meter can be adapted to indicate temperatures directly.

For special purposes where a constant resistance is desirable even for wide variations in temperature as in measuring instruments and in various types of electrical standards, a number of alloys have been developed that have a zero temperature coefficient. In other words, these alloys have a practically negligible variation in resistance as their temperature changes. Manganin is such an alloy. It consists chiefly of copper, but also contains nickel and manganese. A peculiar property of most alloys is that their increase in resistance per degree rise in temperature is less than that of pure metals.

RESISTORS IN A SERIES SYSTEM

A number of resistance units are arranged in series when they are connected so that the current flows through each one of them in succession. Such a series hook-up is sometimes also referred to as a "tandem" arrangement. The various units in a series circuit need not all be resistance elements, one may be a choke or transformer winding, another a tube filament, the third a control rheostat, etc.

A series circuit is inherently a single-path circuit, and the current is the same in all parts; none can be lost or blocked at any point, as long as the circuit is properly insulated, etc. In other words, an ammeter or milliammeter will always give the same reading, no matter where it is connected into the circuit. Also, since in a series circuit the current flows through each element in succession, the total resistance is equal to the sum of the resistance values of the separate units.

As the current flows through a series circuit, it sets up across each unit a potential drop that according to Ohm's Law is equal to the resistance of that unit multiplied by the current strength (I x R); and the total potential drop through a series circuit is equal to the sum of the drops across the successive parts. The current will automatically adjust itself to such a value that the aggregate or total of these potential drops is equal to the applied voltage. That is, the applied voltage will completely dissipate itself in sending the current through the circuit against the total resistance encountered.

These various characteristics of a series circuit can be summed up in the following laws:

1. The current in every part of a series circuit is the same.
2. The total resistance of a series circuit is equal to the sum of the separate resistances.
3. The total voltage drop through a series circuit equals the sum of the drops across the individual sections.

4. The total voltage drop through a series circuit is equal to the applied electromotive force.

No. 1 can be restated in formula form in the following way:

$$R = r1 + r2 + r3 \text{ etc.}$$

Illustrative Example No. 7. The voltage at the output of the rectifier of an A.C. set is 350 volts. The circuit contains a 200-ohm filter choke, a 2500-ohm dynamic speaker, and a 20,000-ohm bleeder resistor. What current flows through the resistor? See Fig. 2.

The total resistance $R = 200 + 2500 + 20{,}000$ or 22,700 Ohms.

$$\text{Current } I = \frac{\text{Volts}}{\text{Ohms}} = \frac{350}{22700} \text{ or } .01542 \text{ Amperes (15.42 Milliamperes)}$$

This condition prevails when the set is turned on and the rectifier tube only is in its socket.

The potential drop across the choke is 200 x .01542 or 3.084 Volts.

The potential drop across the field is 2500 x .01542 or 38.55 Volts.

The potential drop across the bleeder resistor is -

20,000 x .01542 or 308.4 Volts

The total potential drop around the circuit is then -

3.084 + 38.55 + 308.4 or 350.03 volts

and this is equal to the applied voltage at the circuit terminals. The small difference of .03 volt is obtained because in dividing 350 by 22,700, the last figure in the quotient is not equal to 2. These calculations verify the four laws of series circuits stated above.

RESISTORS IN A PARALLEL SYSTEM

Resistors connected in parallel are arranged to form a divided or branched circuit between two points. In such a circuit the main current separates and part flows through each branch. It is evident that the total current supplied to such a parallel system is equal to the sum of the individual branch currents. Also, the current in every branch according to Ohm's Law is equal to the voltage across the parallel system divided by the resistance of that branch, the voltage across all parallel branches being the same.

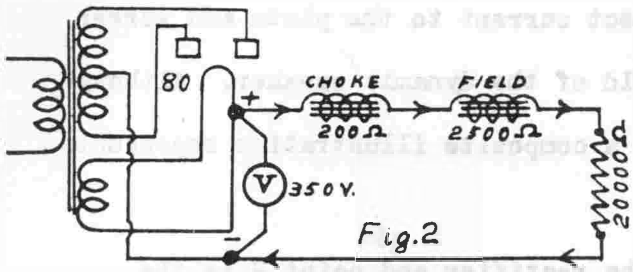


Fig.2

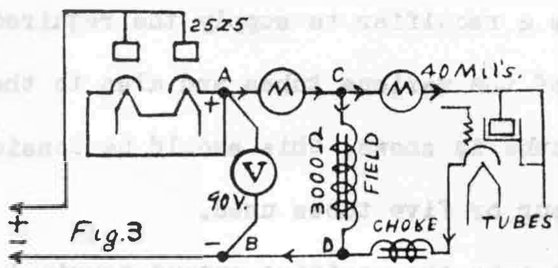


Fig.3

The combined resistance of two equal resistors in parallel is equal to half the resistance of one unit, and the combined resistance of three equal parallel units is one-third the resistance of one unit, etc. If a number of unequal resistor units are connected in parallel, their combined resistance is given by the following formula:

$$\frac{1}{R} = \frac{1}{r1} + \frac{1}{r2} + \frac{1}{r3} \quad \text{etc.}$$

It will be found that when any number of resistors are connected in parallel, the combined resistance is always less than that of the smallest resistor in the group. The other two important points to observe about a parallel combination are: The voltage across all the resistors of a parallel hook-up is the same, and the current through any branch is independent of and has no effect on the current in the other branches.

In the case of a more complex circuit in which two or more parallel combinations are in series with each other and in addition in series with several individual resistors, the circuit conditions are calculated by first working on the parallel combinations and reducing them to equivalent single resistors, and then solving the circuit as a simple series circuit.

ANALYSIS OF A PARALLEL CIRCUIT SYSTEM

In Fig. 3 is illustrated a parallel circuit which is typical of the circuit arrangement used in many 110-volt universal A.C.-D.C. midget receivers. A 25Z5 tube is used as a rectifier to supply the required direct current to the plate and screen circuits of the various tubes and also to the field of the dynamic speaker. Although only one tube is shown, this should be considered a composite illustration representing the four or five tubes used.

Point A is the positive output terminal of the rectifier and point B is the negative terminal returning to the other side of the line. A voltmeter V connected across points A and B generally indicates a pressure of about 90 volts. At point C the circuit divides, one branch leads through the 3000-ohm speaker field and the other to the plate and screen circuits of the various tubes employed. These two branches then unite again at point D. Since both circuits are really connected across points C and D, the same pressure of 90 volts is applied across each.

The current through the field coil can be determined by means of Ohm's Law, namely by dividing 90 by 3000, the result being .03 ampere or 30 milliamperes. A milliammeter M connected into the tube line indicates a current of 40 milliamperes drawn by the various tubes. A current meter inserted into the line between points A and C would register 70 milliamperes. In other words, in a parallel circuit the total current is equal to the sum of the branch currents. The same current strength flows between points D and B.

Since the total current is 70 milliamperes (.07 ampere) and the applied voltage is 90 volts, the resistance of the entire parallel system according to Ohm's Law is 90 divided by .07 or 1285.7 ohms. The combined resistance of the tube circuits can also be calculated, for if the current drain is 40 milliamperes (.04 ampere) and the voltage applied across them is 90 volts, the resistance in ohms is 90 divided by .04 or 2250 ohms. If the resistance of these two parallel circuits is next determined, the same result should be obtained as was arrived at in the first sentence of this paragraph, namely, 1285.7 ohms.

The combined resistance is determined in the following manner:

$$\frac{1}{R} = \frac{1}{r1} + \frac{1}{r2} = \frac{1}{3000} + \frac{1}{2250} = \frac{2250 + 3000}{3000 \times 2250} = \frac{5250}{6750000}$$

Or, if both sides of the equation are inverted, the result is:

$$R = \frac{6750000}{5250} = 1285.7 \text{ Ohms}$$

These simple calculations thus nicely verify the various laws governing the voltage, current and resistance distribution in parallel circuit systems.

RESISTANCE AS A MEANS OF CURRENT CONTROL

When an electrical pressure is impressed across the terminals of a circuit and the circuit is closed so that it forms a continuous and uninterrupted path, current is caused to flow. This current at once encounters opposition or electrical friction called resistance, and the applied pressure is dissipated in overcoming this resistance. The current then automatically adjusts itself to such a value that the total applied pressure is used up in sending it around the circuit. If the circuit resistance becomes greater, less current can flow, for if only a certain pressure is available and the opposition to be overcome is greater, less current can be sent along. Or if the same current is to be sent through the higher resistance, greater circuit voltage is needed.

According to Ohm's Law, in any circuit the current in amperes is equal to the applied pressure in volts divided by the resistance in ohms. This means that at a constant applied voltage the current flow in any circuit is governed entirely by the amount of resistance encountered. Resistance can thus be used as a means of current or voltage control, and this is one of the common applications of resistors in radio and electrical circuits. Resistance used in this mannermay be in the form of a fixed unit having a definite resistance value, or it may be a variable unit like a rheostat or potentiometer. The latter can be made continuously variable as with a slider moving over a coiled piece of wire, or arranged to cut in or out a number of fixed units by means of a switch lever moving over a series of contact points between which the resistance elements are connected.

CALCULATING THE VOLTAGE DROP ACROSS A RESISTOR

The relations expressed by Ohm's Laware true for an entire circuit system as well as for any section of a circuit, and it is with the aid of this law that the voltage drop across a resistor can be calculated or the resistor value needed to bring about a desired voltage drop.

According to Ohm's Law the voltage drop across any part of a circuit is equal to the current flow through it multiplied by the resistance of that part. Or:

Volts = Amperes x Ohms

Illustrative Example No. 8. What is the voltage drop across a 20,000-ohm resistor if the current flow through it is 5 milliamperes? (See Fig. 4.)

Volts = Amperes x Ohms

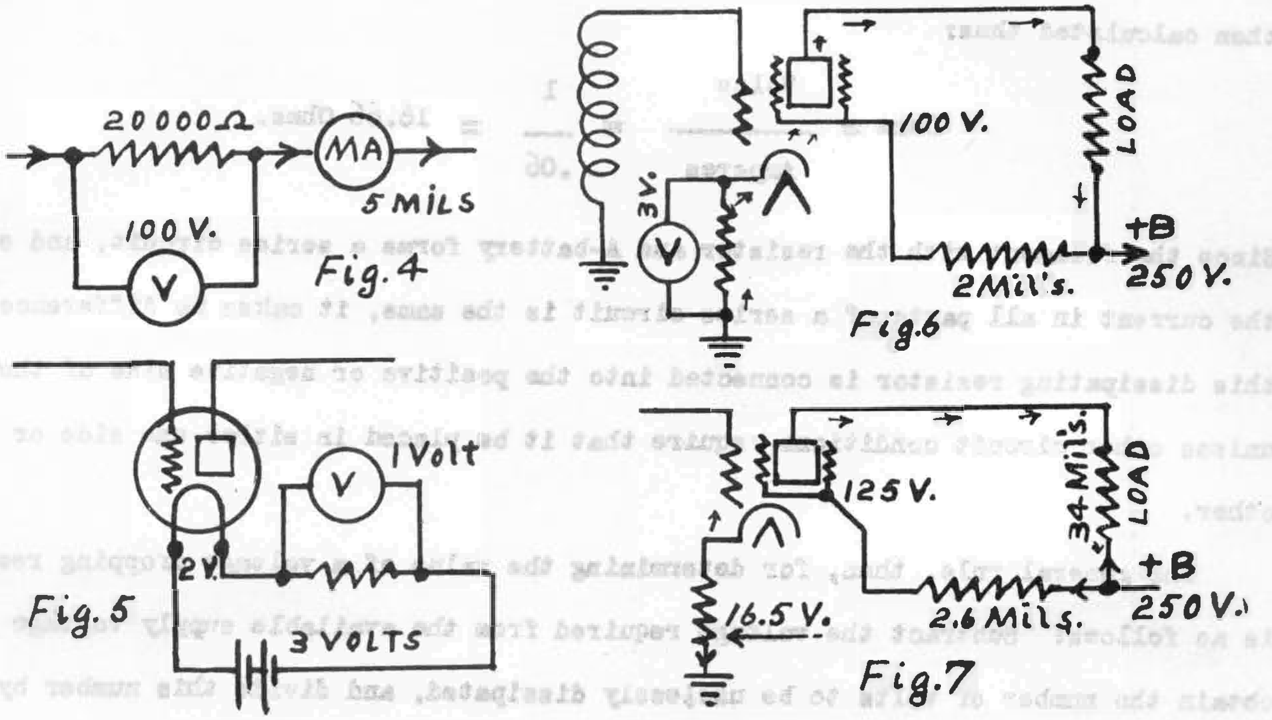
Current is 5 milliamperes or .005 ampere.

Resistance is 20,000 ohms.

Volts = .005 x 20,000 = 100.

Accordingly the drop across the resistor is 100 volts.

Another way of considering this action is by stating that the voltage drop or loss of potential across a resistor is always equal to the voltage or electromotive force that would be needed to send the same current through that resistor. In other words, the current always adjusts itself so that the total voltage drop throughout a circuit is equal to the applied electromotive force. As is explained in a later paragraph, power is thus expended in sending the current through the circuit resistance, this power manifesting itself as heat which causes the temperature of the circuit elements to rise.



CALCULATING THE RESISTANCE VALUE NEEDED FOR A GIVEN VOLTAGE DROP

A very common problem that arises in the calculation of radio circuits is that of determining the value of resistance needed to reduce an available voltage supply to a lower value as required in a certain branch of the circuit. For instance, for operating 2-volt tubes of the 30 or 32 type, two dry cells are commonly used connected in series as a filament supply. The terminal voltage of these is 3 volts, although only 2 volts are needed at the filament terminals. In other words, 1 volt must be disposed of, and the method used is to connect a resistor in series with the circuit so that 1 volt is dissipated across this resistor. See Fig. 5.

According to Ohm's Law resistance in ohms is equal to volts divided by amperes, or:

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$$

The voltage in the case just cited is the 1-volt to be dissipated, and the filament current according to the tube table is .06 ampere. The resistance value needed is then calculated thus:

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}} = \frac{1}{.06} = 16.66 \text{ Ohms.}$$

Since the filament with the resistor and A-battery forms a series circuit, and since the current in all parts of a series circuit is the same, it makes no difference whether this dissipating resistor is connected into the positive or negative side of the line, unless other circuit conditions require that it be placed in either one side or the other.

The general rule, then, for determining the value of a voltage dropping resistor is as follows: Subtract the voltage required from the available supply voltage to obtain the number of volts to be uselessly dissipated, and divide this number by the current strength through that part of the circuit to which the voltage is to be reduced. The whole process is thus first a case of subtraction and then division, the important thing to observe in all cases being the position of the decimal point.

CALCULATING SCREEN GRID SERIES RESISTORS

In the case of screen grid tubes the screen grid is designed to operate at a lower voltage than the plate, and consequently a suitable resistor must be connected in series with the screen grid circuit to reduce the voltage to the proper value. The calculations involved are merely another application of the principles explained in the previous paragraph.

Illustrative Example No. 9. A type 58 or 6D6 tube is designed to operate with a plate potential of 250 volts and a screen potential of 100 volts, the screen current under these conditions being 2 milliamperes. What value of screen resistor must be used? See Fig. 6.

Supply voltage is 250 volts.

Voltage needed is 100 volts.

Voltage to be dissipated in resistor is 250 - 100 or 150 volts.

Current through resistor is 2 milliamperes or .002 ampere.

Therefore, resistor value is -

$$\frac{150}{.002} \text{ or } \frac{150000}{2} = 75{,}000 \text{ ohms.}$$

CALCULATING CATHODE BIAS RESISTORS

In most A.C. operated tubes it is customary to establish the required negative bias on the grid by means of a resistor in series with the cathode return lead. This really places the cathode at a positive potential with respect to the grid, but the effect is the same. The method of calculating the resistor value needed to establish the necessary bias is another simple application of the principles explained and illustrated above.

The procedure is as follows: From a tube data chart the grid bias is obtained for the particular tube in use at the plate voltage at which it is operating. From the same chart the plate current is also obtained at the same plate voltage. The problem then merely becomes a case of calculating the resistance with the voltage and current values known. If the tube contains a screen grid, the screen current also must be considered, for this likewise returns through the cathode resistor.

Illustrative Example No. 10. What value cathode bias resistor is needed for a type 6F6 power amplifier that is operating at a plate pressure of 250 volts if the required grid bias is 16.5 volts? The plate current is 34 milliamperes and the screen current 6.5 milliamperes. See Fig. 7.

The current flow is 34 + 6.5 or 40.5 milliamperes or .0405 ampere.

The voltage drop to be established is 16.5 volts. The required resistor value is then calculated by dividing the voltage by the current flow, or -

$$\text{Resistor value is: } \frac{16.5}{.0405} = \frac{165{,}000}{405} = 407 \text{ ohms.}$$

Accordingly, a 400-ohm resistor would be needed for biasing purposes.

POWER DISSIPATION IN RESISTORS

When an electric current is sent through a resistor, power is expended in overcoming the resistance. This power manifests itself as heat and causes the resistor to become warm. The heat developed, of course, must be dissipated into the surrounding space, and the temperature of the resistor rises until the heat is dissipated as fast as it is developed. It is thus evident that the amount of power that can be expended in a resistor, as well as the temperature rise, are limited chiefly by the rate at which the heat can be disposed of and absorbed by the surroundings.

This rate at which the heat can be disposed of depends upon a number of factors, such as the ease with which the heat can get from the interior of the resistor to the surface, the heat radiating qualities of the surface material, the surface area exposed to ventilation, and lastly and probably most important, the difference in temperature between the resistor itself and the surroundings.

A resistor in which a certain amount of power is expended may operate perfectly satisfactorily and remain fairly cool if it is mounted in the open with free circulation of air about it; but if it is tucked away in a corner under a crowded midget chassis with little chance of the heat being carried away, the temperature of the resistor may rise above a safe degree. Or, what may be worse, if the resistor is mounted near another unit such as a hot transformer, the resistor not only has no means of dissipating its own heat, but is actually forced to absorb additional heat from the higher temperature adjacent object.

Therefore, when resistors are being selected, the reliability of the manufacturer should always be considered to make sure that only ingredients of good quality are used and that the resistors will stand up under the service for which they are intended. Also, in selecting the mounting position attention should be paid to the ease with which the heat can be carried away so that the resistor will not exceed safe operating temperatures.

If a resistor does become too hot, it may not only change in value sufficiently to upset the entire circuit stability, but may also disintegrate enough to break down and open. The resistor is then said to be burnt out. Resistors should always be chosen of such a size and rating that this disintegrating temperature is far above the normal operating temperature so that the resistor will have a long useful life.

CALCULATING POWER DISSIPATED IN RESISTORS

The amount of power dissipated in a resistor depends upon the current that is sent through it and the ohmic value of the resistor. If the current strength is expressed in amperes, the power in watts in equal to the square of the current multiplied by the resistance. Or, expressed in formula form this would read:

Power = (Current squared) x Resistance

Watts = (Amperes x Amperes) x Ohms

$$P = I \times I \times R$$

Illustrative Example No. 11. What power is expended in a 5-ohm resistor if a current of 2 amperes is sent through it?

$$P = I \times I \times R = 2 \times 2 \times 5 = 20 \text{ Watts.}$$

Illustrative Example No. 12. A current of 40 milliamperes (.04 ampere) flows through the 2500-ohm field of a dynamic speaker. How much power is dissipated in the field?

$$P = I \times I \times R = .04 \times .04 \times 2500$$

$$= .0016 \times 2500 = 4 \text{ Watts.}$$

Illustrative Example No. 13. The cathode resistor for a type 56 tube operating as an audio amplifier is 2000-ohms and a current of 5 milliamperes (.005 ampere) flows through it. How much power is dissipated in the resistor?

$$P = I \times I \times R = .005 \times .005 \times 2000.$$

$$= .000025 \times 2000 = .05 \text{ Watt.}$$

An important point to observe in connection with the dissipation of power in a resistor, is that as the resistance is doubled the power dissipated also is doubled, but if the current is doubled the power is quadrupled, that is, becomes four times as great. For example, if a current of 2 amperes is sent through a 5-ohm resistor, the power expended is 2 x 2 x 5 or 20 watts. If the resistor value is doubled to 10 ohms, the power expended is 2 x 2 x 10 or 40 watts. However, if with the original resistor the current is doubled, the power dissipation becomes 4 x 4 x 5 or 80 watts. That is why the temperature rise increases so rapidly as the current flow becomes greater.

TO CALCULATE THE CURRENT CAPACITY OF A RESISTOR

To calculate how much current can be carried by a resistor of known value if the power rating of the resistor is known, the process is somewhat the reverse of that explained above. In other words, to calculate the current capacity of a resistor having a given power rating, divide the power in watts by the resistance in ohms and extract the square root. Expressed in formula form this is:

$$I = \sqrt{\frac{P}{R}} \quad \text{or}$$

$$\text{Amperes} = \sqrt{\text{Watts divided by Ohms}}$$

Illustrative Example No. 14. How much current can safely be sent through an 800-ohm wire resistor that is rated at 20 Watts?

1st step: Divide 20 by 800 and get .025.

2nd step: Extract square root of .025 and get .158 Ampere or 158 Milliamperes.

Illustrative Example No. 15. How much current can be carried by a 2000-ohm carbon resistor rated at 1/2 watt?

1st step: Divide .5 by 2000 and get .00025.

2nd step: Extract square root of .00025 and get .0158 Ampere. .0158 Ampere equals 15.8 Milliamperes.

The calculations just illustrated do not take into consideration any factor of safety such as is generally allowed to compensate for the limited heat dissipating conditions that might be encountered, etc. If a 25% safety factor were allowed, the current capacity in the two cases just cited would be one-fourth less.

RMA RESISTOR COLOR CODE

A color code has been adopted by radio parts and set manufacturers to designate the value of resistors so that one can tell by observing the color of a resistor what the value is without having to resort to the use of some suitable measuring device. Without such a color code it would be impossible to tell off hand the value of a defective resistor in a radio set or amplifier.

The resistor color code includes ten colors, one color for each of the numerical digits, and the resistor is colored in three places - one color is applied to the body of the resistor, another color to the tip or end of the resistor, and a third color in the form of a ring or spot at the center of the resistor. The number corresponding to the color of the body is the first figure in the resistor value, the number represented by the tip or end color is the second figure, and the color of the spot at the center indicates the number of zeros that follow these first two figures. Following are the ten colors used and the digit each represents.

Brown	1	Blue	6
Red	2	Violet	7
Orange	3	Gray	8
Yellow	4	White	9
Green	5	Black	0

For example, if the body color of a resistor is brown, the tip green, and the center band or spot orange, the first figure in the resistor value is 1 and the second figure 5 and these are followed by three zeros. The value of the resistor is thus 15,000 ohms. In the following table are given a number of color combinations used on resistors and the resistor value each color combination represents.

Body Color		End Color		Band Color		Resistor Value
Gray	(8)	Gray	(8)	Black	(None)	88 Ohms
Brown	(1)	Blue	(6)	Brown	(0)	160 Ohms
Yellow	(4)	Green	(5)	Red	(00)	4500 Ohms
Orange	(3)	Black	(0)	Orange	(000)	30000 Ohms
Red	(2)	Purple	(7)	Yellow	(0000)	270000 Ohms

EXAM QUESTIONS ON PAGES 24 and 25.