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LESSON NO. 41

OHM'S LAW FOR A.C. CIRCUITS

• *RESONANCE* •

IN THIS LESSON, WE ARE GOING TO CONTINUE OUR INVESTIGATION OF THE PHYSICS ASSOCIATED WITH A.C. CIRCUITS BY STUDYING FIRST THE RELATION BETWEEN PARTIAL VOLTAGES AND THE COMBINED VOLTAGE OF CIRCUITS INVOLVING IMPEDANCE.

THIS NEXT POINT WHICH WE SHALL CONSIDER IS A MOST IMPORTANT ONE AND SO YOU WANT TO BE SURE TO GET IT STRAIGHT. IN FIG. 1, FOR EXAMPLE, WE HAVE A CIRCUIT CONTAINING THREE RESISTORS WHICH ARE CONNECTED IN SERIES IN AN A.C. CIRCUIT. AN AMMETER IN THIS CIRCUIT INDICATES A CURRENT FLOW OF 6 AMPERES, AND SUCH A READING, OF COURSE, WILL INDICATE THE EFFECTIVE CURRENT FLOW IN THE CIRCUIT.

SINCE THIS SAME 6 AMPERES MUST FLOW THROUGH ALL OF THESE RESISTORS, WE FIND ACCORDING TO OHM'S LAW THAT THE VOLTAGE DROP ACROSS THE 4 OHM RESISTOR IS EQUAL TO 4 X 6 OR 24 VOLTS ($E = I \times R$). THE DROP ACROSS THE 9 OHM RESISTOR IS 6 X 9 OR 54 VOLTS AND THE DROP ACROSS THE 6 OHM RESISTOR IS 6 X 6 OR 36 VOLTS. THE TOTAL VOLTAGE, WHICH IS IMPRESSED ACROSS THE ENTIRE GROUP OF RESISTORS THUS BECOMES EQUAL TO 24 + 54 + 36 OR 114 VOLTS. THESE VOLTAGES UNDER CONSIDERATION ARE THE EFFECTIVE VOLTAGES OF THE A.C. CIRCUIT.

25
15
30
70

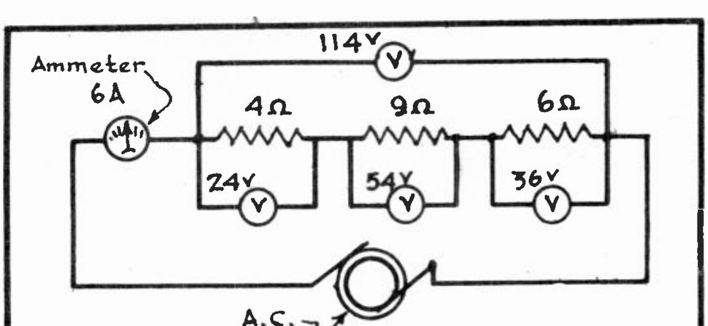


FIG. 1
Voltage Distribution In a Pure Resistance Circuit.

WITH THIS POINT FIRMLY IN MIND, LET US NEXT CONSIDER FIG. 2. HERE WE HAVE ANOTHER A.C. CIRCUIT BUT THIS TIME, A RESISTOR, A CONDENSER AND AN INDUCTANCE ARE CONNECTED IN SERIES.

OHM'S LAW CAN BE APPLIED EQUALLY WELL TO CONDENSERS AND INDUCTANCES JUST AS IT CAN TO RESISTORS, ONLY THAT IN THE CASE OF CONDEN-

SERS AND INDUCTANCES THE REACTANCE TAKES THE PLACE OF THE RESISTANCE. WE THUS FIND IN FIG. 2 THAT THE VOLT-DROP ACROSS THE 4 OHM RESISTOR IS EQUAL TO 4 X 6 OR 24 VOLTS. THE VOLT DROP ACROSS THE CONDENSER WILL BE EQUAL TO THE CURRENT IN AMPERES TIMES THE CAPACITIVE REACTANCE OF THIS CONDENSER AT THE FREQUENCY BEING HANDLED. IN OTHER WORDS, THE VOLTAGE DROP ACROSS THIS CONDENSER WILL BE 9 X 6 OR 54 VOLTS. THEN IN LIKE MANNER, THE VOLTAGE DROP ACROSS THE INDUCTANCE WILL BE EQUAL TO THE CURRENT TIMES THE INDUCTIVE REACTANCE OF THIS COIL AT THE FREQUENCY OF THE EXISTING CURRENT FLOW. THAT IS, THE VOLTAGE DROP ACROSS THIS INDUCTANCE IS 6 X 6 OR 36 VOLTS.

NOW THEN, HERE IS THE MOST IMPORTANT THING FOR YOU TO REMEMBER. THE VOLTAGE ACROSS THIS ENTIRE SERIES GROUP OF FIG. 2 WILL NOT BE 24+54+36 OR 114 VOLTS BECAUSE IN THE CASE OF FIG. 2, WE HAVE IMPEDANCE TO CONSIDER. THE IMPEDANCE OF THIS CIRCUIT OF FIG. 2 IS NOT 4+9+6 OR 19 OHMS AS IN THE CASE OF A PURE RESISTANCE CIRCUIT. BUT TO FIND THE IMPEDANCE OF THE CIRCUIT IN FIG. 2, WE MUST USE THE FORMULA $Z=\sqrt{R^2+X^2}$ WHERE R = THE 4 OHMS OF RESISTANCE AND "X" THE NET REACTANCE OF THE CIRCUIT. IN THE CASE OF FIG. 2, THE NET REACTANCE OF THE CIRCUIT IS 9 -6 OR 3 OHMS. THAT IS, THE CAPACITIVE REACTANCE MINUS THE INDUCTIVE REACTANCE. THE IMPEDANCE WOULD THUS BECOME EQUAL TO $\sqrt{4^2+3^2}=\sqrt{16+9}=\sqrt{25}$ OR 5 OHMS.

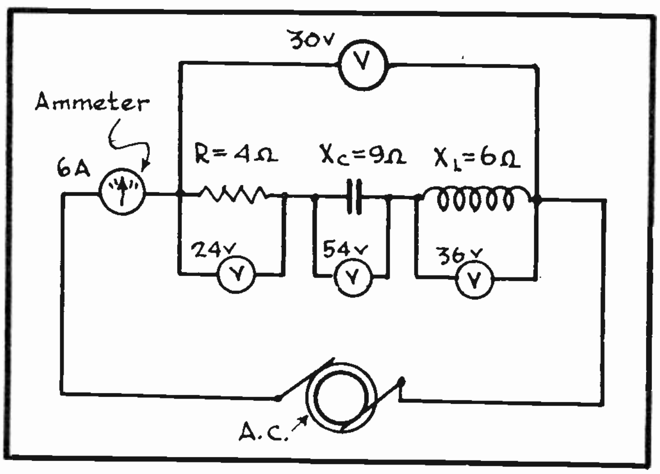


FIG. 2

Voltage Distribution in a Combination Circuit.

IT THUS FOLLOWS THAT THE EFFECTIVE VOLT DROP ACROSS THE SERIES COMBINATION IN FIG. 2 IS EQUAL TO THE CURRENT FLOW TIMES THE IMPEDANCE OR 6 X 5 = 30 VOLTS. SO YOU SEE, THIS VOLT DROP IS LESS THAN ONE MIGHT SUPPOSE UPON FIRST THOUGHT.

OHM'S LAW FOR A.C. CIRCUITS

REMEMBER NOW THAT THE OHM'S LAW RELATION ALSO HOLDS GOOD IN A.C. CIRCUITS JUST AS MUCH AS IT DOES IN THE D.C. CIRCUITS, ONLY THAT IN THE CASE OF A.C., EFFECTIVE VOLTS = EFFECTIVE CURRENT X IMPEDANCE. IMPEDANCE = $\frac{\text{EFFECTIVE VOLTS}}{\text{EFFECTIVE CURRENT}}$ OR EFFECTIVE CURRENT = $\frac{\text{EFFECTIVE VOLTS}}{\text{IMPEDANCE}}$.

IN ALL CASES, THE EFFECTIVE VALUES, ARE THOSE AS INDICATED BY AN A.C. TYPE METER AND OF COURSE THE EFFECTIVE CURRENT MUST BE EXPRESSED IN AMPERES AND NOT IN MILLIAMPERES ETC.

TO BE SURE THAT YOU UNDERSTAND THE APPLICATION OF OHM'S LAW TO A.C. CIRCUITS, LET US WORK OUT A FEW SIMPLE PRACTICAL PROBLEMS. LET US ASSUME, FOR EXAMPLE, THAT WE HAVE A 30 HENRY CHOKE, CONNECTED IN SERIES WITH A 1000 OHM RESISTOR. HOW MUCH VOLTAGE WOULD BE REQUIRED TO FORCE 10 MILLIAMPERES THROUGH THIS CIRCUIT?

To figure this problem, we could picture it as shown you in Fig. 3. The inductive reactance of this choke to the 120 cycle current is found with the formula $X_L = 6.28 f L = 6.28 \times 120 \times 30 = 22{,}608$ ohms. The impedance of this circuit to 120 cycles is found with the formula as follows: $Z = \sqrt{R^2 + X_L^2} = \sqrt{1000^2 + 22608^2} = \sqrt{512{,}121{,}664} = 22630$ ohms. Then according to Ohm's Law, the effective voltage required to force 10 milliamperes through the impedance of 22630 ohms, will be obtained by multiplying the impedance by the effective current. Hence $22630 \times .010 = 226.3$ volts, which is the effective voltage required.

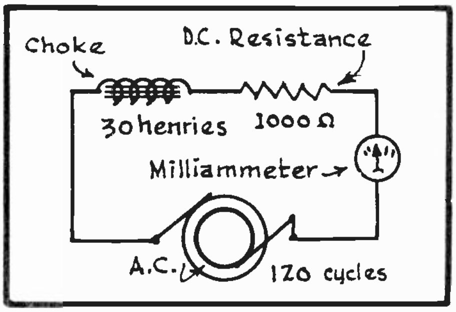


FIG. 3
Figuring Voltage.

For this same circuit of Fig. 3, if the impedance is known to be 22630 ohms and 300 volts is applied across the choke, then the current which will flow can be calculated by dividing the effective volts (300) by the impedance. Hence $\frac{300}{22630} = .013$ amperes or 13 milliamperes.

Then again in the case of Fig. 3, if the effective voltage applied across the ends of the circuit is known to be 200 volts and the milliammeter registers a current flow of 15 milliamperes, then the impedance of the choke can be found by dividing the voltmeter reading by the milliammeter reading. That is, the impedance $= \frac{200}{.015} = 13333$ ohms.

You would handle any other circuit in like manner whether it be made up of a capacity and resistance, capacity and inductance or all three of these characteristics. In all cases, you must consider the impedance of the circuit when applying Ohm's Law to the combined circuit.

RESONANCE

You have already been made familiar with the condition of resonance in receiver circuits. At this time, however, you are going to obtain a still better understanding of this important radio principle.

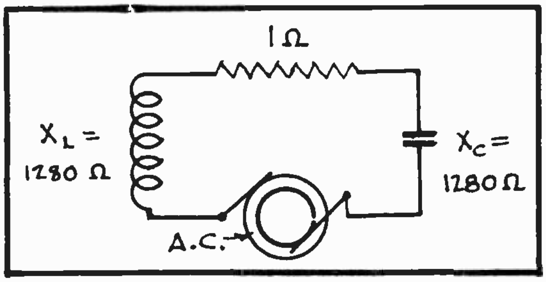


FIG. 4
Series Resonance.

A little earlier in this lesson, you were told that the impedance of a circuit containing resistance, inductance and capacity could be calculated with the formula as follows: $Z = \sqrt{R^2 + X^2}$, in which "X" is the net reactance of the circuit or the arithmetical difference between the capacitive reactance and inductive reactance of the circuit. Consequently, this same formula could be written as $Z = \sqrt{R^2 + (X_C - X_L)^2}$. Now by looking at this latter formula, its is perfectly obvious that if the circuit conditions are such that the inductive reactance at some given frequency is exactly equal to the capacitive reactance at this same frequency, then the arithmetical difference between them or the net reactance, in other words, would be equal to zero (0).

THIS BEING THE CASE, IT IS CLEAR THAT THE IMPEDANCE OF THE CIRCUIT UNDER THESE CONDITIONS WOULD BE EQUAL TO ITS D.C. RESISTANCE. THIS WOULD BE THE LEAST POSSIBLE OPPOSITION, WHICH A CIRCUIT COULD OFFER AN A.C. CURRENT FLOW AND THIS IS THE CONDITION OF RESONANCE. THAT IS TO SAY, AT RESONANCE, THE TOTAL OPPOSITION TO THE CURRENT FLOW IS SIMPLY EQUAL TO THE CIRCUIT'S D.C. RESISTANCE, OR OHMIC RESISTANCE, AND THEREFORE, THE MAXIMUM CURRENT CAN FLOW THROUGH IT.

SO THAT YOU WILL GAIN A STILL CLEARER UNDERSTANDING OF THE RESONANCE CONDITION, LET US LOOK CAREFULLY AT FIG. 4. HERE WE HAVE A COIL AND CONDENSER CONNECTED IN SERIES ACROSS AN A.C. SOURCE OF E.M.F. AND WE SHALL CONSIDER THIS CIRCUIT AS HAVING A RESISTANCE OF 1 OHM, WHICH WE HAVE PICTURED SEPARATELY IN FIG. 4. NOW THEN, NOTE CAREFULLY THAT THE INDUCTIVE REACTANCE OF THE COIL TOWARD THE FREQUENCY BEING HANDLED IS 1280 OHMS AND THE CONDENSER OFFERS A CAPACITIVE REACTANCE OF 1280 OHMS. THE IMPEDANCE OF THE CIRCUIT AT THIS TIME IS $Z=\sqrt{R^2+(X_C - X_L)^2}=\sqrt{R^2+(0)^2}=\sqrt{R^2}=\sqrt{1^2}=1$ OHM. THUS YOU WILL SEE THAT AT RESONANCE, THE ONLY OPPOSITION OFFERED THE CURRENT FLOW IS THE OHMIC RESISTANCE OF THE CIRCUIT. NATURALLY, THIS CIRCUIT IS NOW EQUIVALENT TO A PURE RESISTANCE CIRCUIT AND THEREFORE, THERE WILL BE NO PHASE DIFFERENCE BETWEEN THE VOLTAGE AND CURRENT WHICH ARE PRESENT IN THE CIRCUIT AT THIS TIME.

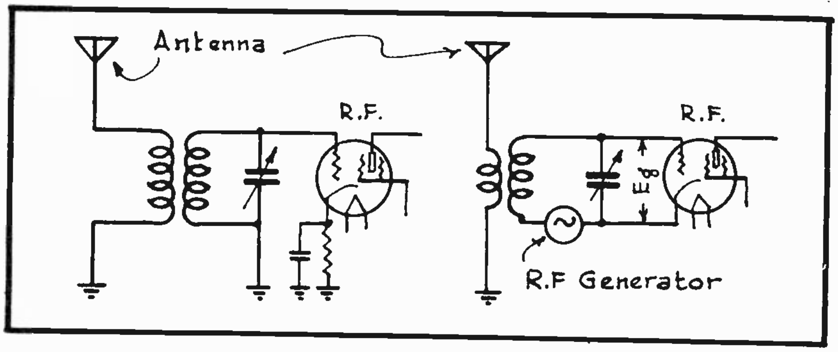


FIG. 5
Example of a Series Resonance Circuit.

SHOULD THE FREQUENCY OF THE CURRENT FLOW THROUGH THIS CIRCUIT REMAIN CONSTANT, THEN YOU WOULD FIND THAT IF EITHER THE INDUCTIVE OR CAPACITIVE VALUES SHOULD BE CHANGED, THEN THESE OPPOSITE REACTANCES WOULD NO LONGER NEUTRALIZE EACHOTHER TO GIVE A NET REACTANCE VALUE OF ZERO AND THEREFORE, THE CIRCUIT WOULD NO LONGER BE RESONANT TO THE GIVEN FREQUENCY. THIS, OF COURSE, IS THE WHOLE PRINCIPLE OF TUNING, FOR IN RADIO RECEIVERS, WE GENERALLY VARY THE CAPACITY OF THE TUNING CONDENSER AND WHENEVER THIS CONDENSER IS ADJUSTED TO THE POSITION WHERE ITS CAPACITY CAUSES ITS CAPACITIVE REACTANCE TO BE EQUAL TO THE INDUCTIVE REACTANCE OF THE COIL FOR A GIVEN FREQUENCY, THEN THE CIRCUIT WILL BE TUNED OR RESONANT TO THAT SAME FREQUENCY.

CALCULATING THE RESONANT FREQUENCY

THE THING WHICH YOU HAVE NO DOUBT BEEN WONDERING ABOUT FOR SOMETIME IS TO WHAT FREQUENCY A GIVEN CONDENSER AND INDUCTANCE COMBINATION WILL RESONATE. THIS PROBLEM IS QUITE SIMPLE, HOWEVER, BECAUSE A HANDY FORMULA AGAIN COMES TO OUR ASSISTANCE. THIS FORMULA IS AS FOLLOWS: $f=\frac{1}{2\pi\sqrt{LC}}$ WHERE:

f = FREQUENCY IN CYCLES PER SECOND AT RESONANCE
π = THE CONSTANT 3.1416
L = INDUCTANCE IN HENRIES AT RESONANCE
C = CAPACITY IN FARADS AT RESONANCE.

IN CASE THE PROBLEM, WHICH YOU ARE SOLVING, HAS THE INDUCTANCE EXPRESSED IN MICHROHENRIES AND THE CAPACITY IN MICROFARADS, THEN YOU CAN USE THE FOLLOWING FORMULA: $f = \frac{159,000}{\sqrt{LC}}$ WHERE:

f = FREQUENCY IN CYCLES PER SECOND AT RESONANCE
L = INDUCTANCE IN MICROHENRIES AT RESONANCE
C = CAPACITY IN MICROFARADS AT RESONANCE

TO ILLUSTRATE THE USE OF THIS LATTER FORMULA, LET US SUPPOSE THAT WE WISH TO KNOW TO WHAT FREQUENCY A CAPACITY OF .00035 MFD. AND A 300 MICROHENRY INDUCTANCE WILL RESONATE.

THE FORMULA IS: $f = \frac{159,000}{\sqrt{LC}}$ AND SUBSTITUTING OUR VALUES INTO THIS FORMULA, WE HAVE $f = \frac{159,000}{\sqrt{300 \times .00035}}$ WHENCE $f = \frac{159,000}{.324} = 500,000$ CYCLES (APPROXIMATELY). THAT IS, 500 KC.

NOW LET US SEE HOW THE FORMULA $f = \frac{1}{2\pi \sqrt{LC}}$ CAN BE USED. TO ILLUSTRATE THIS, LET US SUPPOSE THAT A 30 HENRY CHOKE COIL IS CONNECTED IN SERIES WITH A 2 MFD. CONDENSER SO AS TO FORM A RESONANT CIRCUIT. IN THIS CASE, THE VALUE 2 MFD. WILL HAVE TO BE CHANGED TO FARADS, THUS BECOMING .000002 FARADS. WE THEN HAVE $f = \frac{1}{6.28 \sqrt{30 \times .000002}}$ WHENCE $f = \frac{1}{6.28 \times .0077} = 20.6$ CYCLES. FREQUENTLY YOU WILL FIND THE GREEK LETTER OMEGA (ω) USED TO INDICATE THE VALUE OF $2\pi f$ IN THIS FORMULA.

IN DESIGN WORK, YOU WILL FIND THESE CALCULATIONS TO BE STILL SIMPLER BECAUSE VARIOUS TABLES ARE AVAILABLE SO AS TO REDUCE THE AMOUNT OF REQUIRED COMPUTATION. YOU WILL FIND THESE HANDY TABLES IN FOLLOWING LESSONS.

A SERIES RESONANT CIRCUIT

FIG. 5 SHOWS YOU A PRACTICAL EXAMPLE OF A SERIES RESONANT CIRCUIT AS USED IN THE TUNED R.F. STAGE OF A RADIO RECEIVER. THE ACTUAL RECEIVER CIRCUIT IS SHOWN AT THE LEFT OF THIS ILLUSTRATION WHILE THAT AT THE RIGHT IS ITS ELECTRICAL EQUIVALENT FOR EXPLANATORY PURPOSES.

A GREAT MANY PEOPLE CONSIDER THIS TYPE OF A TUNED CIRCUIT AS BEING A PARALLEL RESONANT CIRCUIT BECAUSE THE TUNING CONDENSER IS CONNECTED IN PARALLEL OR SHUNTED ACROSS THE ENDS OF THE COIL. THUS IT IS TRUE THAT AS FAR AS THESE TWO INDIVIDUAL PARTS OF THE CIRCUIT ARE CONCERNED, THEY ARE ACTUALLY CONNECTED IN PARALLEL WITH RESPECT TO EACHOTHER BUT THERE IS STILL ANOTHER PART WHICH EXISTS IN THIS CIRCUIT WHICH IS OVERLOOKED BY MANY PEOPLE AND THAT IS THAT WITH SIGNAL VOLTAGES IMPRESSED UPON THE CIRCUIT, WE HAVE THE EFFECT OF A SMALL HIGH FREQUENCY OR R.F. GENERATOR, WHICH IS CONNECTED IN THIS TUNED CIRCUIT AS ILLUSTRATED IN THE DIAGRAM AT THE RIGHT OF FIG. 5. ALTHOUGH THIS GENERATOR IS NOT PRESENT IN THIS CIRCUIT IN A PHYSICAL SENSE, YET ITS EFFECTS ARE NEVERTHELESS PRESENT DUE TO THE FACT THAT THESE HIGH FREQUENCY CURRENTS ARE INDUCED INTO THE

TUNED CIRCUIT BY MEANS OF THE TRANSFORMER ACTION BETWEEN THE ANTENNA CIRCUIT AND THE TUNED CIRCUIT.

WHENEVER, AN E.M.F. IS INDUCED IN A CIRCUIT AS IN THIS CASE, THE SOURCE OF E.M.F. CAN BE CONSIDERED AS BEING CONNECTED IN SERIES WITH THE TUNED CIRCUIT AS ILLUSTRATED AT THE RIGHT OF FIG. 5. THUS YOU SEE, THAT HERE WE HAVE A SERIES RESONANT CIRCUIT BECAUSE THE SECONDARY WINDING OF THE R.F. TRANSFORMER, THE TUNING CONDENSER AND THE SOURCE OF E.M.F. ARE ALL CONNECTED IN SERIES WITH ONE ANOTHER.

IF THE TUNED CIRCUIT AT THE RIGHT OF FIG. 5 IS TUNED TO RESONANCE WITH LET US SAY A SIGNAL FREQUENCY OF 600 KC., THEN THE IMPEDANCE OF THIS CIRCUIT BECOMES EQUAL TO THE OHMIC RESISTANCE OF THIS CIRCUIT, WHICH WE WILL ASSUME TO BE 10 OHMS. IF THE SIGNAL VOLTAGE INDUCED INTO THE SECONDARY WINDING OF THE FIRST R.F. TRANSFORMER IS 2 MILLIVOLTS (.002 VOLTS) THEN THE CURRENT CAUSED TO FLOW THROUGH THE RESONANT CIRCUIT WILL BE $I = E/R = \frac{.002}{10} = .0002$ AMPERES OR .2 MILLIAMPERE. IF THE CONDENSER AT THIS FREQUENCY SETTING HAS A REACTANCE OF 1326.2 OHMS, THEN THE VOLTAGE DEVELOPED ACROSS ITS PLATES BY THE CURRENT FLOW OF .0002 AMPS. THROUGH IT WILL BE $E = I \times R = .0002 \times 1326.2 = .265$ VOLTS. THIS WILL BE THE VOLTAGE "EG" IN THE ILLUSTRATION AT THE RIGHT OF FIG.5, WHICH IS APPLIED ACROSS THE GRID CIRCUIT OF THE FIRST R.F. TUBE. THUS YOU CAN NOW SEE JUST EXACTLY HOW THE VOLTAGE IS PRODUCED, IN ORDER TO OPERATE THE GRID OF A RADIO TUBE. ALSO NOTE THE VOLTAGE INCREASE FOR GRID APPLICATION AS MADE POSSIBLE BY THIS TUNED CIRCUIT.

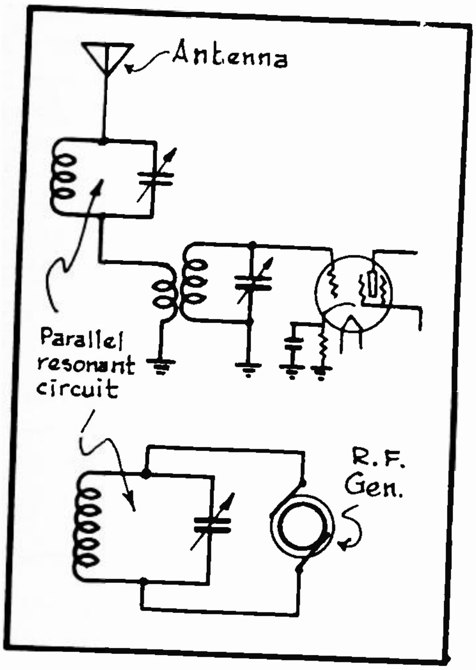


FIG. 6
The Parallel Resonant Circuit.

SINCE AT RESONANCE, THE IMPEDANCE OF THIS SERIES RESONANT CIRCUIT BECOMES EQUAL TO ITS OHMIC RESISTANCE, IT IS OBVIOUS THAT IN ORDER TO HAVE A SENSITIVE CIRCUIT, IT IS NECESSARY TO KEEP THIS OHMIC RESISTANCE DOWN TO AS LOW A VALUE AS PRACTICAL. HERE IS WHERE CAREFUL COIL DESIGN BECOMES SUCH AN IMPORTANT ITEM IN SCIENTIFIC RADIO CONSTRUCTION, FOR IT IS QUITE A PROBLEM TO HAVE INDUCTANCE WITH LITTLE RESISTANCE BECAUSE THE RESISTANCE INCREASES AS MORE TURNS ARE ADDED TO INCREASE A GIVEN COIL'S INDUCTANCE.

CALCULATING THE RESONANT WAVELENGTH

BESIDES THE FORMULA EXPRESSING THE RELATION BETWEEN THE INDUCTANCE AND CAPACITY OF A CIRCUIT FOR A GIVEN FREQUENCY, WE HAVE ANOTHER HANDY FORMULA BY MEANS OF WHICH WE CAN READILY CALCULATE THE WAVELENGTH IN METERS TO WHICH A GIVEN INDUCTANCE AND CAPACITY COMBINATION WILL RESONATE. THIS FORMULA IS AS FOLLOWS:

$$\text{WAVE LENGTH IN METERS} = 1885 \sqrt{\text{INDUCTANCE IN MICROHENRIES} \times \text{CAPACITY IN MFD.}}$$

Generally you will find this formula written as: $\lambda = 1885\sqrt{LC}$, where λ (the Greek letter "Lambda) is the symbol for wavelength, "L", the symbol for inductance and "C" the symbol for capacity.

To illustrate the use of this formula, let us suppose that we wish to know to what wavelength a 300 microhenry inductance and a .00035 mfd. condenser will tune. Substituting these values into our formula, we have : $\lambda = 1885\sqrt{300 \times .00035}$ whence $\lambda = 1885\sqrt{.1050}$; $\lambda = 1885 \times .324 = 610$ meters.

PARALLEL RESONANT CIRCUITS

Now let us compare a PARALLEL RESONANT circuit with a series resonant circuit and note the differences between them. A parallel resonant circuit is illustrated for you in Fig. 6. In the upper illustration, you will see the parallel resonant circuit applied as a wave-trap in the antenna circuit of a receiver. Observe that the condenser in this case is also shunted across the ends of the coil, the same as in the series resonant circuit, which we considered a few moments ago. The big difference, however, is that in Fig. 6, the signal voltage is applied ACROSS the tuned circuit. In other words, you can consider this circuit as pictured in the lower portion of Fig. 6, where the source of E.M.F. or signal energy can be thought of as a small R.F. generator, which is connected across the circuit as illustrated.

In the case of a parallel resonant circuit such as this, we have an action altogether different from that experienced with the series resonant circuit, for when the parallel resonant circuit is tuned to resonance with some given frequency, the impedance of the circuit towards this frequency becomes MAXIMUM. In other words, this type of resonant circuit tends to reject the resonant frequency and for this reason it can be used successfully as a wave or frequency trap.

Since the characteristics of a parallel resonant circuit are such that its impedance is maximum or greatest at resonance, it is no more but natural that the least possible current flows through the parallel resonant circuit at the resonance frequency.

It is interesting to note, however, that our same two resonance formula apply equally well to both series and parallel resonant circuits provided that the ohmic resistance of the circuit is quite low. This, of course, is the general case in circuits where such connections are used. Thus for parallel resonant circuits, we also have that $f = \dfrac{1}{6.28\sqrt{LC}}$;

that $f = \dfrac{159,000}{\sqrt{L \text{ in microhenries} \times C \text{ in mfd.}}}$ and that $\lambda = 1885\sqrt{LC}$.

POWER IN A.C. CIRCUITS

Now let us consider the POWER in A.C. circuits. From your earlier lessons, you will recall that in order to calculate the power consumed by a circuit through which a direct current flowed, it was only necessary for us to multiply the applied voltage by the current flow in the circuit and the result was the power in Watts. In the case of an A.C. circuit containing resistance only and no inductance or capacity, we can figure the power consumed by the circuit in the same way. That is, all that we have to

DO IS TO MULTIPLY THE EFFECTIVE VOLTAGE BY THE EFFECTIVE CURRENT AND THE RESULT WILL BE THE POWER IN WATTS. THIS POWER CONSUMED BY THIS PURE RESISTIVE CIRCUIT WILL BE DISSIPATED IN THE FORM OF HEAT.

IN A.C. CIRCUITS CONTAINING INDUCTANCE OR CAPACITY OR BOTH, WE HAVE AN ENTIRELY DIFFERENT CONDITION TO FACE. FOR EXAMPLE, WHEN A.C. IS PASSED THROUGH AN INDUCTANCE, SOME POWER IS EXPENDED IN ORDER TO ESTABLISH A MAGNETIC FIELD BUT AS THIS FIELD COLLAPSES AGAIN, POWER IS RETURNED TO THE CIRCUIT. WE HAVE A SIMILAR CONDITION IN THE CASE WHERE A CONDENSER ALTERNATELY CHARGES AND DISCHARGES AS AN ALTERNATING CURRENT IS PASSED THROUGH IT. THE ONLY POWER ACTUALLY USED UP BY EITHER OF THESE TWO DEVICES IS THAT WHICH IS DISSIPATED AS HEAT BY THE OHMIC RESISTANCE WHICH THEY CONTAIN.

SINCE THE OHMIC RESISTANCE IS GENERALLY VERY SMALL AS COMPARED TO THE REACTANCE OF SUCH CIRCUITS, WE FIND THAT MUCH MORE POWER IS RETURNED TO THE CIRCUIT THAN IS DISSIPATED AS HEAT. BECAUSE OF THIS CONDITION, IT IS CLEAR THAT IN SUCH CIRCUITS, WE CANNOT MULTIPLY THE EFFECTIVE VOLTAGE BY THE EFFECTIVE CURRENT AND OBTAIN THE TRUE POWER VALUE. THIS CALCULATION GIVES US WHAT IS KNOWN AS THE "APPARENT POWER" OR AS IT IS SOMETIMES EXPRESSED "VOLT-AMPERES". THAT IS, IF WE SHOULD CONNECT A VOLTMETER AND AMMETER TO SUCH A CIRCUIT AND FIND THE VOLTMETER READING TO BE 100 VOLTS AND THE AMMETER READING 3 AMPERES, THE "APPARENT POWER" WOULD BE 300 VOLT-AMPERES AND NOT 300 WATTS.

THE "POWER FACTOR"

TO FIND THE TRUE POWER OF SUCH A CIRCUIT, WE HAVE TO MULTIPLY THE APPARENT POWER BY A NUMBER WHICH WE CALL THE "POWER FACTOR." THIS POWER FACTOR IS DEPENDENT UPON THE ANGLE OF LEAD OR LAG BETWEEN THE VOLTAGE AND CURRENT OF THE CIRCUIT. THUS THE TRUE POWER OR WATTS = "VOLT-AMPERES" X POWER FACTOR AND IT IS EQUALLY TRUE THAT THE POWER FACTOR $= \dfrac{\text{WATTS}}{\text{"VOLT-AMPERES"}}$.

IN OTHER WORDS, IF THE POWER IN THE CIRCUIT IS MEASURED BY MEANS OF A SPECIAL WATTMETER AND THE APPARENT POWER IS CALCULATED BY MULTIPLYING TOGETHER A VOLTMETER AND AMMETER READING OF THE CIRCUIT, THEN THE POWER FACTOR WILL BE EQUAL TO THE WATTMETER READING DIVIDED BY THE VOLT-AMPERE PRODUCT.

FOR GENERAL RADIO USE, YOU WILL ALSO FIND THAT THE POWER FACTOR OF A CIRCUIT IS EQUAL TO THE OHMIC RESISTANCE OF THE CIRCUIT DIVIDED BY THE IMPEDANCE IN OHMS. THAT IS, POWER FACTOR $= \dfrac{\text{RESISTANCE IN OHMS}}{\text{IMPEDANCE IN OHMS}}$. THUS IF IF THE RESISTANCE OF THE CIRCUIT IS 10 OHMS AND THE CIRCUITS IMPEDANCE IS 25 OHMS, THEN THE POWER FACTOR OF THE CIRCUIT WILL BE EQUAL TO $\dfrac{10}{25} = .4$

THE POWER FACTOR OF A PURE RESISTANCE CIRCUIT IS 1 AND FOR ANY A.C. CIRCUIT CONTAINING INDUCTANCE, CAPACITY OR BOTH IN ADDITION TO SOME RESISTANCE, THE POWER FACTOR WILL BE LESS THAN 1. THAT IS, SOMEWHERES BETWEEN 0 AND 1 AND THE GENERAL PRACTICE IS TO EXPRESS IT AS A DECIMAL, SUCH AS .4 ; .7 ; .8 ETC. THEREFORE, SINCE THE APPARENT POWER MUST BE MULTIPLIED BY SOME FACTOR LESS THAN 1, IN ORDER TO GIVE THE TRUE POWER, IT IS OBVIOUS THAT THE TRUE POWER OR POWER ACTUALLY USED BY THE CIRCUIT WILL BE LESS THAN THE APPARENT POWER.

SINCE YOU HAVE LEARNED THAT THE IMPEDANCE OF A RESONANT CIRCUIT BE-

COMES EQUAL TO ITS OHMIC RESISTANCE AT THE RESONANT FREQUENCY, YOU WILL ALSO READILY BE AWARE OF THE FACT THAT THE POWER FACTOR OF SUCH A CIRCUIT AT RESONANCE IS ALSO 1.

RESONANCE CURVES

IN TECHNICAL LITERATURE PERTAINING TO RADIO, YOU WILL COME ACROSS VARIOUS TYPES OF CURVES WHICH ARE USED TO ILLUSTRATE THE PERFORMANCE OF DIFFERENT RADIO UNITS AND AS YOU PROCEED WITH YOUR STUDIES, YOU WILL BECOME ACQUAINTED WITH ALL OF THEM. AT THE PRESENT TIME, WE ARE GOING TO CONSIDER THE RESONANCE CURVES FOR SERIES TUNED CIRCUITS AND YOU WILL FIND THEM TO POINT OUT MANY IMPORTANT FACTS.

LET US SUPPOSE, FOR EXAMPLE, THAT WE APPLY A SIGNAL OF GIVEN VOLTAGE ACROSS A SERIES TUNED CIRCUIT AND AT THE SAME TIME MEASURE THE CURRENT FLOW THROUGH THIS CIRCUIT. WE WOULD FIND THAT WITH THE SIGNAL VOLTAGE VALUE BEING CONSTANT AND ITS FREQUENCY VARIED IN BOTH DIRECTIONS FROM THE FREQUENCY TO WHICH THIS PARTICULAR CIRCUIT IS TUNED, THE CURRENT FLOW THROUGH THE TUNED CIRCUIT WOULD BE MAXIMUM AT THE RESONANT FREQUENCY AND THEN DROP OFF QUITE RAPIDLY BOTH SIDES OF THE RESONANT FREQUENCY.

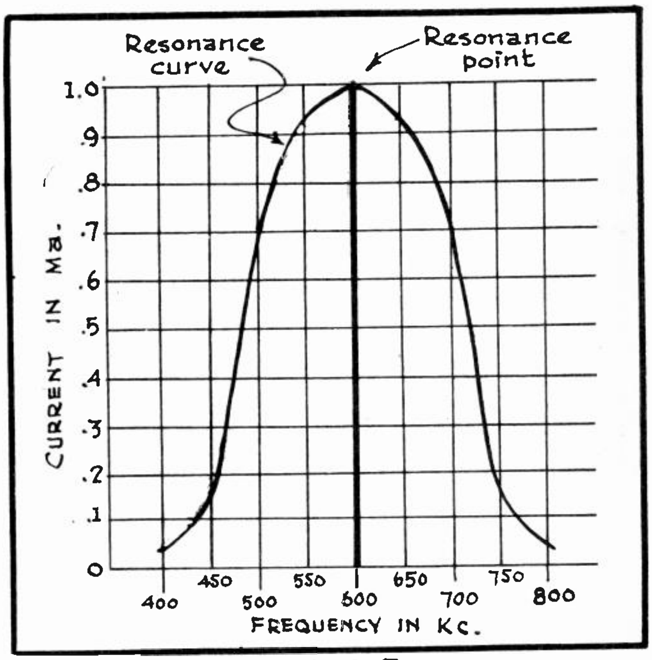


FIG. 7
The Resonance Curve.

FOR INSTANCE LET US ASSUME THAT THE RESONANT FREQUENCY IS 600 KC. AND THAT WITH A GIVEN SIGNAL VOLTAGE AT 600 KC., A CURRENT OF 1 MA. FLOWS THROUGH THE CIRCUIT. WE SHALL FURTHER ASSUME THAT THE CURRENT WITH THE DIFFERENT FREQUENCIES ABOVE RESONANCE IS AS FOLLOWS: .95 MA. AT 650 KC; .7 MA AT 700 KC; .15 MA. AT 750 KC.; .05 MA. AT 800 KC., WHEREAS BELOW THE RESONANT FREQUENCY, THE CURRENT VALUES ARE: .95 MA. AT 550 KC; .7 MA. AT 500 KC; .15 MA. AT 450 KC., AND .05 MA. AT 400 KC.

NOW THEN, PLOTTING THESE VALUES ON A PIECE OF GRAPH PAPER (PAPER MARKED OFF IN SQUARES) AND THEN DRAWING A CONTINUOUS LINE THROUGH THESE POINTS, WE WOULD OBTAIN A CURVE LIKE THAT ILLUSTRATED IN FIG. 7. WE CALL THIS A RESONANCE CURVE.

BY STUDYING FIG. 7, YOU WILL OBSERVE THAT THE RESONANCE CURVE REACHES ITS MAXIMUM HEIGHT AT THE RESONANT FREQUENCY AND THEN DROPS OFF RAPIDLY TOWARD EACH SIDE OF THE RESONANT FREQUENCY. HOWEVER, AS WE GET FARTHER AWAY FROM RESONANCE, THE SLOPE OF THE CURVE BECOMES MORE GRADUAL AND IT COMMENCES TO FLARE OR BROADEN OUT CONSIDERABLY.

FOR RECEIVERS WHICH ARE VERY SELECTIVE, THIS RESONANCE CURVE IS

QUITE NARROW AND ITS SIDES DROP OFF ABRUPTLY TOWARDS EACH SIDE OF THE RESONANT FREQUENCY. THE CURVE THUS SHOWS THE CURRENT TO BE MAXIMUM AT RESONANCE WHILE AT THE SAME TIME BEING REDUCED MATERIALLY AT FREQUENCIES ONLY SLIGHTLY REMOVED FROM THE RESONANT FREQUENCY. IT IS THIS FACT WHICH DETERMINES THE SHARPNESS OF TUNING FOR ANY PARTICULAR CIRCUIT.

ANOTHER IMPORTANT THING TO REMEMBER REGARDING RESONANCE CURVES IS THAT THE D.C. RESISTANCE OF THE TUNED CIRCUIT IN A LARGE MEASURE DETERMINES THE BROADNESS OF THE RESONANCE CURVE. FOR INSTANCE, IN FIG. 8, WE HAVE THREE INDIVIDUAL CURVES, EACH FOR A TUNED CIRCUIT OF DIFFERENT D.C. RESISTANCE AND ALL DRAWN ON THE SAME GRAPH.

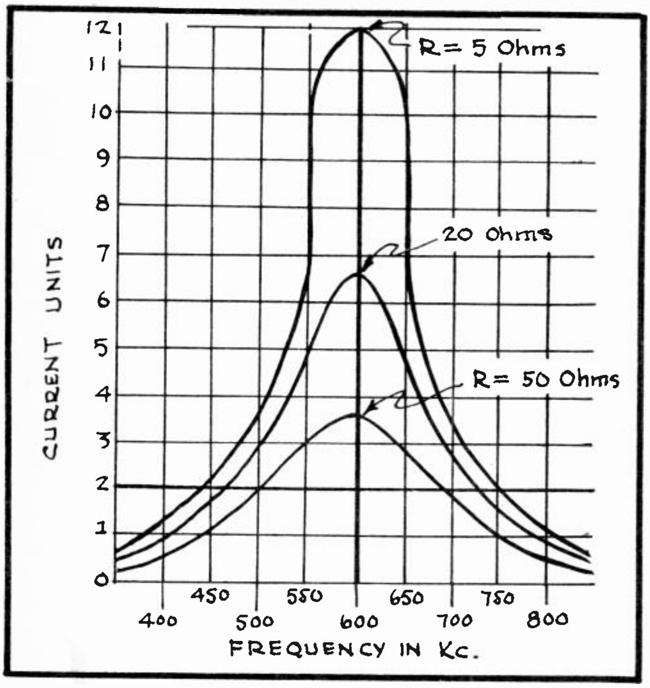


FIG. 8
Effect of Resistance Upon Tuning.

NOTICE ESPECIALLY IN FIG. 8 THAT THE CURRENT AT THE RESONANT FREQUENCY OF 600 KC. IS GREATEST FOR THE TUNED CIRCUIT HAVING THE LEAST D.C. RESISTANCE. ALSO OBSERVE THAT THE SIDES OR SLOPE OF THE CURVE IS STEEPER WHEN THE D.C. RESISTANCE OF THE TUNED CIRCUIT IS LESS AND THAT THE GREATER THE D.C. RESISTANCE OF THE TUNED CIRCUIT, THE BROADER WILL BE THE RESONANCE CURVE.

BY CAREFULLY STUDYING THESE COMPARISONS IN FIG. 8, YOU WILL QUICKLY REALIZE THAT TO HAVE A SHARP TUNING AND SENSITIVE CIRCUIT, ITS D.C. RESISTANCE MUST BE KEPT DOWN TO AS LOW A VALUE AS POSSIBLE.

CHOICE OF BYPASS CONDENSERS

THE CONDENSER CAPACITY RATING TO USE FOR BYPASSING PURPOSES IS DETERMINED BY THE LOWEST FREQUENCY ENCOUNTERED IN THAT THE CAPACITIVE REACTANCE OF THE CONDENSER DECREASES AS THE FREQUENCY INCREASES. THIS NATURALLY MEANS THAT A CONDENSER CAPACITY WHICH IS SATISFACTORY FOR THE LOWEST FREQUENCY BEING HANDLED WILL BE EVEN MORE EFFECTIVE WHEN SUBJECTED TO HIGHER FREQUENCIES.

IN PRACTICE, IT IS GENERALLY THE CUSTOM TO CHOOSE R.F. BYPASS CONDENSERS WHICH HAVE A CAPACITY RATING OF SUCH VALUE THAT ITS CAPACITIVE REACTANCE AT THE LOWEST FREQUENCY BEING HANDLED (500 KC. IN THE CASE OF BROADCAST RECEIVERS) IS LESS THAN FROM ONE-ONE HUNDREDTH TO ONE-ONE THOUSANDTH THAT OF THE RESISTOR ACROSS WHICH IT IS CONNECTED. FOR INSTANCE, IF A CONDENSER IS TO BE USED TO BYPASS R.F. ENERGY AROUND A 2000 OHM RESISTOR IN A BROADCAST RECEIVER AS ILLUSTRATED IN FIG. 9, THEN IN ORDER THAT THIS PARTICULAR BYPASS CONDENSER MAY HAVE A CAPACITIVE REACTANCE EQUAL TO APPROXIMATELY ONE-ONE THOUSANDTH THAT OF THE 2000 OHM RESISTOR, ITS CAPACITIVE REACTANCE AT 500 KC. MUST BE $\frac{2000}{1000} = 2$ OHMS.

A .25 MFD. CONDENSER WILL HAVE A CAPACITIVE REACTANCE OF 1.28 OHMS AT 500 KC., WHILE A .1 MFD. CONDENSER WILL HAVE A CAPACITIVE REACTANCE OF 3.2 OHMS AT THIS SAME FREQUENCY. THE .25 MFD. CONDENSER WOULD THEREFORE BE THE PREFERABLE OF THESE TWO STANDARD SIZES WHICH COME CLOSEST TO OUR DESIRE VALUE.

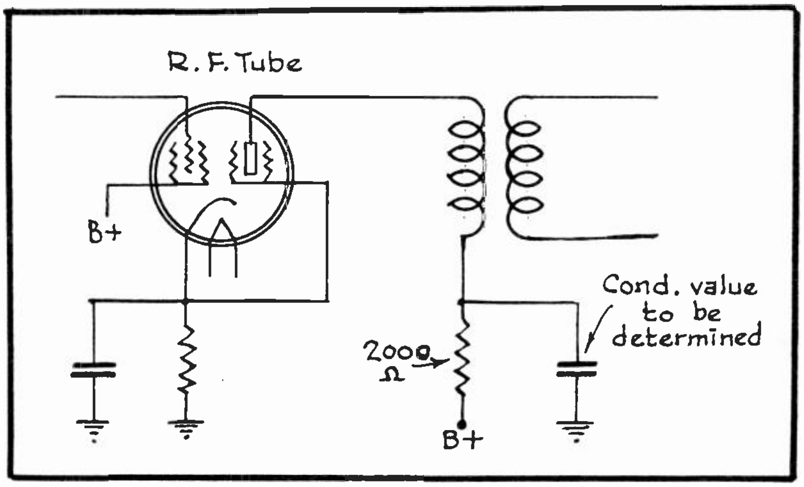


FIG. 9

Calculating the By-pass Condenser Value.

IN THE CASE OF BY PASS CONDENSERS WHICH ARE EXPECTED TO HANDLE AUDIO FREQUENCIES, THE GENERAL PRACTICE IS TO CHOOSE A CONDENSER WHOSE CAPACITY VALUE IS SUCH THAT ITS CAPACITIVE REACTANCE AT THE LOWEST FREQUENCY BEING HANDLED IS ABOUT 1/10 THE RESISTANCE VALUE OF THE RESISTOR WHICH IT BY-PASSES. THAT IS, IF A RESISTOR OF 2000 OHMS IN AN A.F. AMPLIFIER IS TO BE BYPASSED BY A CONDENSER AND THE LOWEST FREQUENCY BEING HANDLED IS 50 CYCLES, THEN THE CAPACITIVE REACTANCE OF THIS CONDENSER AT 50 CYCLES SHOULD BE ABOUT $\frac{2000}{10}$ OR 200 OHMS. THIS WOULD THEREFORE CALL FOR A CONDENSER HAVING A CAPACITY RATING OF ABOUT 16 MFD.

TABLE I OFFERS YOU A HANDY MEANS WHEREBY YOU CAN EASILY DETERMINE THE CAPACITIVE REACTANCE OF MOST POPULAR CONDENSER SIZES TO THE FREQUENCY LIMITS REQUIRED OF BYPASS CONDENSERS IN BOTH THE R.F. AND A.F. STAGES.

SINCE THE REACTANCE OF A CONDENSER IS INVERSELY PROPORTIONAL TO THE

TABLE I

CAP. IN MFDS	FREQUENCY IN CYCLES PER SECOND						
	Broadcast Radio Frequencies		Audio Frequencies		Power Supply Frequencies		
	500,000	1,500,000	50	10,000	25	60	120
	CAPACITIVE REACTANCE IN OHMS						
.00005	6,369.4	2,123.1	63,694.267	318,471	127,388,534	53,078,503	26,539,252
.0001	3,184.7	1,061.6	31,847,133	159,235	63,694,267	26,539,252	13,269,626
.00025	1,273,8	424.6	12,738,853	63,694	25,477,706	10,615,600	5,307,850
.0005	636.9	212.3	6,369.426	31,847	12,738,853	5,307,850	2,653,925
.001	318.5	106.2	3,184,713	15,924	6,369,427	2,653,925	1,326,963
.005	63.7	21.2	636,943	3,185	1,273,885	530,785	265,393
.01	31.8	10.6	318,471	1,592	636,943	265,393	132,696
.015	21.2	7.1	212,314	1,061	424,629	176,929	88,464
.02	15.9	5.3	159,235	796	318,471	132,697	66,348
.05	6.4	2.1	63,694	318	127,389	53,078	26,539
.1	3.2	1.1	31,847	159	63,694	26,539	13,270
.25	1.28	.42	12,739	64	25,478	10,616	5,308
.5	.64	.21	6,369	32	12,739	5,308	2,654
1.0	.32	.11	3,184	15.9	6,369	2,654	1,327
2.0	.16	.05	1,592	7.9	3,184	1,327	663
4.0	.08	.03	769	3.9	1,592	664	332
6.0	.05	.02	531	2.6	1,062	442	221
8.0	.04	.01	398	2.0	796	332	166
10.0	.03	.01	318	1.6	637	265	133
15.0	.02	.01	212	1.1	425	177	88

Reactances of Condensers of Standard Capacity at Commonly Used Frequencies.

FREQUENCY AND CAPACITY, DOUBLING THE CAPACITY OF THE CONDENSER WILL REDUCE THE REACTANCE BY ONE-HALF. THIS BEING TRUE, IT IS A SIMPLE MATTER TO CALCULATE MENTALLY THE REACTANCE OF ANY CONDENSER NOT GIVEN IN TABLE I AND AT PRACTICALLY ANY FREQUENCY, SIMPLY BY BASING ONE'S CALCULATIONS UPON THE INFORMATION GIVEN IN TABLE I.

THESE PAST FEW LESSONS ON THE "ESSENTIALS OF A.C. CIRCUITS" HAVE PROVIDED YOU WITH A GREAT DEAL MORE VALUABLE RADIO INFORMATION. EVEN IF THESE LESSONS APPEAR SOMEWHAT DIFFICULT TO YOU, REMEMBER THAT THEY ARE IMPORTANT AND THAT IT IS NOT NECESSARY FOR YOU TO MEMORIZE THESE VARIOUS FORMULAE. THE MAIN THING IS TO KNOW HOW TO USE THEM AND WHERE TO FIND THEM WHEN YOU HAVE NEED FOR THEM AT SOME FUTURE TIME.

YOU WILL SOON REALIZE THAT YOU ARE LEARNING FAR MORE THAN THE AVERAGE RADIO MAN KNOWS AND CONSEQUENTLY, YOU WILL BE FORTIFIED WITH THAT KNOWLEDGE, WHICH WILL WIN FOR YOU A HIGH POSITION IN THIS MARVELOUS RADIO INDUSTRY.

EXAMINATION QUESTIONS

LESSON NO. 41

1. - IF A CONDENSER OF 8 MFD, AN INDUCTANCE OF 30 HENRIES AND A RESISTANCE OF 1000 OHMS ARE ALL CONNECTED IN SERIES, WHAT WILL BE THE IMPEDANCE WHICH THIS CIRCUIT WILL OFFER TOWARDS A 60 CYCLE CURRENT?

2. - HOW MUCH CURRENT WILL FLOW THROUGH THE CIRCUIT DESCRIBED IN QUESTION #1? THE APPLIED VOLTAGE IS 100 VOLTS.

3. - WHAT WILL BE THE VOLTAGE DROP ACROSS THE CONDENSER, INDUCTANCE AND RESISTOR INDIVIDUALLY OF THIS SAME SERIES CIRCUIT?

4. - EXPLAIN THE CONDITION OF RESONANCE IN A TUNED CIRCUIT IN TERMS OF INDUCTIVE REACTANCE, CAPACITIVE REACTANCE AND RESISTANCE.

5. - IF A CONDENSER OF .00025 MFD. IS CONNECTED IN SERIES WITH AN INDUCTANCE OF 250 MICROHENRIES, TO WHAT FREQUENCY WILL THIS CIRCUIT RESONATE?

6. - EXPLAIN THE DIFFERENCE BETWEEN A SERIES RESONANT CIRCUIT AND A PARALLEL RESONANT CIRCUIT?

7. - IF A CONDENSER OF 140 MMFD. AND AN INDUCTANCE OF 100 MICROHENRIES ARE CONNECTED IN SERIES, TO WHAT WAVELENGTH WILL THIS CIRCUIT RESONATE?

8. - WHAT IS MEANT BY THE TERM POWER FACTOR?

9. - DESCRIBE A RESONANCE CURVE FOR A SERIES TUNED CIRCUIT.

10. - HOW DOES THE D.C. RESISTANCE OF A SERIES TUNED CIRCUIT AFFECT THE RESONANCE CURVE AND SELECTIVITY OF THE RECEIVER?

RADIO - TELEVISION

Practical • J. A. ROSENKRANZ, Pres. • Training

NATIONAL SCHOOLS

Established 1905

Los Angeles, California

LESSON NO. 42

• R. F. COIL DESIGN •

You have heard a great deal about R.F. amplifiers so far in your studies and no doubt you are by this time beginning to realize what a tremendous study this radio subject alone requires. The R.F. amplifier is an exceedingly important part of the radio receiver, for the receiver's operating quality depends greatly upon the proper functioning of this portion of the circuit.

Only a few years ago, the construction of this section of the receiver was very crude, primarily so because comparatively little was known about radio frequencies. Our present R.F. stages, however, are built with utmost care and it has only been through the constant experiments of studious radio men that this portion of the receiver has reached its present state of development. Still, there is room for improvement and as time passes, more and more of the present problems will be successfully solved, so that it is really difficult to prophesy just what remarkable achievements will be witnessed in the near future. You should be mighty happy that you have entered the field of Radio at THIS TIME, during which such tremendous progress is being made.

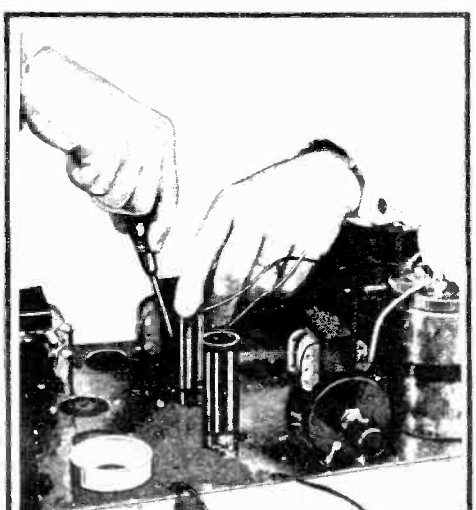


FIG. 1

Mounting the R.F. Transformer.

In preparing you to become a Trained Radio Man, it is our earnest desire that you learn just exactly HOW and WHY certain radio jobs must be done in a certain way. Therefore, in our present discussion of R.F. amplifier design, you will find that instead of just giving you a list of specifications to follow for constructing various coils etc., we are going to show you just exactly WHY these different specifications are suitable. All of this information is going to be of great value to you because it will enable you to intell-

IGENTLY LAY OUT WORK THROUGH YOUR OWN THOUGHTS AND EFFORTS INSTEAD OF RELYING SOLELY UPON THE WORK LAID OUT BY OTHERS.

THE R.F. TRANSFORMER

FIRST OF ALL, LET US CONSIDER THE R.F. TRANSFORMER. ALTHOUGH THESE UNITS CAN BE BOUGHT READY MADE AT A PRICE WHICH IS QUITE REASONABLE, YET THERE ARE TIMES WHEN YOU WILL WISH TO CONSTRUCT THEM ACCORDING TO YOUR OWN IDEAS. FURTHERMORE, IT IS PART OF YOUR TRAINING TO LEARN HOW SUCH COIL DESIGNS ARE WORKED OUT.

AS YOU ALREADY KNOW, THE SECONDARY WINDING OF THE R.F. TRANSFORMER IS GENERALLY CONNECTED ACROSS A TUNING CONDENSER AS SHOWN IN FIG.2 AND THE FREQUENCY TO WHICH THIS TUNED CIRCUIT WILL RESONATE, IS DEPENDENT UPON THE INDUCTANCE OF THIS WINDING AND THE CAPACITY OF THE CONDENSER WITH WHICH IT IS USED.

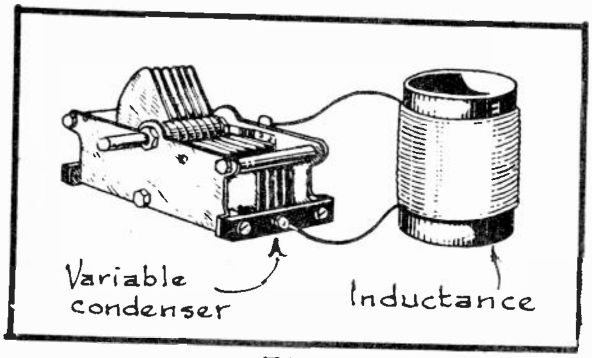


FIG. 2
The Tuned Circuit.

IN ORDER TO ENABLE THIS CIRCUIT TO TUNE OVER A GIVEN RANGE OR BAND OF FREQUENCIES, IT IS OF COURSE NECESSARY TO EITHER VARY THE INDUCTIVE, CAPACITIVE OR BOTH VALUES BUT THE MOST COMMON PRACTICE IS TO USE A FIXED INDUCTANCE AND TO VARY THE CAPACITY WITH THE AID OF A VARIABLE CONDENSER.

ALTHOUGH WE HAVE TOLD YOU CONSIDERABLE ABOUT INDUCTANCE AND ITS VARIOUS EFFECTS AND ACTIONS, YET WE HAVE AS YET NOT TOLD YOU JUST EXACTLY HOW TO GO ABOUT THE TASK OF CALCULATING INDUCTANCE. IN OUR PRESENT DISCUSSION OF R.F. TRANSFORMERS, YOU WILL HAVE NEED FOR THIS INFORMATION AND SO WITHOUT FURTHER DELAY, WE SHALL INVESTIGATE THIS MATTER THOROUGHLY.

CALCULATING THE INDUCTANCE OF SOLENOID TYPE WINDINGS

AT THE PRESENT TIME, TUNING INDUCTANCES OF THE CYLINDRICAL SHAPE SHOWN IN FIG. 2 ARE MOST EXTENSIVELY USED. THE REASON FOR THIS BEING THAT IT HAS BEEN PROVEN TO BE THE MOST EFFICIENT, AS WELL AS THE SIMPLEST TO CONSTRUCT. WE CALL SUCH TUBULAR SHAPED COILS, "SOLENOID COILS OR WINDINGS."

A VERY HANDY FORMULA IS AT OUR DISPOSAL FOR CALCULATING THE INDUCTANCE OF THIS TYPE OF WINDING AND THIS FORMULA IS AS FOLLOWS:

$$L = 0.0251\ D^2\ N\ N_0\ K.$$

THE LETTER "L" IN THIS FORMULA STANDS FOR THE INDUCTANCE EXPRESSED IN MICROHENRIES; THE NUMBER 0.0251 IS A CONSTANT; "D" STANDS FOR THE DIAMETER OF THE COIL IN INCHES; "N" SIGNIFIES THE TOTAL NUMBER OF TURNS; "N_0" IS THE NUMBER OF TURNS PER INCH ON THE WINDING AND "K" IS THE "CORRECTION FACTOR" FOR THE PARTICULAR COIL IN QUESTION. BY ALL MEANS, DON'T BECOME ALARMED WHEN CONFRONTED BY A FORMULA AS THIS BECAUSE IT IS HANDLED EASIER THAN ONE MIGHT AT FIRST SUPPOSE. THIS WILL BE EVIDENT FROM THE EXPLANATION

WHICH IS TO FOLLOW.

FINDING THE CORRECTION OR SHAPE FACTOR

THE COIL DIMENSIONS AS USED IN THIS FORMULA WILL PRESENT NO DIFFICULTY BUT NO DOUBT YOU ARE ALREADY WONDERING WHAT IS MEANT BY THE EXPRESSION "CORRECTION-FACTOR", WHICH IS REPRESENTED BY THE LETTER "K" IN THE FORMULA. THIS CORRECTION FACTOR IS OBTAINED FROM A TABLE, WHICH WE ARE GIVING YOU IN TABLE I AND THE VALUE OF K IS DIFFERENT FOR DIFFERENT SOLENOID COIL SHAPES. THIS VALUE IS ALSO SPOKEN OF AS THE COILS "SHAPE- FACTOR" BECAUSE IT IS DEPENDENT UPON THE RATIO OF THE COIL'S DIAMETER TO ITS LENGTH.

THE VALUE OF "K" TO CHOOSE FROM TABLE I IS DETERMINED AS FOLLOWS: FOR

TABLE I
VALUES OF "K" FOR INDUCTANCE FORMULA

DIAMETER / LENGTH	K	DIAMETER / LENGTH	K	DIAMETER / LENGTH	K
0.00	1.000	1.90	0.538	6.40	0.274
.05	.979	1.95	.532	6.60	.269
.10	.959	2.00	.526	6.80	.263
.15	.939	2.10	.518	7.00	.258
.20	.920	2.20	.503	7.20	.254
.25	.902	2.30	.492	7.40	.249
.30	.884	2.40	.482	7.60	.245
.35	.867	2.50	.472	7.80	.241
.40	.850	2.60	.463	8.00	.237
.45	.834	2.70	.454	8.50	.227
.50	.818	2.80	.445	9.00	.219
.55	.803	2.90	.437	9.50	.211
.60	.789	3.00	.429	10.00	.203
.65	.775	3.10	.422	11.0	.190
.70	.761	3.20	.415	12.0	.179
.75	.748	3.30	.408	13.0	.169
.80	.735	3.40	.401	14.0	.161
.85	.723	3.50	.394	15.0	.153
.90	.711	3.60	.388	16.0	.146
.95	.700	3 70	.382	17.0	.139
1.00	.688	3 80	.376	18.0	.134
1.05	.678	3 90	.371	19.0	.128
1.10	.667	4.00	.365	20.0	.124
1.15	.657	4.10	.360	22.0	.115
1.20	.648	4.20	.355	24.0	.108
1.25	.638	4.30	.350	26.0	.102
1.30	.629	4.40	.346	28.0	.096
1.35	.620	4.50	.341	30.0	.091
1.40	.612	4.60	.336	35.0	.081
1.45	.603	4.70	.332	40.0	.073
1.50	.595	4.80	.328	45.0	.066
1.55	.587	4.90	.324	50.0	.061
1.60	.580	5.00	.320	60.0	.053
1.65	.572	5.20	.312	70 0	.047
1.70	.565	5.40	.305	80.0	.042
1.75	.558	5.60	.298	90 0	.038
1.80	.551	5.80	.292	100.0	.035
1.85	.544	6.00	.285		
		6.20	.280		

EXAMPLE, IN FIG. 3, WE HAVE A COIL OR INDUCTANCE WHICH IS 1.5" IN DIAMETER AND 3" LONG. BY DIVIDING ITS DIAMETER BY ITS LENGTH, WE HAVE $\frac{1.5}{3} = .5$

LOOKING FOR THIS NUMBER UNDER THE COLUMNS HEADED $\frac{\text{DIAM.}}{\text{LENGTH}}$ IN TABLE I, WE SEE THAT .5 CORRESPONDS TO A SHAPE OR CORRECTION FACTOR OF .818. HENCE THE CORRECTION FACTOR OR VALUE OF K FOR A COIL HAVING THE DIMENSIONS AS INDICATED IN FIG. 3 WILL BE 0.818.

TRUE MEANING OF "LENGTH OF WINDING" AND "TURNS PER INCH"

WHEN REFERRING TO WINDINGS ON SUCH COILS, WE FREQUENTLY SPEAK OF THE COIL AS BEING WOUND WITH A CERTAIN NUMBER OF TURNS TO THE INCH. BY THIS EXPRESSION, WE MEAN THE NUMBER OF TURNS OF THE WINDING THAT ARE CONTAINED IN ONE INCH OF THE WINDING'S LENGTH. THIS IS IMPORTANT BECAUSE QUITE OFTEN, A SPACE IS ALLOWED BETWEEN ADJACENT TURNS OF A WINDING AND THIS HAS A PRONOUNCED EFFECT UPON THE WINDING'S INDUCTANCE. THEN IT IS ALSO APPARENT THAT IN SUCH CASES, WHERE ADJACENT TURNS ARE WOUND SIDE BY SIDE WITHOUT ANY SEPARATIONS, ONE WILL BE ABLE TO WIND MORE TURNS PER INCH WHEN SMALLER WIRE OR WIRE OF THINNER INSULATION IS USED. TABLE II, TELLS YOU HOW MANY TURNS PER INCH CAN BE WOUND WITH STANDARD SIZES AND TYPES OF COPPER WIRE AS USED IN THE CONSTRUCTION OF R.F. TRANSFORMERS. NOTE, THAT IN THE CASE OF THIS TABLE, THE TURNS ARE CONSIDERED WOUND SIDE BY SIDE IN A SINGLE LAYER AND NO SPACE IS ALLOWED BETWEEN ADJACENT TURNS. ALSO BEAR IN MIND THAT THE LENGTH OF THE TUBING, UPON WHICH THE COIL IS WOUND, HAS NOTHING TO DO WITH THE LENGTH OF THE WINDING AND WE ONLY CONSIDER THE SPACE ACTUALLY OCCUPIED BY THE WIRE AS CONSTITUTING THE LENGTH OF THE WINDING. THIS IS ILLUSTRATED CLEARLY IN FIG. 3.

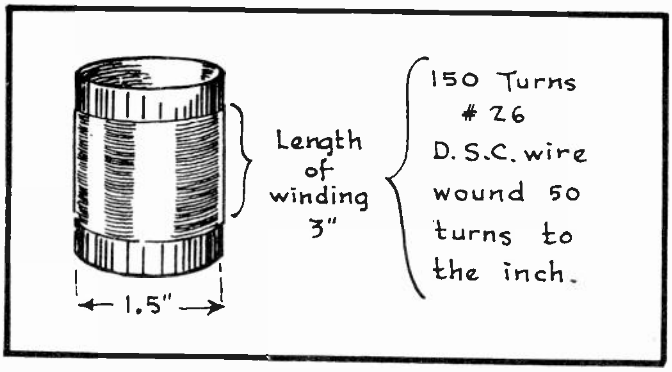


FIG. 3
Calculating Inductance.

YOU CAN CHECK UP ON YOURSELF AS TO YOUR UNDERSTANDING OF TABLE II BY MEANS OF FIG. 3. NOTICE IN THIS ILLUSTRATION, THAT THE COIL IS WOUND WITH 150 TURNS OF #26 DOUBLE SILK COVERED WIRE, WITH THE TURNS WOUND SIDE BY SIDE AND UPON REFERRING TO TABLE II, YOU WILL OBSERVE THAT #26 B&S DOUBLE SILK COVERED WIRE CAN BE WOUND 50 TURNS TO THE INCH AND THIS CHECKS WITH FIG. 3, AS HERE THERE ARE 150 TURNS OF THIS WIRE IN A 3" WINDING LENGTH.

CALCULATING THE INDUCTANCE

NOW LET US PROCEED TO CALCULATE THE INDUCTANCE OF THE COIL WHICH IS ILLUSTRATED IN FIG. 3. FOR THIS, WE WILL USE OUR FORMULA:

$L = 0.0251\, D^2\, N\, N_o\, K$. THE VALUE FOR "D" ACCORDING TO FIG. 3 WILL BE 1.5", THE VALUE FOR "N" WILL BE 150 TURNS, "N_o" WILL BE 50 TURNS PER INCH AND "K" WE HAVE ALREADY FOUND TO BE 0.818.

SUBSTITUTING THESE VALUES IN OUR FORMULA WE HAVE:

L = 0.0251 X 1.5² X 150 X 50 X .818, WHENCE L = 346.47. THAT IS, THE INDUCTANCE OF THE COIL, WHICH IS SHOWN IN FIG. 3, IS APPROXIMATELY 346.47 MICROHENRIES AS DETERMINED BY CALCULATION.

BEAR IN MIND, THAT THIS INDUCTANCE FORMULA WHICH WAS JUST GIVEN YOU, ONLY APPLIES TO SOLENOID TYPE (AIR CORE) COILS, HAVING A SINGLE LAYER WINDING. FOR BANKED COILS, THAT IS, SOLENOID COILS CONSISTING OF SEVERAL LAYERS OF WINDING, YOU CAN USE THE FORMULA $L = 0.0251\ D^2\ N\ n\ n_o\ K$ WITH CONSIDERABLE ACCURANCY AND IN THIS CASE, "N" SIGNIFIES THE NUMBER OF LAYERS MAKING UP THE WINDING. ALSO REMEMBER, THAT THIS LATTER FORMULA IS ONLY CONSISTENT IN SUCH CASES WHERE THE DEPTH OF THE WINDING IS NOT TOO GREAT AS COMPARED WITH ITS DIAMETER.

IN VARIOUS MAGAZINES OR BOOKS, WHICH YOU MAY READ FROM TIME TO TIME, YOU WILL FIND STILL OTHER FORMULAS FOR CALCULATING THE INDUCTANCE OF SOLENOID TYPE WINDINGS BUT YOU WILL FIND THAT THE ONE WHICH WE HAVE JUST GIVEN YOU IS USED EXTENSIVELY IN RADIO MANUFACTURING CONCERNS BY FOREMOST ENGINEERS.

TABLE II
TURNS PER INCH WOUND SIDE BY SIDE WITH WIRE HAVING FOLLOWING INSULATION

WIRE SIZE GAUGE B & S	BARE WIRE	ENAMELLED	SINGLE SILK	SILK ENAM.	DOUBLE SILK	SINGLE COTTON	COTTON ENAM.	DOUBLE COTTON
# 16	20	19	18	18	17	17	16	16
18	25	23	23	22	22	21	20	19
20	32	29	29	27	27	26	25	23
22	40	37	36	34	33	33	31	29
24	50	46	44	42	41	40	38	34
26	63	57	54	51	50	48	46	41
28	79	74	67	63	60	59	55	47
30	100	90	82	76	71	70	65	54
32	126	112	99	92	83	82	77	60
34	159	141	119	110	97	95	89	67
36	200	178	140	131	111	108	102	74
40	317	270	200	195	140	139	139	102

THE INDUCTANCE AND CAPACITY RELATION FOR TUNING

NOW THAT YOU ARE FAMILIAR WITH THE MANNER IN WHICH R.F. INDUCTANCES OF THIS TYPE ARE CALCULATED, THE NEXT STEP WILL BE TO SEE WHAT VALUE OF INDUCTANCE TO USE WITH A GIVEN TUNING CONDENSER IN ORDER FOR THE ARRANGEMENT TO TUNE OVER A CERTAIN BAND OF FREQUENCIES.

BY LOOKING AT THE FAMILIAR FORMULA $f = \frac{159{,}000}{\sqrt{LC}}$, YOU WILL NOTE THAT SINCE THE NUMBER 159,000 IS A CONSTANT IN THIS FORMULA, THE RESONANT FREQUENCY IN THIS FORMULA WILL BE GOVERNED BY THE VALUES L AND C. THAT IS, ACCORDING TO THE INDUCTANCE AND THE CAPACITY. WE GENERALLY REFER TO THIS RELATION BETWEEN L AND C AS THE "LC" FACTOR AND FOR ANY GIVEN FREQUENCY, WE WILL HAVE A DEFINITE "LC" FACTOR. FOR YOUR CONVENIENCE, WE ARE GIVING YOU A COMPLETE TABLE OF LC FACTORS FOR THE ENTIRE WAVELENGTH RANGE BETWEEN 1 AND 1000 METERS OR BETWEEN 300,000 TO 300 KC. THIS HANDY TABLE IS HEAD-

ED TABLE III IN THIS LESSON. LET US NOW SEE HOW THIS TABLE CAN BE USED. FOR OUR FIRST EXAMPLE, LET US ASSUME THAT WE HAVE THE INDUCTANCE OF 346.47 MICROHENRIES, WHICH WAS ALREADY SHOWN YOU IN FIG. 3. IF THIS INDUCTANCE IS USED TOGETHER WITH A TUNING CONDENSER, HAVING A MAXIMUM CAPACITY OF .00035 MFD, THEN TO WHAT FREQUENCY WILL THIS COMBINATION RESONATE? THE LXC FACTOR FOR THIS ARRANGEMENT WILL BE THE INDUCTANCE IN MICROHENRIES MULTIPLIED BY THE CAPACITY IN MICROFARADS OR 346.47 X .00035 ≅ .1212645 OR APPROXIMATELY 0.1213. NOW BY LOOKING FOR THE NUMBER 0.1213 UNDER THE LXC COLUMNS OF TABLE III, WE FIND THAT IT LIES BETWEEN THE VALUES OF 0.1208 AND 0.1226. THUS ACCORDING TO TABLE III, YOU ARE SHOWN THAT THIS LXC FACTOR WILL

TABLE III

WAVELENGTH IN METERS -- FREQUENCY IN KC. -- INDUCTANCE IN MICROHENRIES CAPACITY IN MICROFARADS

METERS	FREQ. IN KC.	LXC	METERS	FREQ. IN KC.	LXC	METERS	FREQ. IN KC.	LXC
1	300,000	0.0000003	450	667	0.0570	740	405	0.1541
2	150,000	0.0000111	460	652	0.0596	745	403	0.1562
3	100,000	0.0000018	470	639	0.0622	750	400	0.1583
4	75,000	0.0000045	480	625	0.0649	755	397	0.1604
5	60,000	0.0000057	490	612	0.0676	760	395	0.1626
6	50,000	0.0000101	500	600	0.0704	765	392	0.1647
7	42,900	0.0000138	505	594	0.0718	770	390	0.1669
8	37,500	0.0000180	510	588	0.0732	775	387	0.1690
9	33,333	0.0000228	515	583	0.0747	780	385	0.1712
10	30,000	0.0000282	520	577	0.0761	785	382	0.1734
20	15,000	0.0001129	525	572	0.0776	790	380	0.1756
30	10,000	0.0002530	530	566	0.0791	795	377	0.1779
40	7,500	0.0004500	535	561	0.0806	800	375	0.1801
50	6,000	0.0007040	540	556	0.0821	805	373	0.1824
60	5,000	0.0010140	545	551	0.0836	810	370	0.1847
70	4,290	0.0013780	550	546	0.0852	815	368	0.1870
80	3,750	0.0018010	555	541	0.0867	820	366	0.1893
90	3,333	0.0022800	560	536	0.0883	825	364	0.1916
100	3,000	0.00282	565	531	0.0899	830	361	0.1939
110	2,727	0.00341	570	527	0.0915	835	359	0.1962
120	2,500	0.00405	575	522	0.0931	840	357	0.1986
130	2,308	0.00476	580	517	0.0947	845	355	0.201
140	2,143	0.00552	585	513	0.0963	850	353	0.203
150	2,000	0.00633	590	509	0.0980	855	351	0.206
160	1,875	0.00721	595	504	0.0996	860	349	0.208
170	1,764	0.00813	600	500	0.1013	865	347	0.211
180	1,667	0.00912	605	496	0.1030	870	345	0.213
190	1,579	0.01015	610	492	0.1047	875	343	0.216
200	1,500	0.01126	615	488	0.1065	880	341	0.218
210	1,429	0.01241	620	484	0.1082	885	339	0.220
220	1,364	0.01362	625	480	0.1100	890	337	0.223
230	1,304	0.01489	630	476	0.1117	895	335	0.225
240	1,250	0.01621	635	472	0.1135	900	333	0.228
250	1,200	0.01759	640	469	0.1153	905	331	0.231
260	1,154	0.01903	645	465	0.1171	910	330	0.233
270	1,111	0.0205	650	462	0.1189	915	328	0.236
280	1,071	0.0221	655	458	0.1208	920	326	0.238
290	1,034	0.0237	660	455	0.1226	925	324	0.241
300	1,000	0.0253	665	451	0.1245	930	323	0.243
310	968	0.0270	670	448	0.1264	935	321	0.246
320	938	0.0288	675	444	0.1283	940	319	0.249
330	909	0.0306	680	441	0.1302	945	317	0.251
340	883	0.0325	685	438	0.1321	950	316	0.254
350	857	0.0345	690	435	0.1340	955	314	0.257
360	834	0.0365	695	432	0.1360	960	313	0.259
370	811	0.0385	700	429	0.1379	965	311	0.262
380	790	0.0406	705	426	0.1399	970	309	0.265
390	769	0.0428	710	423	0.1419	975	308	0.268
400	750	0.0450	715	420	0.1439	980	306	0.270
410	732	0.0473	720	417	0.1459	985	305	0.273
420	715	0.0496	725	414	0.1479	990	303	0.276
430	698	0.0520	730	411	0.1500	995	302	0.279
440	682	0.0545	735	408	0.1521	1000	300	0.282

TUNE THE CIRCUIT TO A FREQUENCY OF ABOUT 457 KC. NOTE HOW SIMPLE THAT THIS WORK BECOMES THROUGH THE AID OF TABLE III AND THAT HARDLY ANY CALCULATION IS NECESSARY.

NOW LET US SUPPOSE THAT WE HAVE A TUNING CONDENSER WITH A CAPACITY RATING OF .00035 MFD. THIS RATING, AS GIVEN BY THE MANUFACTURER, IS THE MAXIMUM CAPACITY OF THE CONDENSER. SO WITH THIS CONDENSER AT HAND, LET US ASSUME THAT WE ARE REQUIRED TO CONSTRUCT AN R.F. TRANSFORMER, WHOSE SECONDARY WINDING WILL TUNE WITH THIS GIVEN VARIABLE CONDENSER OVER A FREQUENCY RANGE OF APPROXIMATELY 541 KC TO 1500 KC.

THE FIRST THING THAT WE WILL HAVE TO DO IN THIS CASE IS TO DETERMINE THE INDUCTANCE, WHICH IS REQUIRED FOR THE SECONDARY WINDING OF THIS TRANSFORMER. THE MAXIMUM INDUCTANCE WHICH IS REQUIRED IN THIS INSTANCE IS WHEN THE TUNING CONDENSER PLATES ARE ALL THE WAY IN MESH, SO THAT THE CIRCUIT IS TUNED TO THE LOWEST FREQUENCY LIMIT, THAT IS, TO 541 KC. SO WE BEGIN BY LOOKING UP THE "L x C" FACTOR FOR 541 KC IN TABLE III AND WE FIND IT TO BE 0.0867.

SINCE THE VALUE OF "C" IN THIS PROBLEM IS KNOWN TO BE .00035 MFD; THE L x C FACTOR 0.0867; AND SINCE L x C = 0.0867, THEN IT IS ALSO TRUE THAT THE REQUIRED INDUCTANCE "L" $= \frac{0.0867}{C}$ OR $L = \frac{0.0867}{.00035} = 247.71$ MICROHENRIES. SO THE SECONDARY WINDING OF THE TRANSFORMER WHICH WE ARE TO CONSTRUCT MUST HAVE AN INDUCTANCE OF 247.71 MICROHENRIES.

NOW THAT WE HAVE DETERMINED THE INDUCTANCE VALUE, SO THAT THE CIRCUIT WILL RESONATE TO THE LOWEST FREQUENCY LIMIT REQUIRED, OUR NEXT STEP WILL BE TO FIND OUT IF THESE CIRCUIT CONSTANTS WILL ALSO PERMIT THE CIRCUIT TO BE TUNED TO THE HIGHEST FREQUENCY LIMIT, OR 1500 KC. SINCE THE VALUE OF THE INDUCTANCE REMAINS FIXED, IT IS CLEAR THAT THE RESPONSE OF THE CIRCUIT TO THE HIGHEST FREQUENCY WILL BE DETERMINED ENTIRELY BY THE MINIMUM CAPACITY WHICH THE GIVEN TUNING CONDENSER OFFERS.

IF THE CONDENSER MANUFACTURER SPECIFIES THAT HIS .00035 MFD CONDENSER HAS A MINIMUM CAPACITY OF .000038 MFD, THEN ALL THAT YOU HAVE TO DO IS TO MULTIPLY THIS MINIMUM CAPACITIVE VALUE BY THE INDUCTANCE OF YOUR COIL IN ORDER TO FIND THE L x C FACTOR FOR THE HIGHEST FREQUENCY LIMIT. THAT IS, IN OUR PARTICULAR EXAMPLE, THE L x C FACTOR FOR 1500 KC WILL BE AS FOLLOWS: $247.71 \times .000038 = 0.00941298$, OR APPROXIMATELY 0.00941.

THUS, BY LOOKING UP THIS L x C FACTOR IN TABLE III, WE FIND THAT THIS VALUE CORRESPONDS TO A FREQUENCY SOMEWHERE BETWEEN 1579 AND 1667 KC. HENCE THIS INDUCTANCE AND VARIABLE CONDENSER COMBINATION WILL COVER THE RANGE OF FREQUENCIES BETWEEN 541 AND 1500 SATISFACTORILY WITH A LITTLE TO SPARE.

THE MINIMUM CAPACITY OF AVERAGE-TYPE TUNING CONDENSERS

WHENEVER THE EXACT MINIMUM CAPACITY OF A TUNING CONDENSER IS NOT KNOWN, THEN IT IS GENERAL PRACTICE TO ASSUME THE MINIMUM CAPACITY TO BE 10% OR 1/10 THAT OF THE CONDENSER'S RATED OR MAXIMUM CAPACITY. IN OTHER WORDS, WE WOULD CONSIDER A .00035 MFD TUNING CONDENSER AS HAVING A MINIMUM CAPACITY OF .000035 MFD. BY WORKING ON THIS BASIS, WE FIND THAT THE L x C FACTOR FOR THE HIGHEST FREQUENCY LIMIT IN OUR PARTICULAR PROBLEM WOULD BE 1/10 OF THE L x C FACTOR FOR THE LOWEST FREQUENCY LIMIT. THAT IS, THE L x C FACTOR FOR THE 541 KC FREQUENCY AS PER TABLE III IS 0.0867 AND 1/10

OF THIS VALUE IS 0.00867. HENCE BY LOOKING UP THE LXC FACTOR OF 0.00867 IN TABLE III, WE FIND THAT IT CORRESPONDS TO A FREQUENCY BETWEEN 1667 AND 1764 KC. AND FROM THIS, WE AGAIN SEE THAT THE 247.71 MICROHENRY INDUCTANCE WILL TUNE SATISFACTORILY WITH THE .00035 MFD. CONDENSER OVER THE 541-1500 KC. RANGE. TABLE III ALSO SHOWS YOU THAT THIS PARTICULAR INDUCTANCE-CONDENSER COMBINATION TUNES OVER A WAVELENGTH RANGE OF FROM APPROXIMATELY 185 METERS TO 555 METERS, THUS COVERING A LITTLE MORE THAN THE BROADCAST BAND.

CALCULATING THE TURNS REQUIRED

NOW THAT WE HAVE DETERMINED THE REQUIRED VALUE FOR THE INDUCTANCE OF THE SECONDARY WINDING OF THE R.F. TRANSFORMER, THE NEXT THING WILL BE TO DECIDE UPON THE NUMBER OF TURNS, WIRE SIZE ETC. TO USE IN ORDER TO WIND THE COIL SO THAT WHEN FINISHED, IT WILL HAVE THE INDUCTANCE VALUE WHICH WE WANT. IT IS OF COURSE IMPOSSIBLE TO CALCULATE THE EXACT NUMBER OF TURNS BUT BY MEANS OF A LITTLE MATHEMATICS, WE CAN DETERMINE THE APPROXIMATE NUMBER OF TURNS AND AFTER THE COIL IS CONSTRUCTED, ADJUSTMENT CAN BE MADE ON THE WINDING SO AS TO OBTAIN THE EXACT VALUE.

A SIMPLE FORMULA FOR DETERMINING THE APPROXIMATE NUMBER OF TURNS TO USE IS AS FOLLOWS: $N^2 = \frac{L\,(3\,D+9B)}{0.2\,D^2}$ WHERE N = THE NUMBER OF TURNS, L = THE COILS INDUCTANCE IN MICROHENRIES, B = LENGTH OF THE WINDING IN INCHES, D = DIAMETER OF THE WINDING IN INCHES.

OUR FIRST CHOICE WILL BE TO DECIDE UPON THE DIAMETER OF THE COIL AND THIS WILL DEPEND LARGELY UPON THE CHASSIS SPACE AVAILABLE FOR THE COILS AND THEIR SHIELDS. THE MODERN PRACTICE IS TO KEEP THE COIL DIAMETER QUITE SMALL, SO AS TO ALLOW AMPLE SPACE BETWEEN THE COIL AND ITS SHIELD CAN, WITHOUT REQUIRING A CAN OF TOO GREAT SIZE. COIL DIAMETERS OF ABOUT 1" ARE QUITE POPULAR FOR THIS VERY REASON BUT OF COURSE, YOU ARE NOT LIMITED TO THIS DIMENSION BUT MAY CHOOSE A DIAMETER OF 1½" OR 1¾" OR ANY OTHER VALUE TO SUIT YOURSELF, PROVIDED THAT YOU STAY WITHIN REASONABLE LIMITS. FOR OUR PRESENT EXAMPLE, LET US CHOOSE A COIL DIAMETER OF 1".

NOW THAT WE HAVE DECIDED UPON THE COIL'S DIAMETER, THE NEXT THING WILL BE TO CHOOSE A PROPER LENGTH FOR THE WINDING AND FOR THIS, WE ALSO HAVE A HANDY RULE. IT SO HAPPENS THAT IF A SOLENOID WINDING IS MADE 2.46 OR APPROXIMATELY 2.5 TIMES AS LONG AS ITS DIAMETER, IT WILL BE MOST EFFICIENT, IN THAT IT PROVIDES A GIVEN INDUCTANCE WITH THE LEAST WIRE AND THIS MEANS LESS RESISTANCE, WHICH IN TURN PERMITS SHARPER TUNING. BECAUSE OF THIS CONDITION, IT IS ALSO APPARENT WHY R.F. COILS WITH LARGE DIAMETERS ARE NOT DESIRABLE BECAUSE INCREASING THE COILS' DIAMETER WOULD CALL FOR A STILL GREATER INCREASE IN ITS CORRESPONDING LENGTH, THUS RESULTING IN A LARGE AND CUMBERSOME COIL.

SINCE WE HAVE CHOSEN A COIL DIAMETER OF 1" AND DESIRE UTMOST EFFICIENCY, WE WILL MAKE OUR WINDING 2.5 TIMES AS LONG AS ITS DIAMETER. THAT IS, WE WILL MAKE THE WINDING 2.5 INCHES LONG. THE COIL IS TO BE WOUND WITH THE ADJACENT TURNS SIDE BY SIDE, THAT IS, NO SPACING IS ALLOWED BETWEEN TURNS. NOW RETURNING TO OUR FORMULA OF $N^2 = \frac{L(3\,D+9B)}{0.2\,D^2}$ WE HAVE SO FAR THAT L = 247.71 MICROHENRIES; D = 1" AND "B" = 2.5". SUBSTITUTING THESE VALUES IN THE ABOVE FORMULA, WE HAVE AS FOLLOWS:

$$N^2 = \frac{247.71\left[(3 \times 1) + (9 \times 2.5)\right]}{0.2 \times 1^2} = \frac{247.71\left[(3 + 22.5)\right]}{0.2} = \frac{247.71 \times 25.5}{0.2} =$$

$$\frac{6316.605}{0.2} = 31583.02$$. THEREFORE $N = \sqrt{31583.02} = 177.7$ OR APPROXIMATELY 178 TURNS.

DETERMINING THE WIRE SIZE TO USE

KNOWING THAT ABOUT 178 TURNS WILL HAVE TO BE WOUND IN A SPACE 2.5" LONG, WE CAN CALCULATE THE TURNS PER INCH BY DIVIDING 178 BY 2.5". THAT IS, $178 \div 2.5 = 71.2$ TURNS PER INCH. THE NEXT STEP IS TO FIND OUT WHAT KIND OF WIRE CAN BE WOUND AT APPROXIMATELY 71 TURNS PER INCH AND FOR THIS INFORMATION, WE REFER TO TABLE II OF THIS LESSON. HERE YOU WILL FIND THAT #30 B&S DOUBLE SILK COVERED WIRE FILLS THE BILL EXACTLY. IT WOULD ALSO BE ALRIGHT TO USE #30 SINGLE COTTON COVERED WIRE.

SO FROM ALL THIS INFORMATION WHICH WE HAVE GATHERED, WE WOULD WIND THIS PARTICULAR R.F. COIL WITH 178 TURNS OF #30 D.S.C. WIRE, MAKING THE COIL 1" IN DIAMETER. IN PRACTICE, YOU WILL FIND THAT BY MEANS OF THIS METHOD OF CALCULATION, YOU WILL HAVE A FEW MORE TURNS OF WIRE ON THE COIL THAN YOU ACTUALLY NEED. THIS, HOWEVER, IS PERFECTLY ALRIGHT BECAUSE WHEN YOU TEST THE INDUCTANCE VALUE AS WILL BE SHOWN YOU LATER, YOU CAN UNWIND A FEW TURNS IN ORDER TO BRING THE COIL'S INDUCTANCE DOWN TO THE EXACT VALUE. NEVERTHELESS, BY CALCULATING THE APPROXIMATE REQUIRED NUMBER OF TURNS FIRST, YOU HAVE A GOOD IDEA OF THE NUMBER OF TURNS NEEDED, SO THAT YOU WILL NOT BE WORKING IN THE DARK SO TO SPEAK AND SIMPLY GUESSING AS TO HOW MANY TURNS TO PUT ON THE COIL.

WITH RESPECT TO THE CALCULATED COIL VALUES, ONE MUST ALSO CONSIDER THE FACT THAT THE R.F. TRANSFORMER SHIELD CANS HAVE A TENDENCY TO INCREASE THE "EFFECTIVE INDUCTANCE" OF THE TRANSFORMER WINDINGS DUE TO THE ADDITIONAL CAPACITY EFFECT WHICH THE SHIELD CANS OFFER. THIS MEANS THAT WHEN TESTING THE FINISHED TRANSFORMERS WITH THE SHIELD CANS IN PLACE, ONE WILL FIND IT NECESSARY TO REMOVE A FEW TURNS FROM THE SECONDARY WINDINGS IN ORDER TO COMPENSATE FOR THE ADDITIONAL CAPACITY INTRODUCED BY THE SHIELD CANS.

THE ABOVE CONDITION CAN BE READILY DETERMINED BY NOTING HOW THE FINISHED TRANSFORMER PERMITS THE TUNING CONDENSER TO COVER THE DESIRED RANGE WITH THE SHIELD CANS IN POSITION. IF UNDER THESE CIRCUMSTANCES, IT IS FOUND THAT THE BROADCAST STATION OF LOWEST FREQUENCY CAN BE TUNED IN WITHOUT THE TUNING CONDENSER PLATES BEING COMPLETELY MESHED, WHILE AT THE SAME TIME THE STATIONS OCCUPYING THE HIGHER FREQUENCY RANGES IN THE BAND CANNOT BE OBTAINED WITH THE CONDENSER PLATES ALL THE WAY OUT OF MESH, THEN THE TEST INDICATES THAT THE INDUCTANCE OF THE R.F. TRANSFORMER SECONDARY WINDINGS IS TOO GREAT AND THEREFORE, IT BECOMES NECESSARY TO REMOVE SECONDARY TURNS UNTIL THE DESIRED BAND OF FREQUENCIES CAN BE PROPERLY COVERED.

SIMPLIFIED COIL FORMULAS

A SIMPLE FORMULA FOR DETERMINING THE INDUCTANCE OF A PLAIN SINGLE-LAYER SOLENOID TYPE COIL AND WHICH CAN BE APPLIED VERY EASILY IS AS FOLLOWS: $L = \frac{A^2 N^2}{9a + 10B}$ WHERE L IS THE INDUCTANCE EXPRESSED IN MICROHENRIES, N THE TOTAL NUMBER OF TURNS, "B" THE WINDING LENGTH IN INCHES AND "A" BEING $\frac{1}{2}$ THE COIL DIAMETER EXPRESSED IN INCHES. THESE DIMENSIONS ARE ALL INDIC-

ATED IN FIG. 4 SO THAT THERE WILL BE NO DOUBT IN YOUR MIND CONCERNING THEM.

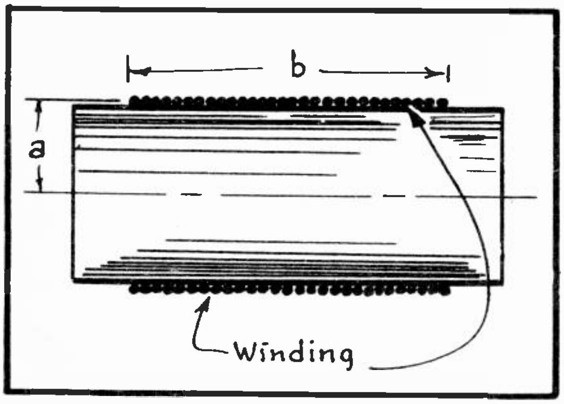


FIG. 4
The Plain Solenoid

FOR INSTANCE, IF THE COIL IN FIG. 4 CONSISTS OF 60 TURNS OF WIRE AND THE DIMENSIONS "A" AND "B" ARE 1" AND 3" RESPECTIVELY, THEN BY SUBSTITUTING THESE VALUES IN THE PRECEDING FORMULA, WE HAVE AS FOLLOWS:

$$L = \frac{1^2 \times 60^2}{(9 \times 1) + (10 \times 3)} = \frac{3600}{9 + 30} = \frac{3600}{39} = 92.3 \text{ MICROHENRIES.}$$

SHOULD THE WINDING IN QUESTION BE OF THE MULTI-LAYER TYPE AND HAVE A CROSS-SECTION AS ILLUSTRATED IN FIG. 5, SUCH AS MIGHT BE USED IN THE INTERMEDIATE-FREQUENCY TRANSFORMER OF A SUPERHETERODYNE RECEIVER, THEN YOU CAN CALCULATE ITS INDUCTANCE BY EMPLOYING THE FOLLOWING FORMULA: $L = \frac{.8A^2N^2}{6A + 9B + 10C}$, WHERE L = THE INDUCTANCE IN MICROHENRIES, N THE TOTAL NUMBER OF TURNS AND "A", "B" AND "C" THE DIMENSIONS AS SPECIFIED IN FIG. 5, EACH OF WHICH IS EXPRESSED IN INCHES.

ASSUMING, FOR INSTANCE, THAT SUCH A COIL CONSISTS OF 800 TURNS, "A" BEING .5"; "C", .5"; AND "B", .4". SUBSTITUTING THESE VALUES IN OUR FORMULA, WE HAVE

$$L = \frac{.8 \times .5^2 \times 800^2}{(6 \times .5) + (9 \times .4) + (10 \times .5)} = \frac{.8 \times .25 \times 640000}{3 + 3.6 + 5} = \frac{128,000}{11.6} =$$

11,034.4 MICROHENRIES, APPROX. 11 MILLIHENRIES.

FINALLY, IF THE COIL IS IN THE FORM OF A HELICAL OR SPIRAL WINDING SUCH AS FREQUENTLY USED FOR A PRIMARY WINDING OF AN R.F. TRANSFORMER, AS AN ANTENNA COUPLING, ETC., THE CROSS SECTION OF WHICH APPEARS IN FIG. 6, THEN YOU CAN USE THE FORMULA $L = \frac{A^2N^2}{8A + 11C}$ IN WHICH CASE L IS AGAIN THE INDUCTANCE IN MICROHENRIES, N THE TOTAL NUMBER OF TURNS IN THE WINDING AND "C" AND "A" THE DIMENSIONS DESIGNATED IN FIG. 6 AND EXPRESSED IN INCHES.

IN THIS CASE, IF 300 TURNS ARE USED AND DIMENSIONS "A" AND "C" ARE .5" AND .1", RESPECTIVELY, THEN

$$L = \frac{.5^2 \times 300^2}{(8 \times .5) + (11 \times .1)} = \frac{.25 \times 90000}{4 + 1.1} = \frac{22500}{5.1} = 4411.7 \text{ MICROHENRIES OR } 4.41 \text{ MILLIHENRIES}$$

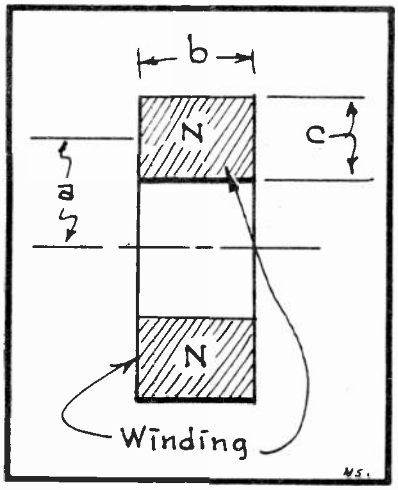


FIG. 5
The Multi-Layer Winding.

DESIGNING SINGLE-LAYER SOLENOID COILS BY MEANS OF GRAPHS

THE TASK OF DESIGNING SINGLE-LAYER SOLENOID COILS, WHICH ARE THE MOST EXTENSIVELY USED TYPE OF TUNED WINDING FOR R.F. TRANSFORMERS, CAN BE STILL FURTHER SIMPLIFIED THROUGH THE USE OF CHARTS AND GRAPHS. WITH THIS METHOD, CALCULATION IS ELIMINATED ENTIRELY.

IN TABLE IV, FOR EXAMPLE, YOU ARE GIVEN A CHART WHEREBY YOU CAN DETERMINE TO WHAT FREQUENCY ANY GIVEN CONDENSER AND COIL COMBINATION WILL RESONATE IN A MOST SIMPLE MANNER.

THE VERTICAL LINE AT THE LEFT OF TABLE IV IS CALIBRATED FOR CAPACITY EXPRESSED IN MICRO-MICROFARADS, THE VERTICAL LINE AT THE CENTER FOR FREQUENCY IN KILOCYCLES AND THE VERTICAL LINE AT THE RIGHT FOR INDUCTANCE IN MICROHENRIES. NOW THEN, YOU CAN DETERMINE ANY ONE OF THESE THREE VALUES IN TERMS OF THE OTHER TWO, SIMPLY BY CONNECTING THE TWO KNOWN VALUES TOGETHER WITH A STRAIGHT EDGE OR RULER AND NOTING THE POINT AT WHICH IT CROSSES THE THIRD VERTICAL LINE FOR THE VALUE BEING SOUGHT.

FOR INSTANCE, IF YOU WANT TO KNOW TO WHAT FREQUENCY A .00035 MFD. CONDENSER AND A 240 MICROHENRY COIL WILL RESONATE, SIMPLY LAY A STRAIGHT EDGE ACROSS TABLE IV SO THAT IT CUTS THROUGH THE CAPACITY LINE AT THE 350 MARK (.00035 MFD = 350 MMFDS.) AND THE INDUCTANCE LINE AT THE 240 MARK. THIS POSITION OF THE STRAIGHT EDGE IS INDICATED BY THE DOTTED LINE IN TABLE IV. AS YOU WILL OBSERVE, THE STRAIGHT EDGE WILL CUT THE FREQUENCY LINE AT THE 550 MARK, WHICH MEANS THAT THIS PARTICULAR CONDENSER AND COIL COMBINATION WILL RESONATE AT 550 KC.

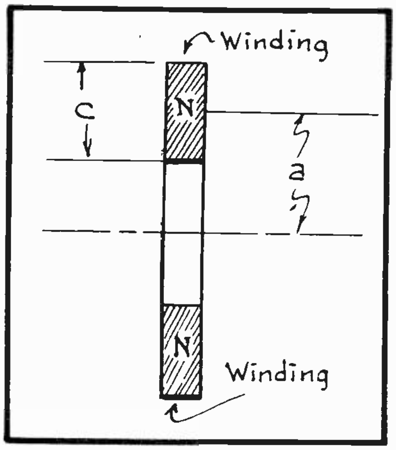


FIG. 6
The Helical Winding

YOU CAN ALSO USE THIS CHART IN STILL OTHER WAYS. FOR EXAMPLE, IF YOU HAVE A .00035 MFD. TUNING CONDENSER AND WANT TO KNOW HOW MUCH INDUCTANCE TO USE TO CONSTRUCT A CIRCUIT WHICH WILL RESONATE AT 550 KC., THEN LAY THE STRAIGHT EDGE THROUGH THE 350 MMFD. AND THE 550 KC. MARKS AND NOTE WHERE IT PASSES THROUGH THE INDUCTANCE LINE. THIS POINT ON THE INDUCTANCE LINE TELLS YOU THE INDUCTANCE EXPRESSED IN MICROHENRIES -- 240 MICROHENRIES IN THIS PARTICULAR CASE.

HAVING THUS ESTABLISHED THE CORRECT RELATION BETWEEN CAPACITY, INDUCTANCE AND FREQUENCY, YOU CAN DETERMINE THE REST OF THE COIL DESIGN CONSTANTS WITH THE CHART IN TABLE V, AIDED BY THE INFORMATION OBTAINED FROM TABLE II.

TO BETTER EXPLAIN THE USE OF TABLE V, LET US EMPLOY A SPECIFIC PROBLEM, NAMELY TO DETERMINE THE DESIGN DATA FOR THE 240 MICROHENRY WINDING WHICH WE HAVE JUST BEEN DEALING WITH. WE SHALL ASSUME THAT THIS COIL IS TO BE WOUND WITH #28 B&S ENAMELED WIRE AND ON A FORM 2" IN DIAMETER.

BY FIRST REFERRING TO TABLE II, YOU WILL NOTICE THAT THIS PARTICULAR WIRE CAN BE WOUND AT APPROXIMATELY 74 TURNS PER INCH.

THE NEXT STEP IS TO LAY A STRAIGHT EDGE UPON THE CHART OF TABLE V SO THAT IT WILL PASS THROUGH THE 240 MARK ON THE INDUCTANCE LINE AND THROUGH THE FORM DIAMETER LINE AT THE POINT MARKED "2". THE POSITION OF THE STRAIGHT EDGE AT THIS TIME IS INDICATED BY THE DOTTED LINE #1. WITH THE STRAIGHT EDGE IN THIS POSITION, CAREFULLY NOTE THE POINT OF INTERSECTION ON THE "TURNING SCALE".

TABLE IV

RELATION BETWEEN FREQUENCY, INDUCTANCE AND CAPACITY

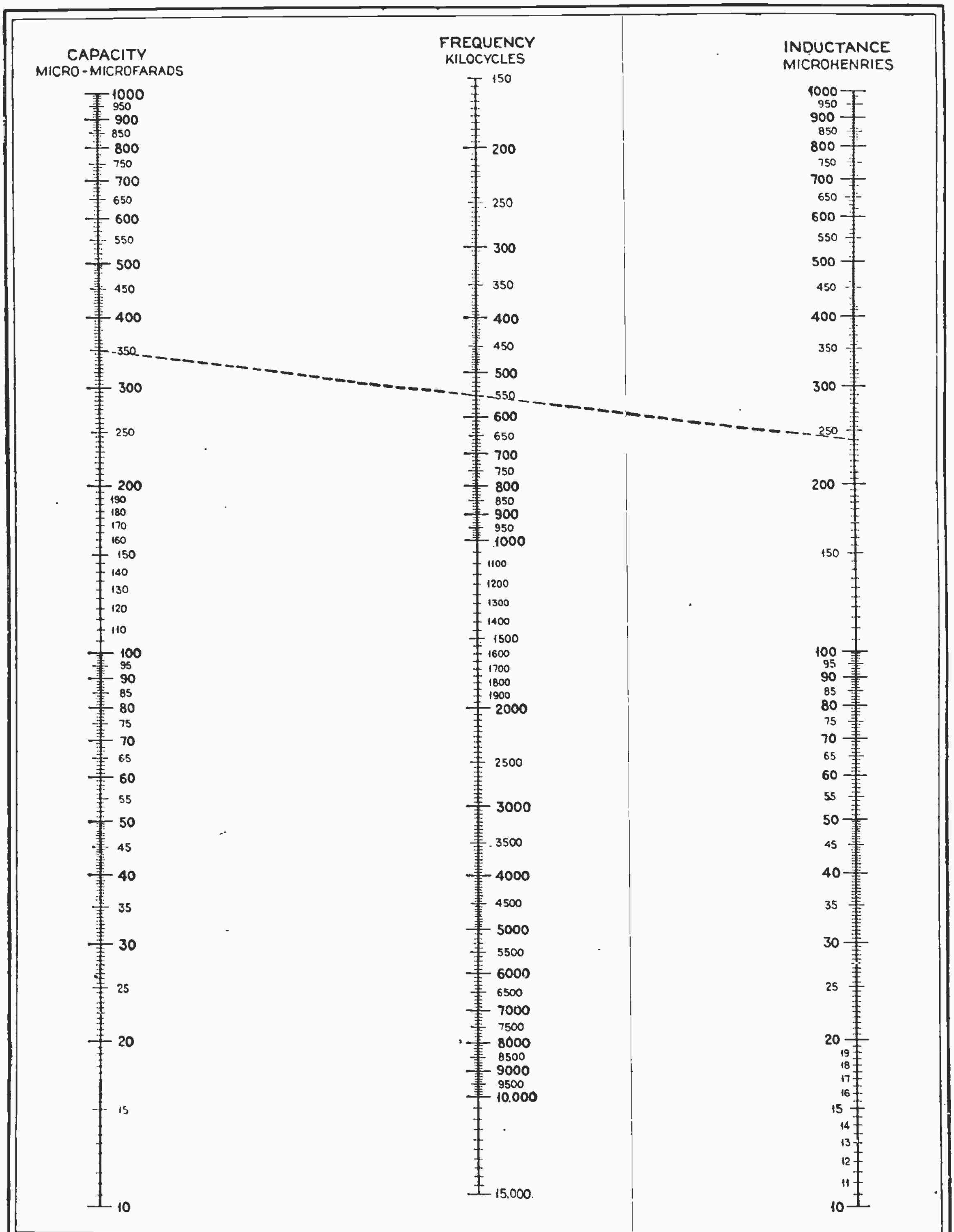
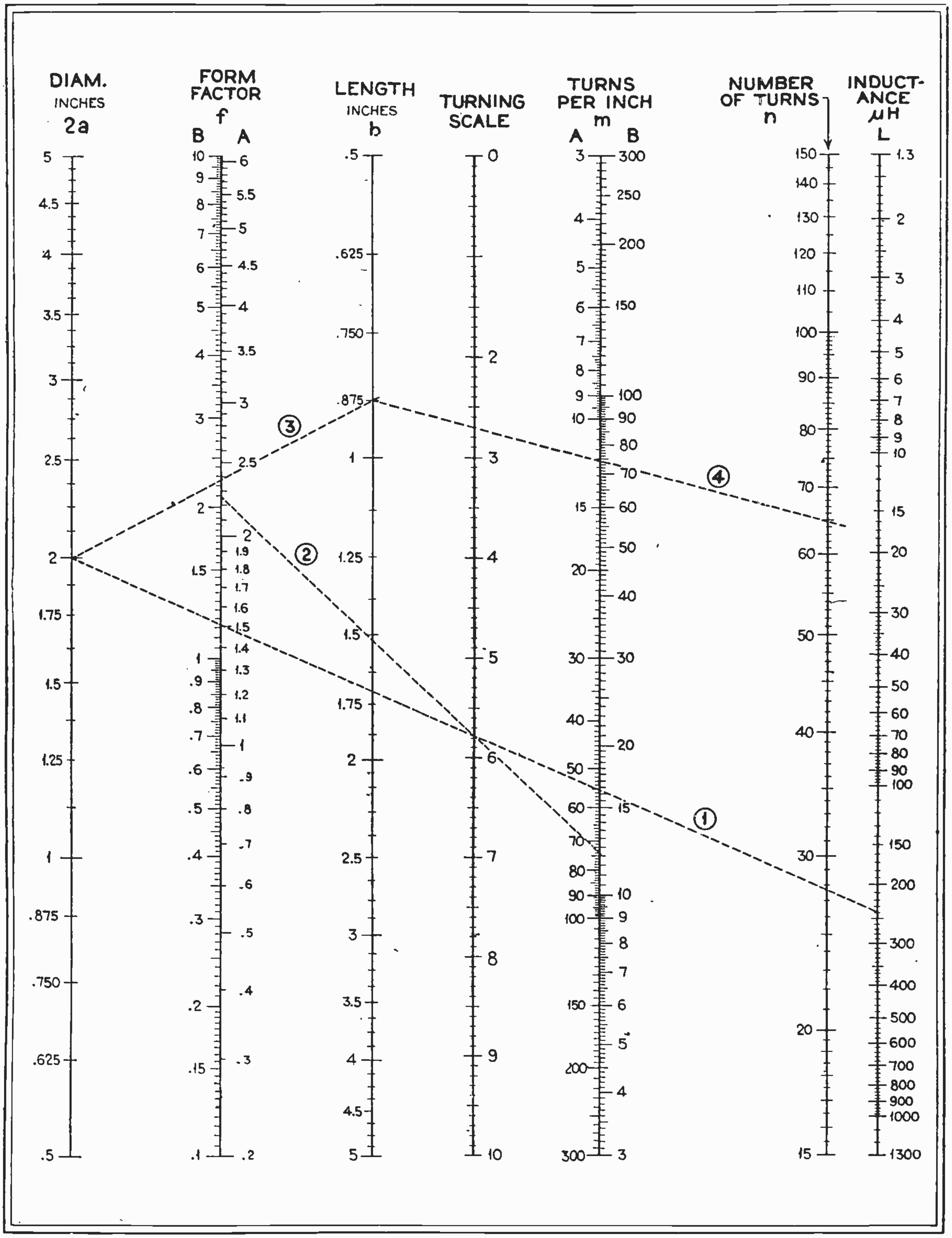


TABLE V

THE DESIGN OF SINGLE-LAYER SOLENOID COILS



Now pass your straight edge through this same point on the turning scale as well as through the 74 mark on the "A" scale of the "turns per inch" line. The position of the straight edge will now be as indicated by the dotted line #2. Notice carefully at this instant, where the straight edge intersects the "A" scale of the "form factor line" — you will find it to be 2.25 for our present example.

The next step is to pass the straight edge through the 2 mark of the diameter line and through the 2.25 mark on the "B" scale of the "form factor line" as shown by the dotted line #3. Observe where it intersects the "length" line — this you will find to be the .875 mark. This means that the length of this winding is .875" or approximately 7/8".

The final step is to lay the straight edge through the .875 mark of the "length" line and the 74 mark on the "B" scale of the turns per inch line as shown by dotted line #4. Now observe where the straight edge intersects the "number of turns" line and you will find it to be at the 65 mark. In other words, for the particular coil under our immediate attention, we would employ 65 turns of #28 B&S enameled wire wound on a form 2" in diameter and to a winding length of 7/8".

You can work out any similar problem by means of these charts in the same manner as just explained. Theoretically, the most efficient coil has a form factor of 2.46. However, since the efficiency does not fall off very rapidly on both sides of this value, we can accept as the best range for the form-factor from 1.5 to 4.

If you wish to design your coils starting with a definite form-factor, you can still do so with the same chart in TABLE V. For example, if we should set the form-factor to a value of 2.25 rather than starting with the wire size, then for the second position of the straight edge, we would run it through the 2.25 mark on the "A" scale of the form factor line and thru the previously determined point on the "turning scale" and note the point at which it intersects the "A" scale of the "turns per inch" line. By thus finding the turns per inch to be 74, we find by reference to TABLE II that we can use either #28 B&S enameled wire or a #36 B&S double cotton covered wire. All other operations will remain the same as already described.

ANOTHER FORM OF COIL DESIGN GRAPH

Radio concerns, who engage in the manufacture of R.F. transformers, have gained a great deal of knowledge and data which they accumulated over a period of years. From the information obtained from these previous experiences, most of them plot "coil design graphs" for future use. An example of such a graph is shown you in Fig. 7 and this graph applies only to a single layer solenoid type coil 2.75" in diameter.

This graph, as you will note, consists of cross-ruled paper, which is also known as "graph-paper". The number of turns required for various inductances are marked along the bottom of the graph, starting with "0" at the far left. Each of the heavier vertical lines are then successively marked 10-20-30 etc. toward the right. You will find that there are 10 thinner vertical lines between each pair of the numbered vertical lines and each of these thin vertical lines stands for 1 turn of wire. Thus the

VERTICAL LINE HALF WAY BETWEEN THE NUMBER 30 AND 40 WILL SIGNIFY 35 TURNS ETC.

THE REQUIRED INDUCTANCES OF THE COILS ARE MARKED ALONG THE RIGHT EDGE OF THE GRAPH AS 100 MICROHENRIES, 200 MICROHENRIES ETC., FROM THE BOTTOM TOWARD THE TOP. IN THIS CASE, THE INDUCTANCE INCREASES BY 5 MICROHENRIES AS WE MOVE UPWARD 1 HORIZONTAL LINE AT A TIME. HENCE THE HEAVY HORIZONTAL LINE BETWEEN THE VALUES OF 200 AND 300 MICROHENRIES WILL REPRESENT 250 MICROHENRIES.

NOW LET US SEE HOW SUCH A COIL DESIGN GRAPH IS USED. SUPPOSE, FOR EXAMPLE, THAT WE WISH TO CONSTRUCT A SINGLE LAYER, CLOSELY WOUND (TURNS PLACED SIDE BY SIDE WITH NO SPACING) COIL 2.75" IN DIAMETER WITH AN INDUCTANCE OF 300 MICROHENRIES BY MEANS OF THIS GRAPH. TO DO THIS, WE BEGIN BY LOOKING ALONG THE RIGHT HAND EDGE OF THIS GRAPH UNTIL WE COME TO THE HORIZONTAL LINE WHICH IS MARKED 300.

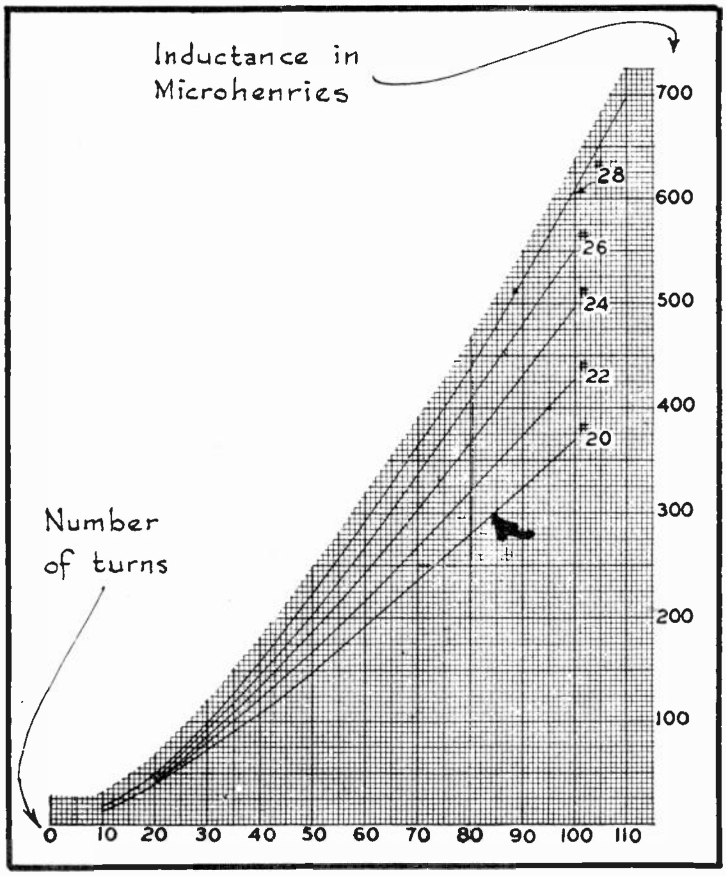


FIG. 7
Example of a Coil Design Graph.

NOW THEN, YOU WILL SEE THAT FIVE CURVED LINES, WHICH ARE RESPECTIVELY MARKED #20, #22, #24, #26 AND #28, CROSS THIS GRAPH IN A DIAGONAL FASHION. IF WE WISH TO WIND THIS 300 MICROHENRY COIL WITH #20 WIRE, WE NOTE THE POINT AT WHICH THE CURVED LINE MARKED #20 CROSSES THE "300" HORIZONTAL LINE. FOR YOUR CONVENIENCE, WE ARE INDICATING THIS POINT IN FIG. 7 WITH AN ARROW. NOW IF YOU WILL MOVE YOUR PENCIL POINT STRAIGHT DOWN FROM THIS POINT, YOU WILL FIND ACCORDING TO THE NUMBERS ALONG THE BOTTOM OF THE GRAPH THAT APPROXIMATELY $84\frac{1}{2}$ TURNS OF #20 WIRE ARE REQUIRED TO WIND A COIL OF THIS SIZE SO AS TO HAVE AN INDUCTANCE OF 300 MICROHENRIES.

SHOULD YOU WISH TO USE #22 WIRE TO CONSTRUCT THIS 300 MICROHENRY COIL OF 2.75" DIAMETER, THEN NOTE WHERE THE CURVED LINE LABELED #22 CROSSES THE "300" HORIZONTAL LINE. YOU WILL FIND THAT THE #22 LINE CROSSES THE "300" LINE ON A VERTICAL LINE OF THE GRAPH WHICH CORRESPONDS TO 76 TURNS. THUS ONLY 76 TURNS OF #22 WIRE IS REQUIRED. THIS GRAPH HAS BEEN WORKED OUT FOR DOUBLE SILK-COVERED WIRE OF THE DESIGNATED SIZES ONLY.

FOR COILS OF A DIFFERENT DIAMETER, OR FOR WIRE OF A DIFFERENT TYPE

OF INSULATION, ANOTHER GRAPH IS REQUIRED. THUS IT IS OBVIOUS THAT COIL MANUFACTURERS HAVE MANY OF SUCH COIL DESIGN GRAPHS IN THEIR FILES TO WHICH THEY CAN REFER. BY MEANS OF SUCH GRAPHS, IT IS CLEAR THAT COILS CAN BE DESIGNED RAPIDLY WITHOUT THE NEED OF LENGTHY CALCULATIONS, THEREBY RESULTING IN A GREAT SAVING OF TIME. OTHER GRAPHING METHODS HAVE ALSO BEEN WORKED OUT AND THEIR USE WILL BE APPARENT UPON INSPECTION.

IN THIS LESSON, WE HAVE DISCUSSED BOTH THE CALCULATION AND GRAPH METHODS OF DESIGNING R.F. TRANSFORMER SECONDARY WINDINGS, SO THAT YOU WILL HAVE A KNOWLEDGE OF BOTH OF THESE METHODS. THUS IF YOU ARE PROVIDED WITH DATA FOR EITHER OF THESE TWO METHODS AT SOME FUTURE TIME, YOU WILL HAVE NO DIFFICULTY IN EFFECTING A SOLUTION BECAUSE YOUR KNOWLEDGE OF THE SUBJECT IS NOW QUITE THOROUGH.

Examination Questions

1. - WHAT IS MEANT BY THE EXPRESSION "SOLENOID TYPE WINDING"?
2. - IF A CERTAIN R.F. TRANSFORMER SECONDARY WINDING IS 4" LONG AND HAS A DIAMETER OF 2", WHAT IS ITS "SHAPE FACTOR"?
3. - IF YOU ARE GOING TO WIND A COIL WITH #30 B&S ENAMELED WIRE WITHOUT ANY SPACING BETWEEN ADJACENT TURNS, THEN HOW MANY TURNS OF THIS WIRE WILL YOU BE ABLE TO WIND PER INCH OF THE WINDING LENGTH?
4. - IF A CIRCUIT IS TO BE TUNED TO 600 KC. WHAT WILL BE ITS "L C" FACTOR OR CONSTANT?
5. - IF A VARIABLE CONDENSER IS SPECIFIED AS HAVING A .0005 MFD. CAPACITY RATING, WHAT WILL BE ITS APPROXIMATE MINIMUM CAPACITY?
6. - IF FROM THE COIL DESIGN GRAPH OF FIG. 7, YOU WANTED TO CONSTRUCT A COIL 2.75" IN DIAMETER AND HAVING AN INDUCTANCE OF 400 MICROHENRIES, HOW MANY TURNS OF #22 B&S SILK COVERED WIRE WOULD YOU USE?
7. - IS THE LENGTH OF A SOLENOID TYPE COIL ASSUMED TO BE THE SAME AS THE LENGTH OF THE FORM UPON WHICH IT IS WOUND?
8. - IF YOU SHOULD WISH TO CONSTRUCT AN R.F. TRANSFORMER TO COVER THE BROADCAST BAND WHEN USED WITH A STANDARD TUNING CONDENSER OF .00035 MFD. RATING, WHAT INDUCTANCE VALUE SHOULD THE SECONDARY WINDING OF THIS R.F. TRANSFORMER HAVE?
9. - IF A CERTAIN SOLENOID WINDING IS 1" IN DIAMETER AND IS WOUND WITH 180 TURNS OF WIRE AT 90 TURNS PER INCH, WHAT WILL BE THE APPROXIMATE INDUCTANCE VALUE OF THIS WINDING?
10. - ASSUME THAT A TUNING CONDENSER OF .00035 MFD. IS AVAILABLE, TOGETHER WITH A COIL FORM OF 1¼" DIAMETER. THE WIRE TO BE USED FOR THE TUNED WINDING IS #30 B&S ENAMEL COATED. HOW MANY TURNS OF THIS WIRE WILL BE REQUIRED SO THAT THIS COIL AND CONDENSER COMBINATION WILL COVER THE BROADCAST BAND WITH 550 KC. BEING THE LOWEST FREQUENCY? (WORK OUT THIS PROBLEM WITH THE AID OF TABLES IV, AND V AS GIVEN IN THIS LESSON.)

WM. F. LIESKE

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NATIONAL SCHOOLS

Established 1905

Los Angeles, California

LESSON NO. 43

BAND PASS FILTER CIRCUITS
SUPERHETERODYNE DESIGN

YOU HAVE ALREADY HAD AN INTRODUCTION TO BAND-PASS FILTER CIRCUITS AND SUPERHETERODYNE RECEIVERS EARLIER IN YOUR STUDIES BUT NOW THAT YOU HAVE A MORE THOROUGH UNDERSTANDING OF RADIO PRINCIPLES IN GENERAL, YOU ARE READY TO BEGIN A MORE INTENSIVE STUDY OF THESE TWO FASCINATING SUBJECTS WHICH ARE OF SUCH GREAT IMPORTANCE IN MODERN RADIO PRACTICE.

WE SHALL CONSIDER THE CONSTRUCTION AND OPERATING CHARACTERISTICS OF THE BAND PASS FILTER CIRCUITS FIRST, AND AS YOU WILL REMEMBER FROM YOUR EARLIER INVESTIGATION OF THIS SUBJECT, THE CHIEF ADVANTAGE OF A CIRCUIT OF THIS TYPE, WHEN USED IN AN R.F. AMPLIFIER, IS THAT IT OFFERS SHARP TUNING WITHOUT LOSING THE HIGH AUDIO FREQUENCIES.

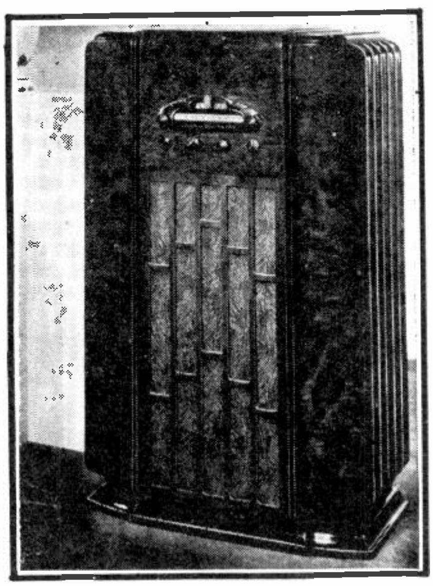

FIG. 1
A MODERN SUPERHETERODYNE RECEIVER

IN ORDER THAT YOU MAY GAIN A PERFECT UNDERSTANDING REGARDING THE PRINCIPLES UPON WHICH THIS TYPE OF CIRCUIT OPERATES, WE WILL BEGIN THE STUDY OF THIS SYSTEM WITH THE BASIC FACTS AFFECTING THE CIRCUIT, GRADUALLY DEVELOPING THE FUNDAMENTAL PRINCIPLES SO THAT THE COMPLETE CIRCUIT WILL BECOME A CLEAR PICTURE IN YOUR MIND.

THE SIMPLE TUNED CIRCUIT

TO BEGIN WITH, LET US LOOK AT FIG.2. IN THE UPPER PORTION OF THIS ILLUSTRATION, WE HAVE A SINGLE TUNED CIRCUIT OF THE CONVENTIONAL TYPE COUPLED TO AN R.F. TUBE. ALTHOUGH THIS CIRCUIT WILL TUNE AFTER A FASHION OVER THE RANGE PERMITTED BY THE VARIABLE CONDENSER, YET IT WILL NOT TUNE SHARP.

A SELECTIVITY CURVE PLOTTED FOR A

RECEIVER WITH BUT A SINGLE TUNED CIRCUIT AS THIS WOULD LOOK SOMETHING LIKE THAT PICTURED IN THE LOWER PORTION OF FIG. 2. HERE THE ENCLOSURE OF THE CURVE HAS BEEN SHADED, IN ORDER TO ACCENTUATE ITS SHAPE.

IN THIS GRAPH OF FIG. 2, THE VERTICAL LINE MARKED ZERO INDICATES THE RESONANT FREQUENCY. EACH VERTICAL LINE TOWARD THE RIGHT OF ZERO INDICATES AN INCREASE OF 5Kc. ABOVE RESONANCE AND EACH VERTICAL LINE TOWARD THE LEFT OF ZERO INDICATES AN INCREASE OF 5Kc. BELOW THE RESONANT FREQUENCY.

DUE TO THE BROADNESS OF THIS SELECTIVITY CURVE, IT EXTENDS CONSIDERABLY OVER THE FREQUENCIES TOWARD EITHER SIDE OF RESONANCE. SINCE BROADCAST STATIONS ARE ASSIGNED TO A FREQUENCY CHANNEL 10Kc. IN WIDTH, IT CAN READILY BE SEEN THAT A RECEIVER WITH SUCH A BROAD SELECTIVITY CURVE AS THAT IN FIG. 2 WILL BE BOTHERED CONSIDERABLY BY INTERFERENCE BETWEEN STATIONS. IN OTHER WORDS, THE TUNED CIRCUIT OF FIG. 2 WOULD BE CLASSIFIED AS "BROAD TUNING".

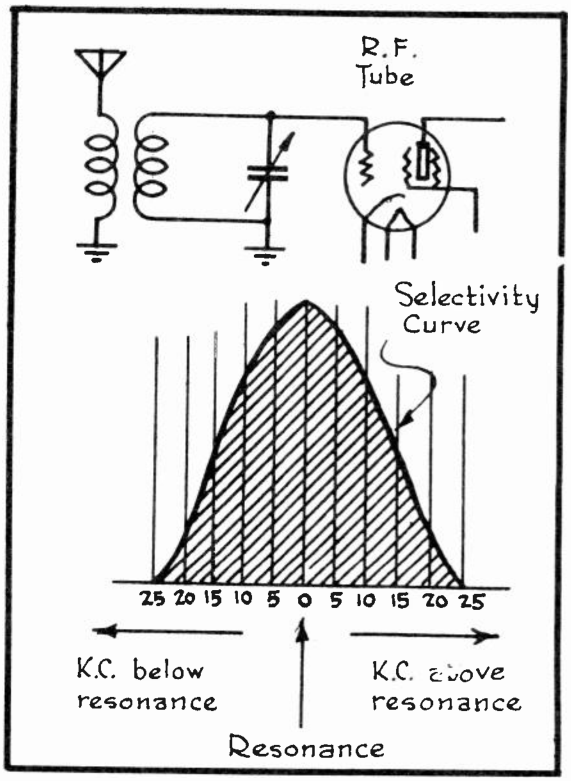

FIG. 2

Tuning Response of a Single Tuned Circuit.

MULTIPLE TUNED CIRCUITS

BY PASSING A BROADCAST SIGNAL OF GIVEN FREQUENCY THROUGH SEVERAL OF SUCH TUNED CIRCUITS AS IS DONE IN THE CONVENTIONAL TYPES OF TUNED R.F. CIRCUITS, SUCH AS PICTURED IN THE UPPER PART OF FIG. 3, EACH OF THE SUCCESSIVE TUNED CIRCUITS WILL TEND TO INCREASE THE SELECTIVITY OF THE RECEIVER.

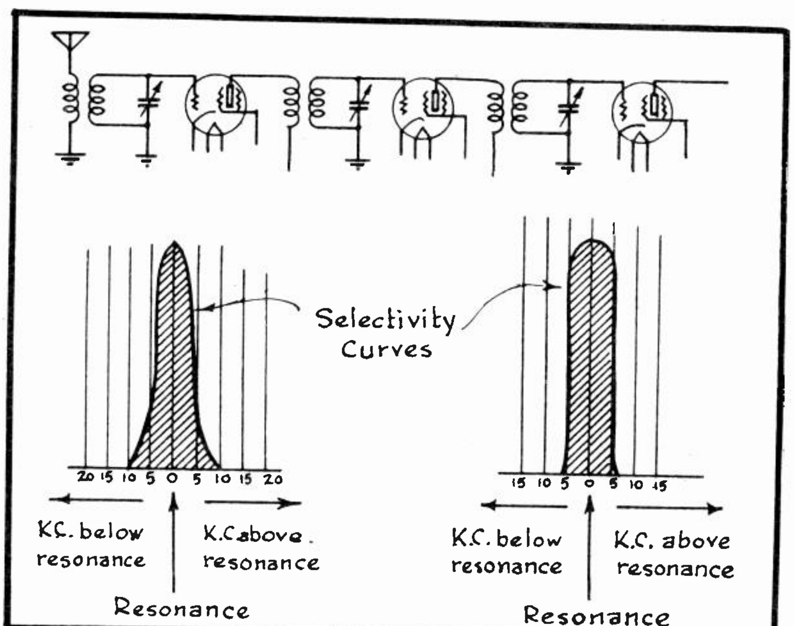

FIG. 3

Tuning Response of Multiple-Tuned Circuits.

SEVERAL TUNED CIRCUITS WORKING TOGETHER IN THIS WAY MAY INCREASE THE SHARPNESS OF TUNING TO SUCH A DEGREE THAT THE SELECTIVITY CURVE WILL BE NARROWED TO THE EXTENT SOMEWHAT AS ILLUSTRATED IN THE GRAPH AT THE LEFT FIG. 3. IN FACT, IF FOUR OR MORE SUCH TUNED CIRCUITS ARE USED IN SUCCESSIVE STAGES, THE SELECTIVITY CURVE

WILL BECOME TOO NARROW IF CARE IS NOT TAKEN IN THEIR DESIGN. UNDER THESE CONDITIONS, SOME POINTS ALONG THE SIDES OF THE CURVE WILL NOT EVEN REACH OUT TO 5 KC. EACH SIDE OF THE RESONANT FREQUENCY. THIS IN TURN MEANS THAT THE TUNED CIRCUITS DON'T EVEN PASS A BAND OF FREQUENCIES 10 KC IN WIDTH WHEN TUNED TO ANY ONE STATION AND THE RESULT IS THAT THE HIGHER AUDIO FREQUENCIES ARE NOT AMPLIFIED AND THE SOUNDS AT THE SPEAKER THEN BECOMES "BOOMY" (UNATURALLY LOW-PITCHED).

THE IDEAL SELECTIVITY CURVE

SO FAR, WE HAVE CONSIDERED THE TOO EXTREME CONDITIONS, NAMELY TOO BROAD TUNING AS OFFERED BY AN ORDINARY SINGLE TUNED CIRCUIT AND TOO SHARP TUNING AS OFFERED BY TOO MANY TUNED STAGES OF GOOD SELECTIVITY. NOW THE IDEAL CONDITION WOULD BE AN R.F. AMPLIFIER WHOSE TUNING CHARACTERISTICS ARE SUCH THAT A SELECTIVITY CURVE PLOTTED FROM TESTS WOULD LOOK LIKE THE ONE AT THE LOWER RIGHT OF FIG. 3. THIS CURVE, YOU WILL NOTE, HAS PERPENDICULAR SIDES AND THE CURVE IS PRACTICALLY 10KC. WIDE (5 KC EACH SIDE OF THE RESONANT FREQUENCY) THROUGHOUT ITS ENTIRE LENGTH.

THIS IDEAL SELECTIVITY CURVE SHOWS THAT WITH THE RECEIVER TUNED TO RESONANCE WITH ANY GIVEN FREQUENCY, NONE OF THE HIGHER AUDIO FREQUENCIES ARE LOST AND YET AT THE SAME TIME, THERE IS NO POSSIBILITY FOR STATION INTERFERENCE. A RECEIVER CAPABLE OF OFFERING SUCH IDEAL TUNING PERFORMANCE WOULD BE SPOKEN OF AS OFFERING "10KC. SEPARATION."

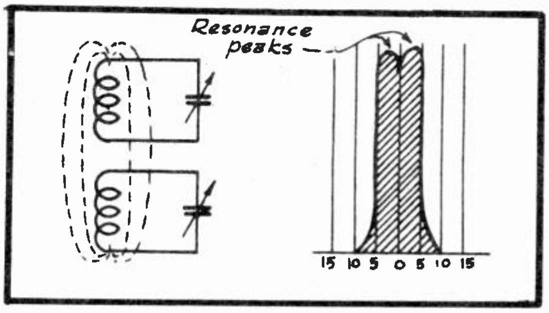

FIG. 4
Inductively Coupled Tuned Circuits.

UP UNTIL THE PRESENT TIME, NO COMMERCIAL TUNED R.F. CIRCUITS HAVE BEEN CONSTRUCTED WHICH WILL OFFER THE IDEAL SELECTIVITY CURVE AS THAT AT THE LOWER RIGHT OF FIG. 3 BUT MANY OF THE LEADING RECEIVER MANUFACTURERS HAVE DEVELOPED RECEIVERS OFFERING VERY NEARLY SELECTIVITY OF THIS NATURE. THE TUNING CHARACTERISTICS OF THE BAND-PASS FILTER CIRCUITS AS USED IN R.F. AMPLIFIERS, MOST NEARLY MEET THE DEMANDS OF THE IDEAL SELECTIVE CURVE AND IT IS BROUGHT ABOUT IN A MOST INGENIOUS MANNER AS THE FOLLOWING EXPLANATION WILL SHOW.

REACTION OF INDUCTIVELY COUPLED TUNED CIRCUITS

NOW UPON LOOKING AT FIG. 4, YOU WILL SEE TWO CONVENTIONAL TUNING CIRCUITS ORIENTED TO EACHOTHER IN SUCH A MANNER THAT THERE IS ELECTROMAGNETIC COUPLING BETWEEN THEM. THAT IS, THE LINES OF FORCE GENERATED AROUND ONE OF THE COILS INTERLINK WITH THE WINDINGS OF THE COIL INCLUDED IN THE SECOND TUNED CIRCUIT IN ORDER TO GENERATE CORRESPONDING SIGNAL VOLTAGES IN THIS SECOND CIRCUIT.

IF THE TWO TUNED CIRCUITS OF FIG. 4 WERE EXACTLY ALIKE IN THEIR TUNING CHARACTERISTICS, THEN THEY WOULD PROVIDE IDENTICAL SELECTIVITY CURVES, PROVIDED THAT THERE IS NO MAGNETIC COUPLING BETWEEN THEM. HOWEVER, IF MAGNETIC COUPLING IS PROVIDED BETWEEN THESE TWO CIRCUITS, THEN THE TUNING CHARACTERISTICS OF THE TWO CIRCUITS REACT UPON EACHOTHER IN SUCH A MANNER AS TO ALTER THEIR COMBINED TUNING CHARACTERISTICS. THE RESULT IS, THAT THE SELECTIVITY CURVES OF THE TWO CIRCUITS DIFFER SLIGHTLY

BUT THEY OVERLAP IN ORDER TO PRODUCE THE TYPE OF CURVE ILLUSTRATED AT THE RIGHT OF FIG. 4. THIS CURVE, YOU WILL NOTE, HAS TWO RESONANCE PEAKS, ONE FOR EACH OF THE TWO TUNED CIRCUITS.

THIS CURVE OF FIG. 4 IS THE TYPICAL TYPE OF SELECTIVITY CURVE AS REALIZED WHEN EMPLOYING BAND-PASS PRINCIPLES. OBSERVE IN THIS ILLUSTRATION THE DEGREE OF "STEEPNESS" OF THE SIDES OF THE CURVE, WHICH PREVENTS INTERFERENCE BETWEEN STATIONS AND THAT THE CURVE MAINTAINS A FAIRLY UNIFORM WIDTH THROUGHOUT ITS LENGTH.

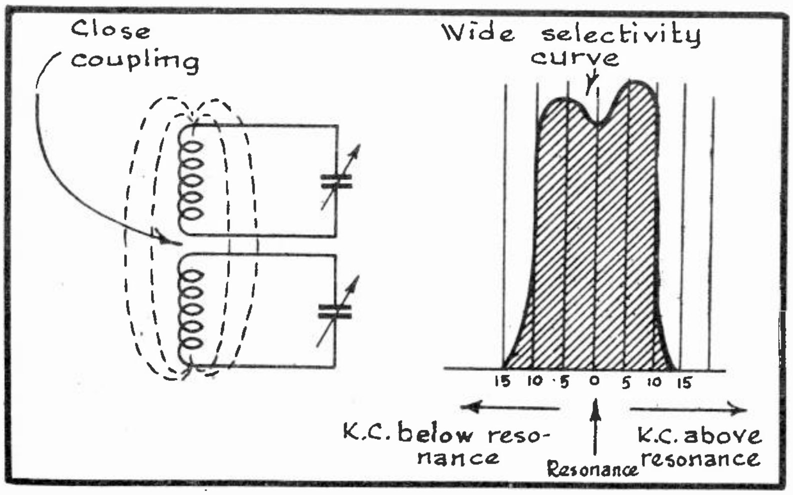

FIG. 5
Close Coupling Widens Curve.

LOOKING AT THE VERY TOP OF THE CURVE IN FIG. 4, YOU WILL OBSERVE THAT AT THE ABSOLUTE RESONANT FREQUENCY OF THE COMBINED TUNED CIRCUITS (CORRESPONDING TO THE VERTICAL LINE MARKED "0") THE CURVE IS SLIGHTLY LOWER THEN THAN AT THE PEAKS TOWARD EITHER SIDE OF THIS FREQUENCY. THIS INDICATES THAT THERE IS A SLIGHT LOSS AS FAR AS AMPLIFICATION IS CONCERNED, AT THE ABSOLUTE RESONANT FREQUENCY AND THIS IS A NATURAL CHARACTERISTIC OF ALL BAND-PASS FILTER CIRCUITS AS USED IN R.F. AMPLIFIERS. NEVERTHELESS, BY DESIGNING HIGH GAIN CIRCUITS THROUGHOUT THE BALANCE OF THE RECEIVER, THIS LOSS CAN BE COMPENSATED FOR AND THE IMPROVEMENT IN COMBINED SELECTIVITY AND TONE QUALITY WARRANTS THE SLIGHT LOSS IN AMPLIFICATION.

HOW COUPLING AFFECTS TUNING

CONTINUING OUR INVESTIGATION OF THE "BAND-PASS EFFECT", WE NEXT COME TO THE MATTER CONCERNING THE WIDTH OF THE SELECTIVITY CURVE OFFERED BY DIFFERENT DESIGNS.

IN FIG. 5, WE SEE WHAT HAPPENS WHEN THE TUNED CIRCUITS OF A BAND PASS CIRCUIT ARE CLOSELY COUPLED. AS YOU WILL OBSERVE, THIS CONDITION CAUSES THE SELECTIVITY CURVE TO BE WIDENED AND THIS OF COURSE MEANS THAT WHEN THE CIRCUITS ARE TOGETHER TUNED TO A GIVEN FREQUENCY, A WIDE CHANNEL OF FREQUENCIES WILL BE PASSED THROUGH THE SYSTEM. THAT IS, THE SYSTEM IS BROAD TUNING WITH A SHARP "CUT-OFF" AT BOTH SIDES OF THE RESONANT FREQUENCY.

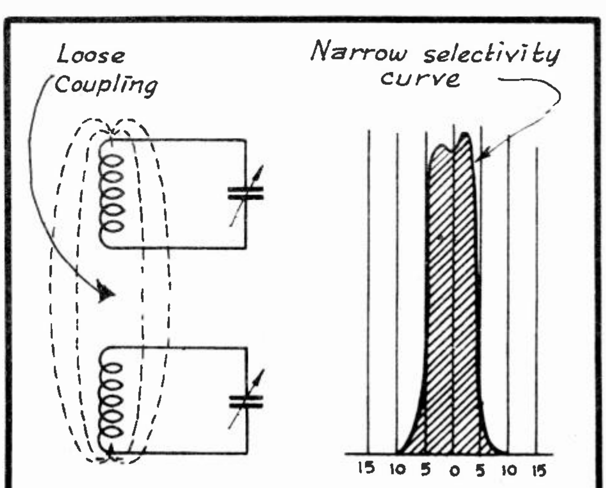

FIG. 6
Loose coupling Narrows Curve.

NOW UPON INSPECTING FIG. 6 VERY CAREFULLY, YOU WILL SEE WHAT TAKES PLACE IN THE SYSTEM UPON DECREASING THE DEGREE OF COUPLING BETWEEN THE TUNED CIRCUITS. UNDER THESE CONDITIONS, THE SELECTIVITY IS INCREASED AND THE SELECTIVITY CURVE IS CORRESPONDINGLY NARROWED, SHOWING THAT EVEN WITH BAND-PASS CIRCUITS IMPROPERLY DESIGNED, IT IS POSSIBLE TO GET SIDE-BAND SUPPRESSION WITH A CORRESPONDING LOSS OF THE HIGHER AUDIO FREQUENCIES. AT THE SAME TIME, A DECIDED LOSS IN AMPLIFICATION IS ENCOUNTED BY TOO LOOSE COUPLING.

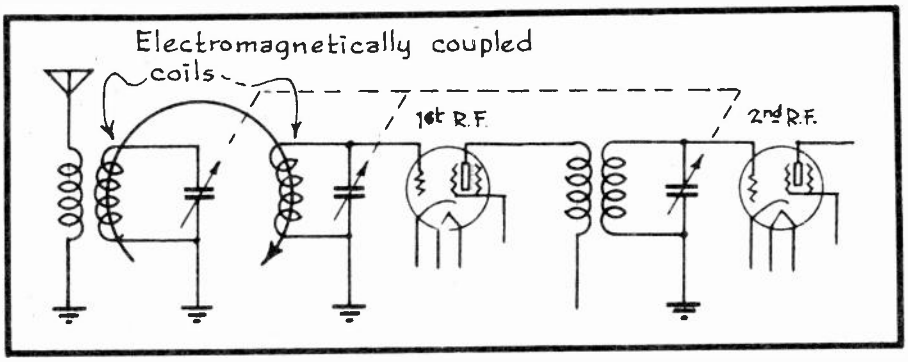

FIG. 7

Band-Pass Circuit Used in a Tuned R.F. Receiver

APPLICATION

HAVING BY THIS TIME FAMILIARIZED YOURSELF WITH THE BASIC PRINCIPLES GOVERNING BAND PASS ACTION, LET US NOW PROCEED BY INVESTIGATING THE MATTER OF HOW THESE PRINCIPLES ARE MOST EFFECTIVELY APPLIED TO USE IN THE DESIGN OF R.F. AMPLIFIERS.

OUR FIRST EXAMPLE IS LAID OUT FOR US IN FIG. 7. HERE YOU WILL SEE HOW THE TYPE OF BAND SELECTOR JUST DESCRIBED CAN BE APPLIED TO A SIMPLE TUNED R.F. RECEIVER CIRCUIT. IT IS UNDERSTOOD, OF COURSE, THAT ONLY THAT PORTION OF THE RECEIVER CIRCUIT IS ILLUSTRATED HERE WHICH HAS A DIRECT BEARING UPON OUR PRESENT DISCUSSION OF BAND PASS FILTER CIRCUITS. THE REMAINDER OF THE CIRCUITS ARE CONVENTIONAL.

FIG. 7 DEMONSTRATES THE CONVENTIONAL MANNER OF ILLUSTRATING THIS PARTICULAR FORM OF BAND PASS CIRCUIT IN A CIRCUIT DIAGRAM. THE LONG CURVED ARROW INTERLINKING THE TWO COILS INDICATES THAT IN THE ACTUAL RECEIVER, THESE TWO COILS ARE SO ORIENTED OR PLACED IN RESPECT TO EACHOTHER THAT THERE IS ELECTROMAGNETIC COUPLING BETWEEN THEM. AS YOU WILL ALSO OBSERVE IN FIG. 7, THIS SYSTEM PROVIDES TWO TUNED CIRCUITS PRECEDING THE 1ST R.F. TUBE. THE TUNING CONDENSERS ARE ALL CONTROLLED BY A SINGLE SHAFT AS INDICATED ON THIS DIAGRAM.

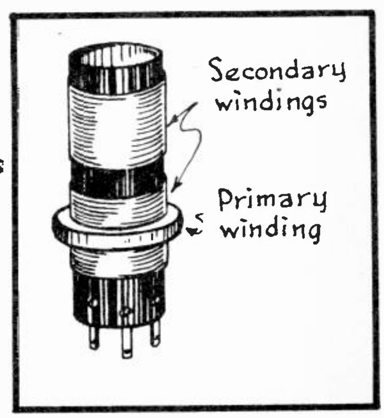

FIG. 8

Band-Pass Coil Assembly.

A TYPICAL BAND-PASS COIL ASSEMBLY

IN FIG. 8 YOU WILL SEE HOW THE TYPE OF BAND PASS COIL ASSEMBLY OF FIG. 7 IS ACTUALLY CONSTRUCTED. AS YOU WILL OBSERVE IN FIG. 8, THE TWO COILS FOR THE TUNED CIRCUITS AND WHICH ARE LABELED AS THE "SECONDARY WINDING'S" IN FIG. 8 ARE BOTH WOUND ON THE SAME COIL FORM. THE SPACE ALLOWED BETWEEN THESE TWO SECONDARY OR TUNING WINDING'S IS SUCH THAT THE DEGREE OF ELECTROMAGNETIC COUPLING BETWEEN THEM WILL BE JUSTEXACTLY RIGHT IN ORDER TO GIVE THE DESIRED BAND-PASS CHARACTERISTIC. THE PRIMARY WINDING IN FIG. 8 IS CONNECTED BETWEEN THE ANTENNA AND GROUND IN

THE CUSTOMARY MANNER AND AS ILLUSTRATED IN FIG. 7.

IF THE GANGED TUNING CONDENSERS, USED IN CONJUNCTION WITH THE TUNING COILS, ARE RATED AT A CAPACITY OF .00035 MFD. PER SECTION, THEN THE TUNING COILS WILL EACH HAVE TO BE DESIGNED TO MATCH THE CONDENSER OF THIS CAPACITY IN THE SAME MANNER AS THOUGH THEY WERE SECONDARIES OF A CONVENTIONAL R.F. TRANSFORMER.

THE TRANSFORMER EMPLOYED BETWEEN THE 1ST AND 2ND R.F. TUBES IN THE CIRCUIT OF FIG. 7 IS A CONVENTIONAL R.F. TRANSFORMER.

A BAND-PASS CIRCUIT WITH COUPLING COIL

BESIDES THE TYPE OF BAND-PASS CIRCUIT SHOWN YOU SO FAR IN THIS LESSON, THERE ARE A NUMBER OF OTHERS AND THESE WILL BE DESCRIBED TO YOU IN THE FOLLOWING PAGES.

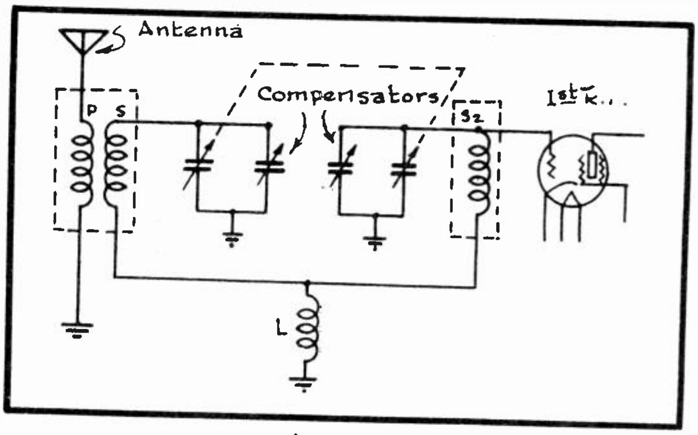

FIG. 9

A Band-Pass Circuit With Coupling Coil.

ONE OF THESE OTHER TYPES, WHICH IS VERY POPULAR AMONG RECEIVER MANUFACTURERS, IS SHOWN YOU IN FIG. 9. HERE YOU WILL SEE THAT THE PRIMARY WINDING "P" OF AN R.F. TRANSFORMER IS CONNECTED BETWEEN THE ANTENNA AND GROUND. THE SECONDARY WINDING "S" OF THIS SAME TRANSFORMER HAS ONE OF ITS EXTREMETIES CONNECTED TO THE INSULATED SIDE OF THE FIRST SECTION OF THE GANGED TUNING CONDENSER, WHILE ITS OTHER EXTREMETY IS CONNECTED DIRECTLY TO THE LOWER END OF ANOTHER COIL S_2. THE UPPER END OF COIL S_2 IS CONNECTED BOTH TO THE CONTROL GRID OF THE 1ST R.F. TUBE AND THE INSULATED SIDE OF THE SECOND SECTION OF THE GANGED TUNING CONDENSER. THE LOWER EXTREMETIES OF BOTH COILS S AND S_2 ARE THEN GROUNDED THROUGH THE SMALL COIL L.

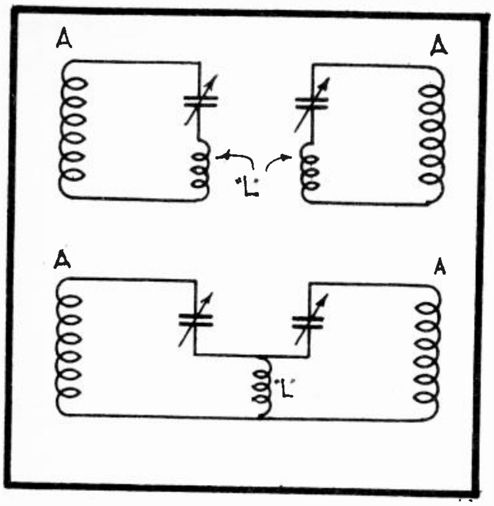

FIG.10

Employing a Coupling Coil

EACH OF THE TUNING CONDENSERS IS SHUNTED BY THE CUSTOMARY TRIMMER OR COMPENSATING CONDENSER. COIL S IS IDENTICAL TO COIL S_2, HAVING THE SAME NUMBER OF TURNS BUT NO PRIMARY WINDING IS USED IN CONJUNCTION WITH S_2. IN ADDITION, S_2 IS ENCLOSED IN A SEPARATE SHIELD CAN, WHILE COILS P AND S, CONSTITUTE A CONVENTIONAL R.F. TRANSFORMER, CONTAINED WITHIN AN INDIVIDUAL SHIELD CAN.

THIS IS A POPULAR TYPE OF MODERN BAND-PASS CIRCUIT PRECEDING THE 1ST R.F. TUBE IN MANY COMMERCIAL RECEIVERS AND SO IT IS IMPORTANT THAT YOU FAMILIARIZE YOURSELF WITH IT THOROUGHLY.

IN ORDER TO ACQUAINT YOU WITH THE OPERATING PRINCIPLE OF THE BAND PASS CIRCUIT OF FIG. 9, YOUR ATTENTION IS GOING TO BE CALLED FIRST TO THE

TWO TUNED CIRCUITS IN THE UPPER PORTION OF FIG. 10. BY STUDYING THEIR CIRCUITS CAREFULLY, YOU WILL NOTE THAT EACH OF THEM CONSISTS OF A TUNING COIL "A" CONNECTED IN SERIES WITH A VARIABLE CONDENSER AND A SMALL INDUCTANCE COIL "L".

THE EFFECT OF THE COUPLING COIL UPON THE CIRCUIT

NOW IF WE SHOULD COUPLE THESE TWO TUNED CIRCUITS TOGETHER, SO THAT A SINGLE COIL "L" WILL BE IN SERIES WITH BOTH OF THE TUNED CIRCUITS, WE WILL OBTAIN A CIRCUIT ARRANGEMENT AS PICTURED IN THE LOWER ILLUSTRATION OF FIG. 10. HERE YOU WILL OBSERVE THAT THE SMALL COUPLING COIL OR INDUCTANCE "L" IS SIMULTANEOUSLY CONNECTED IN SERIES WITH BOTH TUNED CIRCUITS.

FROM AN ELECTRICAL STANDPOINT, THE CIRCUIT ARRANGEMENT IN THE LOWER PART OF FIG. 10 IS EQUAL TO THE BAND-PASS CIRCUIT OF FIG. 9, ONLY THAT DIRECT WIRING IS SHOWN IN FIG. 10 IN PLACE OF THE COMMON GROUND CONNECTIONS.

IN THE CONSTRUCTION OF THIS TYPE OF BAND-PASS, OR "SELECTOR CIRCUIT," THE TWO TUNING CONDENSERS ARE SECTIONS OF THE SAME GANGED TUNING CONDENSER AND CONSEQUENTLY ARE OPERATED BY THE SAME CONTROL. TUNING COILS "A" ARE WOUND ON SEPARATE FORMS AND THE NUMBER OF TURNS AND WIRE SIZE USED IN THESE TWO COILS IS SUCH AS TO MATCH THE TUNING CONDENSER CAPACITY. IN OTHER WORDS, IF THE TUNING CONDENSERS ARE RATED AT .00035 MFD. CAPACITY, THEN COILS "A" ARE WOUND TO MATCH THIS CAPACITY THE SAME AS FOR THE CONVENTIONAL TYPE OF R.F. TRANSFORMER.

SINCE COILS "A" ARE PLACE WITHIN SEPARATE SHIELD CANS, THERE IS NO ELECTROMAGNETIC COUPLING BETWEEN THEM. THE ONLY COUPLING BETWEEN THESE TWO TUNED CIRCUITS IS ACCOMPLISHED THROUGH THE SMALL COUPLING COIL "L", THEREFORE THE DEGREE OF COUPLING IN THIS CASE, DEPENDS ENTIRELY UPON THE INDUCTANCE VALUE OF COIL "L". THAT IS TO SAY, THE GREATER THE INDUCTANCE VALUE OF COIL "L", THE CLOSER WILL BE THE COUPLING, AND THIS WILL IN TURN BROADEN TUNING.

BY DECREASING THE INDUCTANCE OF COIL "L", THE BAND PASS CIRCUIT PASSES A NARROWER BAND OF FREQUENCIES THROUGH THE SYSTEM. THAT IS, THE SYSTEM WILL TUNE SHARPER AND THE SELECTIVITY CURVE WILL BECOME NARROWER. BY CHOOSING A CORRECT INDUCTANCE VALUE FOR COIL "L", IT WILL BE POSSIBLE TO ADJUST THE BAND SELECTOR CIRCUIT TO PASS THE DESIRED 10 KC. FREQUENCY RANGE THROUGH IT.

DATA FOR CONSTRUCTION OF "COMMON INDUCTANCE" BAND-PASS CIRCUIT

AS A PRACTICAL EXAMPLE OF THE CONSTRUCTION OF SUCH A BAND SELECTOR OF FIG. 9, THE FOLLOWING DATA COULD BE USED, ASSUMING THAT THE TUNING CONDENSERS HAVE A CAPACITY RATING OF .00035 MFD: IF THE TUNING COILS S AND S_2 OF FIG. 19 ARE WOUND ON TUBULAR COIL FORMS OF 1" DIAMETER, THEN USE 130 TURNS OF #30 B & S ENAMELED WIRE FOR BOTH OF THESE WINDINGS. THE PRIMARY FOR THE WINDING S CAN BE ANY OF THE CONVENTIONAL TYPES SPECIFIED FOR CONVENTIONAL R.F. TRANSFORMERS IN YOUR PREVIOUS LESSONS.

THE SMALL COUPLING COIL "L" SHOULD BE WOUND ON AN INDIVIDUAL FORM, TO BE PLACED AT SOME CONVENIENT POINT IN THE CIRCUIT BUT ISOLATED FROM BOTH COILS S AND S_2 AS FAR AS ELECTROMAGNETIC COUPLING IS CONCERNED. IF

THIS COIL IS TO BE WOUND ON A 1" DIAMETER FORM, THEN USE FROM 2 TO 6 TURNS OF #30 B & S ENAMELED WIRE. NATURALLY, THE EXACT NUMBER OF TURNS TO USE FOR THIS COUPLING COIL WILL HAVE TO BE DETERMINED BY EXPERIMENT AND THE THING TO DO IN THIS CASE IS SIMPLY TO USE THE NUMBER OF TURNS REQUIRED IN ORDER TO OBTAIN THE SHARPNESS OF TUNING DESIRED.

ANY OTHER TUNING CONDENSER SECTIONS LOCATED IN SUCCEEDING TUNED CIRCUITS CAN BE OPERATED TOGETHER WITH THE BAND SELECTOR SECTIONS BY MEANS OF A SINGLE CONTROL, PROVIDED THAT ALL TUNING COILS ARE PROPERLY MATCHED TO THE SAME TUNING CONDENSER CAPACITY.

ANOTHER SELECTOR CIRCUIT

STILL ANOTHER FORM OF SELECTOR CIRCUIT IS SHOWN YOU IN FIG. 11. IN THIS CASE, A CONVENTIONAL R.F. TRANSFORMER IS USED IN THE ANTENNA INPUT CIRCUIT BUT THE SECONDARY WINDING OF THIS TRANSFORMER COMPLETES ITS CIRCUIT TO GROUND BY WAY OF A SMALL COUPLING COIL, WHICH IS LOCATED IN AN INDUCTIVE RELATIONSHIP TO THE TUNING COIL OF THE SECOND TUNED CIRCUIT.

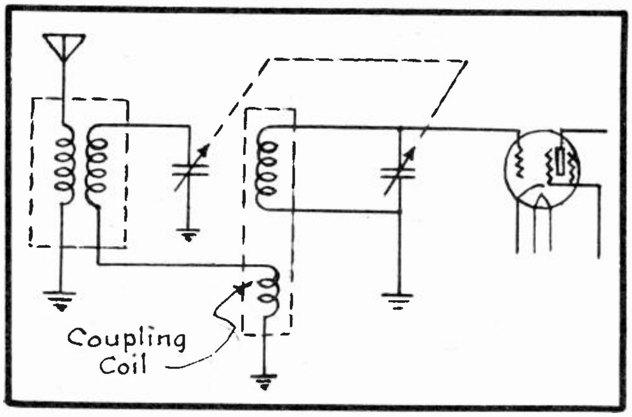

FIG. 11
Another Type of Selector Circuit.

THIS COUPLING COIL MAY CONSIST OF 2 TO 6 TURNS OF MAGNET WIRE WOUND OVER THE SAME FORM WITH THE SECOND TUNING COIL. THE NUMBER OF TURNS AND CLOSENESS OF THIS COIL TO THE SECOND TUNING COIL DETERMINES THE SHARPNESS OF TUNING. SO THIS CAN BE ADJUSTED BY EXPERIMENT IN ORDER TO OBTAIN THE DESIRED TUNING CHARACTERISTICS. THE DOTTED LINES SURROUNDING THE COILS IN FIG. 11 SHOW WHICH OF THE COILS ARE ENCLOSED TOGETHER IN THE SAME SHIELD CAN.

THE OPERATING PRINCIPLES OF THIS TYPE OF CIRCUIT ARE QUITE EASY TO UNDERSTAND. TO BEGIN WITH, ENERGY COLLECTED BY THE ANTENNA CIRCUIT IS TRANSFERRED BY THE PRIMARY WINDING TO THE SECONDARY WINDING BY MEANS OF ELECTROMAGNETIC INDUCTION. THEN SINCE THE COUPLING COIL IS ACTUALLY A

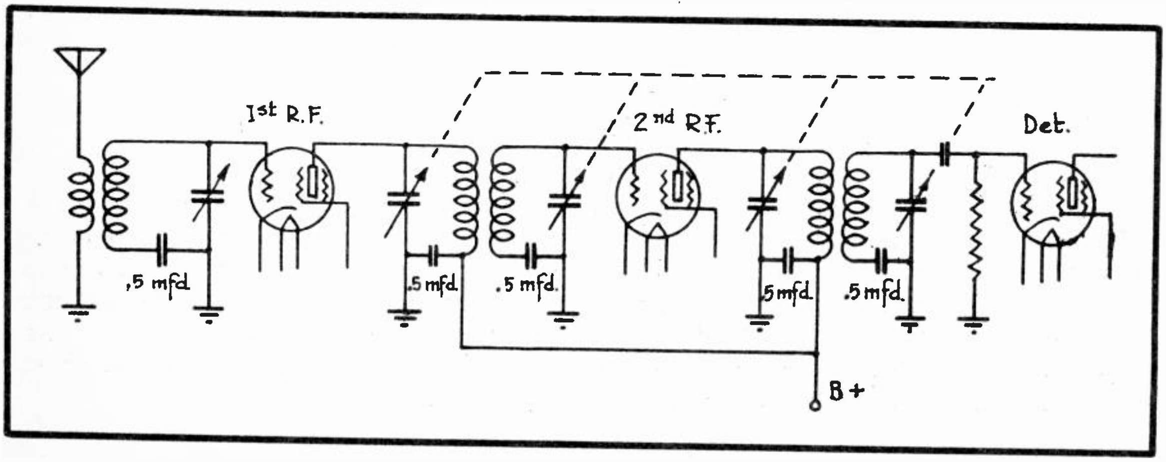

FIG. 12
Band-Pass System with Tuned Plate and Grid Circuits.

PART OF THE FIRST TUNING COIL, IT SERVES TO TRANSFER THE SIGNAL ENERGY THE THE SECOND TUNING COIL ALSO THROUGH THE MEDIUM OF ELECTROMAGNETIC INDUCTION AND THUS THE SIGNAL VOLTAGE CHANGES ARE PASSED ON TO THE GRID OF THE FIRST TUBE.

MULTIPLE BAND-PASS CIRCUITS

A BAND SELECTOR OF STILL DIFFERENT CONSTRUCTION IS ILLUSTRATED FOR YOU IN FIG. 12. IN THIS SYSTEM, A CONVENTIONAL TUNED CIRCUIT IS USED FOR THE INPUT INTO THE FIRST TUBE.

IN THE FOLLOWING STAGES, THE TRANSFORMERS HAVE PRIMARY AND SECONDARY WINDINGS WHICH ARE IDENTICAL, THAT IS THEY ARE COMPOSED OF THE SAME NUMBER OF TURNS AND EACH TUNED WITH A VARIABLE CONDENSER.

THE FIRST TUNING CONDENSER IS CONTROLLED INDIVIDUALLY BUT THE FOLLOWING FOUR TUNING CONDENSER ARE ALL SECTIONS OF A FOUR GANG TUNING CONDENSER AND ARE THUS ALL OPERATED BY A SINGLE CONTROL. SINCE THE ROTOR PLATES OF THE GANGED TUNER ARE ALL MUTUALLY GROUNDED, IT IS NECESSARY TO USE THE .5 MFD. COUPLING CONDENSER BETWEEN THE PLATE CIRCUIT COILS AND THEIR RESPECTIVE TUNING CONDENSERS IN ORDER TO COMPLETE THE PLATE TUNING CIRCUIT WITHOUT GROUNDING OUT THE RESPECTIVE PLATE CIRCUITS.

DUE TO THE NECESSITY OF THESE .5 MFD. COUPLING CONDENSER IN THE TUNED PLATE CIRCUITS, THEY MUST ALSO BE USED IN THE GRID TUNING CIRCUITS SO THAT THE TUNING CHARACTERISTIC OF THESE CIRCUITS WILL BE BALANCED WITH THE PLATE TUNED CIRCUITS.

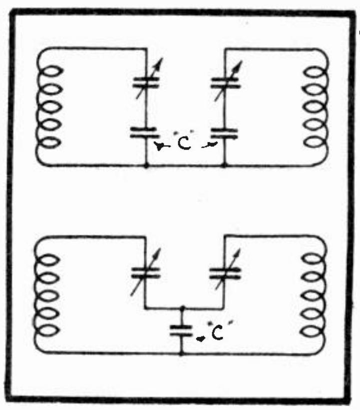

FIG. 13
Capacitive Coupling.

SINCE THE PLATE CIRCUIT COILS ARE COUPLED TO THE GRID CIRCUIT COILS OF THIS BAND-PASS ARRANGEMENT THROUGH THE MEDIUM OF ELECTROMAGNETIC INDUCTION, WE FIND THAT THE DEGREE OF SELECTIVITY IS GOVERENED BY THE EXTENT OF COUPLING BETWEEN THESE TUNED COILS. THEREFORE, THE DISTANCE BETWEEN THE TUNED COILS IS VARIED UNTIL THE DESIRED TUNING CHARACTERISTICS ARE OBTAINED.

CAPACITY COUPLED BAND-PASS CIRCUIT

ANOTHER TYPE OF BAND-PASS CIRCUIT IS BASED UPON THE PRINCIPLES ILLUSTRATED IN FIG. 13. AT THE TOP OF THIS ILLUSTRATION YOU WILL SEE TWO TUNED CIRCUITS, EACH CONSISTING OF AN INDUCTANCE, A TUNING CONDENSER AND A FIXED CONDENSER ALL CONNECTED IN SERIES. IF THE VALUES CHOSEN FOR THE COMPONENT PARTS OF EACH OF THESE TWO CIRCUITS ARE ALIKE, THEN THE TUNING CHARACTERISTICS OF THE TWO CIRCUITS WILL BE IDENTICAL.

NOW IF WE WILL COUPLE THESE TWO TUNED CIRCUITS TOGETHER IN SUCH A WAY THAT THE CONDENSERS "C" ARE REPLACED BY A SINGLE CONDENSER "C", WHICH IS COMMON FOR BOTH CIRCUITS, THEN WE WILL ARRIVE AT THE CIRCUIT ARRANGEMENT ILLUSTRATED IN THE LOWER PORTION OF FIG. 13. SINCE THIS COUPLING CONDENSER IS COMMON TO BOTH CIRCUITS, THE CIRCUITS WILL REACT UPON EACHOTHER AND RESONATE AT TWO DIFFERENT FREQUENCIES, SEPARATED BUT ONLY SLIGHTLY FROM EACHOTHER. THESE SELECTIVITY CURVES WILL OVER-LAP, NEVERTHELESS, SO THAT THE RESULTING SELECTIVITY CURVE OF THE COMBINA-

TION CIRCUIT WILL BE A TYPICAL BAND-PASS TYPE SELECTIVITY CURVE WITH TWIN RESONANCE PEAKS.

THE VALUE OF THE COMMON CAPACITY OR COUPLING CAPACITY "C" OF THE LOWER ILLUSTRATION IN FIG. 13 DETERMINES THE SHARPNESS OF TUNING OFFERED BY THE BAND-PASS CIRCUIT. THE GREATER THE CAPACITY OF CONDENSER "C", THE CLOSER WILL BE THE COUPLING EFFECT BETWEEN THE TWO TUNED CIRCUITS AND THE BROADER THE TUNING. THE SMALLER THAT THE CAPACITIVE VALUE OF "C" IS MADE, THE LOOSER WILL BE THE COUPLING BETWEEN THE CIRCUITS AND THE SHARPER THE TUNING CHARACTERISTICS OF THE CIRCUIT.

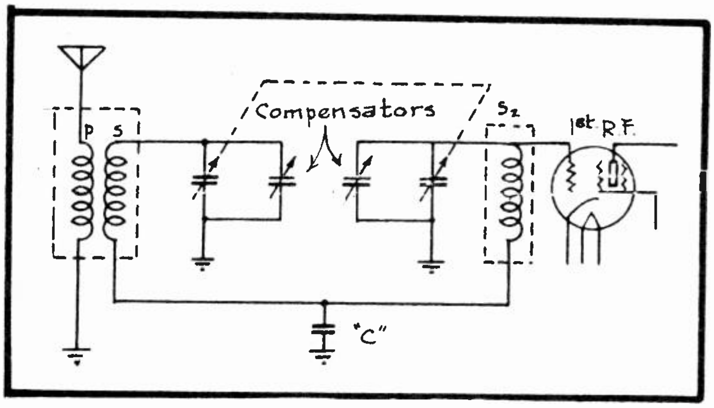

FIG. 14

Application of Band Pass circuit With Capacity Coupling.

FIG. 14 SHOWS YOU HOW THE CAPACITIVE COUPLED BAND-PASS CIRCUIT IS APPLIED TO ACTUAL RECEIVER CONSTRUCTION. ALTHOUGH THE CIRCUIT OF FIG. 14 MAY AT FIRST GLANCE APPEAR AS DIFFERING CONSIDERABLE FROM THE FUNDAMENTAL CIRCUIT OF FIG. 13, YET YOU WILL NOTE AFTER CLOSER INSPECTION THAT THE BAND PASS CIRCUITS OF FIG. 13 AND 14 ARE ALIKE. THE ONLY DIFFERENCE IS THAT THE GROUND RETURN SYSTEM OF WIRING COMPLETES ONE SIDE OF THE CIRCUIT IN FIG. 14. IN ADDITION, FIG. 14 ALSO ILLUSTRATES THE COMPENSATOR CONDENSERS AS SHUNTED ACROSS THE TUNING CONDENSERS.

THE INPUT TRANSFORMER WHICH COUPLES THE ANTENNA CIRCUIT TO THE TUNED CIRCUITS, CONSISTS OF A CONVENTIONAL R.F. TRANSFORMER WITH THE PRIMARY WINDING P AND THE SECONDARY WINDING S. THIS TRANSFORMER IS HOUSED IN AN INDIVIDUAL SHIELD CAN.

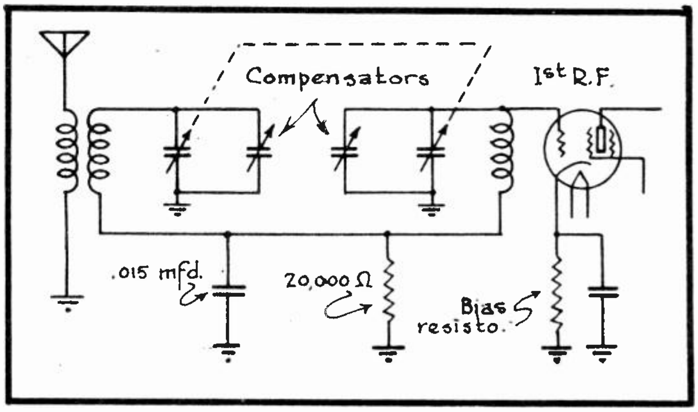

FIG. 15

Applying Bias Voltage to the System.

COIL S_2 CONSISTS OF A TUNING WINDING ONLY, WOUND ON AN INDIVIDUAL FORM AND THE NUMBER OF TURNS USED ON COIL S_2 IS THE SAME AS THE NUMBER OF TURNS USED ON COIL S. THE DIAMETER OF THE FORM, OF COURSE, MUST ALSO BE THE SAME FOR THE R.F. TRANSFORMER AND COIL S_2. COILS S AND S_2 ARE BOTH WOUND TO MATCH THE CAPACITY OF THE TUNING CONDENSERS BEING USED AND S_2 IS HOUSED IN AN INDIVIDUAL SHIELD CAN, AS ILLUSTRATED BY THE DOTTED ENCLOSURE IN FIG. 14.

THE COUPLING CONDENSER "C" CAN BE LOCATED AT ANY CONVENIENT POINT IN THE CIRCUIT. BY EXPERIMENT, THE VALUE FOR CONDENSER "C" CAN BE SELECTED IN ORDER TO GIVE THE CIRCUIT THE DESIRED TUNING CHARACTERISTIC. A CAPA-

CITY OF .015 MFD. IS A GOOD AVERAGE VALUE FOR "C" WHEN USING TUNING CONDENSERS WITH A RATED CAPACITY OF .00035 MFD.

SINCE THE CIRCUIT OF FIG. 14 CONNECTS THE GRID OF THE 1ST R.F. TUBE TO GROUND THROUGH THE CONDENSER "C", IT WOULD BE IMPOSSIBLE TO IMPRESS A BIAS VOLTAGE UPON THIS GRID IN THE CONVENTIONAL WAY BECAUSE THE D.C. BIAS POTENTIAL COULD NOT BE MADE EFFECTIVE THROUGH THE CONDENSER "C".

TO OVERCOME THIS DIFFICULTY, THE COUPLING CONDENSER "C" CAN BE SHUNTED BY A 20,000 OHM FIXED RESISTOR AS SHOWN IN FIG. 15. IN THIS WAY, IT WILL BE POSSIBLE TO PERMIT THE BIAS VOLTAGE, WHICH IS DEVELOPED ACROSS THE CONVENTIONAL BIAS RESISTOR, TO BE APPLIED TO THE GRID OF THE R.F. TUBE BY WAY OF THE 20,000 OHM RESISTOR.

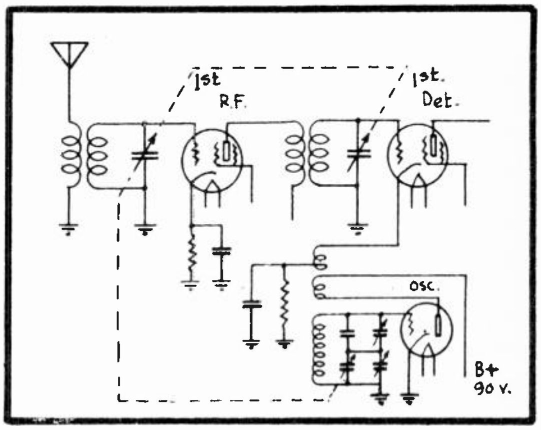

FIG. 16

Superheterodyne Input and Mixing Circuit.

SINGLE CONTROL SUPERHETERODYNES

NOW THAT WE HAVE INVESTIGATED BAND-PASS CIRCUITS QUITE THOROUGHLY, LET US CONTINUE BY GOING INTO A MORE DETAILED STUDY CONCERNING ADDITIONAL DESIGN FEATURES OF SINGLE CONTROL SUPERHETERODYNE RECEIVERS.

FROM YOUR PAST STUDIES OF SUPERHETERODYNE RECEIVER PRINCIPLES, YOU HAVE LEARNED THAT IT IS A COMMON PRACTICE IN THE CONSTRUCTION OF THIS TYPE OF RECEIVER TO EMPLOY ONE TUNED R.F. STAGE PRECEDING THE MIXER TUBE OR FIRST DETECTOR. THIS IS ILLUSTRATED FOR YOU IN FIG. 16 AND AS FAR AS THIS INPUT R.F. STAGE IS CONCERNED, YOU WOULD DESIGN IT ACCORDING TO THE SAME GENERAL PRINCIPLES AS ALREADY GIVEN YOU RELATIVE TO THE CONVENTIONAL TYPE OF TUNED R.F. AMPLIFIER. THAT IS, THE INDUCTANCE OF THE SECONDARY OF THE INPUT R.F. TRANSFORMER WOULD HAVE TO BE SUCH SO THAT THIS TUNED CIRCUIT WILL COVER ALL OF THE BROADCAST FREQUENCIES WHEN USED WITH A GIVEN TUNING CONDENSER. SO IN THIS RESPECT, YOU HAVE NOTHING RADICALLY NEW TO LEARN.

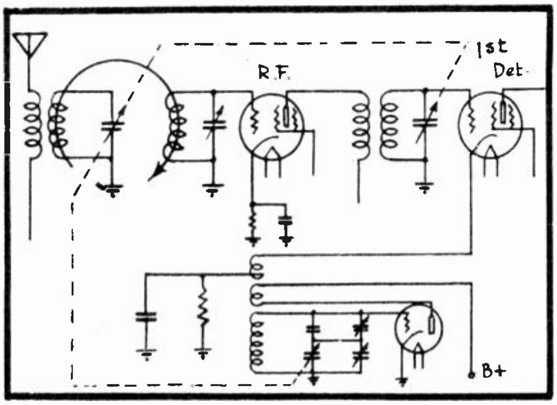

FIG. 17

Superheterodyne Mixer Circuit With Band Pass Pre-selector Stage.

IN THE CIRCUIT DESIGN ILLUSTRATED IN FIG. 16, A THREE-GANG TUNING CONDENSER WOULD BE EMPLOYED. ONE SECTION BEING USED FOR THE 1ST R.F. OR PRESELECTOR STAGE, ONE FOR THE 1ST DETECTOR OR "MIXER STAGE" AND THE THIRD FOR THE OSCILLATOR. ALL THREE SECTIONS ARE OPERATED WITH A SINGLE CONTROL AS INDICATED BY THE DOTTED LINES.

NOW IN FIG. 17 YOU WILL SEE AN EFFECTIVE WAY IN WHICH A BAND PASS FILTER CIRCUIT CAN BE EMPLOYED IN THE 1ST R.F. OR PRESELECTOR STAGE OF A SUPERHETERODYNE RECEIVER. IN THIS CASE, A FOUR GANG TUNING CONDENSER IS EMPLOYED, ALL SECTIONS BEING CONTROLLED BY THE SAME SHAFT AS INDICATED BY THE DOTTED LINES.

WHEN USING A CIRCUIT AS THAT OF FIG. 17, THE TUNING CHARACTERISTICS OF THE PRE-SELECTOR CIRCUITS AND THE TUNING CIRCUIT OF THE 1ST DETECTOR ARE MATCHED TO EACHOTHER AS ALREADY DESCRIBED FOR SIMPLE TUNED R.F. RECEIVERS EMPLOYING A BAND-PASS FILTER CIRCUIT.

HOWEVER, WHEN IT COMES TO THE MIXING CIRCUIT, WHERE THE OSCILLATIONS GENERATED BY THE RECEIVER'S OSCILLATOR COMBINE WITH THE BROADCAST FREQUENCY, IN ORDER TO PRODUCE THE DESIRED INTERMEDIATE FREQUENCY, THEN WE HAVE AN ENTIRELY DIFFERENT CONDITION TO CONTEND WITH AND IT IS THIS OSCILLATOR AND MIXING TUBE CIRCUIT UPON WHICH WE ARE GOING TO CENTER OUR ATTENTION AT THE PRESENT TIME.

YOU HAVE ALREADY LEARNED THAT IN SUPERHETERODYNE RECEIVERS, WE USE THE FREQUENCY DIFFERENCE BETWEEN THE SIGNAL AND OSCILLATOR FREQUENCIES AS THE INTERMEDIATE FREQUENCY FOR FURTHER AMPLIFICATION AND IN MOST MODERN SUPERHETERODYNES, AN INTERMEDIATE FREQUENCY OF 175 KC IS BEING USED. THIS MEANS THAT IF A BROADCAST SIGNAL AT 1000 KC. IS TO BE RECEIVED, THE OSCILLATOR WILL HAVE TO BE ADJUSTED TO GENERATE A FREQUENCY OF 1175 KC. IN ORDER TO GIVE US A BEAT FREQUENCY OF 1175 MINUS 1000 OR 175 KC. FOR THE INTERMEDIATE FREQUENCY AMPLIFIER.

THE OSCILLATOR

IT THUS ALSO FOLLOWS THAT IN ORDER TO RECEIVE BROADCAST SIGNALS IN THE RANGE OF FROM 550 KC. TO 1500 KC. WILL REQUIRE THE USE OF A LOCAL OSCILLATOR, WHICH CAN BE TUNED OVER THE FREQUENCY BAND EXTENDING FROM 725 KC. TO 1675 KC. FURTHERMORE, IT IS CLEAR THAT IN ORDER TO HAVE A SINGLE DIAL TUNING CONTROL, IT IS NECESSARY THAT REGARDLESS OF WHICH FREQUENCY TO WHICH THE INPUT R.F. AND MIXER TUBE CIRCUITS ARE TUNED, THE OSCILLATOR CIRCUIT MUST AT THIS SAME INSTANT BE TUNED EXACTLY TO A FREQUENCY JUST 175 KC. GREATER OR HIGHER THAN THE FREQUENCY OF THE INCOMING SIGNAL. IT THUS ALSO FOLLOWS IN LOGICAL ORDER THAT TO OBTAIN SATISFACTORY ONE DIAL TUNING, THE OSCILLATOR MUST CONSTANTLY MAINTAIN A 175 KC. SEPARATION FROM THE FREQUENCY TO WHICH THE R.F. AND MIXER TUBE CIRCUITS ARE TUNED AS THE SINGLE TUNING CONTROL IS OPERATED FROM ITS ONE EXTREME POSITION TO THE OTHER. WHEN THIS IMPORTANT CONDITION IS FULFILLED, WE SAY THAT THE OSCILLATOR TUNING CONDENSER TRACKS WITH THE TUNING CONDENSERS OF THE R.F. PRE-SELECTOR AND MIXER TUBE STAGES.

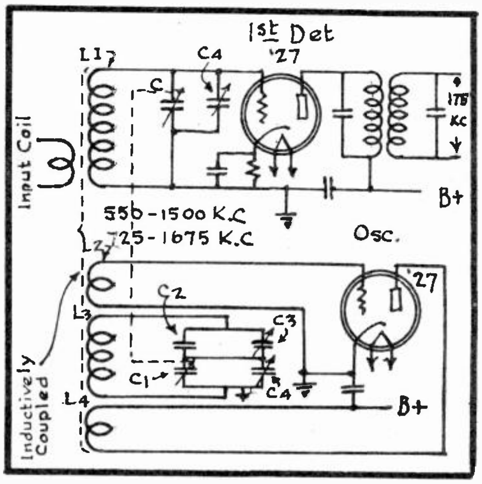

FIG. 18

A Typical Oscillator & 1st Detector Circuit of a Superheterodyne Receiver.

THE MODERN PRACTICE TO PROVIDE THE PROPER TRACKING OF THE OSCILLATOR TUNING CONDENSER WITH THE OTHER TUNED CIRCUITS IS TO USE AN ARRANGEMENT SIMILAR TO THAT PICTURED IN FIG. 18. IN THIS CASE, THE OSCILLATOR TUNING CONDENSER (C_1) HAS A FIXED CONDENSER (C_2) CONNECTED IN SERIES WITH IT AND EACH OF THESE CONDENSERS IS SHUNTED BY A SMALL TRIMMER CONDENSER (C_3) AND (C_4). YOU HAVE ALREADY BEEN INTRODUCED TO THIS METHOD IN AN EARLIER LESSON BUT NOW WE ARE GOING TO GO A STEP FURTHER AND DETERMINE JUST WHAT VALUES FOR THE VARIUS PARTS ARE SUITABLE IN ORDER TO BRING ABOUT THE DESIRED RESULTS.

The design for the circuits of Fig. 18 are worked out in the following manner. First of all, condensers C and C_1 each have the same capacitive value--in fact, each of them is a section of a ganged tuning condenser. For the present, we will assume condenser C and C_1 as each having a maximum capacity of .00035 mfd. and both being controlled by the same rotor shaft. Condensers C_4 in both cases are the conventional trimmer condensers as provided on ganged tuning condensers.

All of the coils of both the oscillator and 1st detector, which are enclosed in the bracket, indicating that they are inductively coupled, are wound on the same tubular winding form, yes, even the input coil is wound on the same form so as to produce the proper coupling with coil L_1.

Now then, the number of turns used for coil L_1 must be such that the inductance of this winding will tune with condenser C over the broadcast range the same as though it were used in any ordinary tuned R.F. amplifier circuit. Hence for a given diameter of winding form, coil L_1 would be calculated as explained in the previous lessons and for the sake of explanation, we will say that coil L_1 has an inductance of 245 microhenries.

DESIGNING THE OSCILLATOR COIL

The next step will be to determine the required inductance of coil L_3 and in this respect, we have a very handy rule which was worked out by many experiments. This rule is as follows: If condensers C and C_1 of Fig. 18 are exactly alike and the value of condenser C_2 is equal to TWICE the maximum capacitive value of condenser C or C_1, then if the inductance of coil L_3 is made 22% less than the inductance of coil L_1, the oscillator circuit will track properly with the tuned circuit of the 1st detector so that the 175 Kc. separation will be maintained over the entire broadcast range.

This rule may seem a little complicated at first glance but with a little further explanation you will find it to be greatly simplified. In practice, we use this rule as follows: First of all, we would chose a value for condenser C_2 equal to twice .00035 mfd. which is .0007 mfd. Then we will construct coil L_3 so that its inductance is 22% less than that of coil L_1. In other words, if L_1 has an inductance of 245 microhenries, as stated previously, the inductance of coil L_3 should be 245 minus 245X.22 or 245 minus 53.9 which is equal to 191.1 microhenries. Thus knowing that coil L_3 must have an inductance of 191.1 microhenries, we would calculate the number of turns required as described in the previous lessons.

Condenser C_3 in Fig. 18 is also the conventional type of tuning condenser trimmer, the same as C_4. These can be purchased as a separate unit and can then be connected across the circuit as desired.

Now as to the matter of coils L_2 and L_4. For these, the least number of turns should be used, which will permit good oscillating action over the entire tuning range. If too many turns are used for these two windings, the intensity of the locally generated oscillations may become so great as to overload the 1st detector tube and of course this is undesirable. Experiments conducted after the receiver has been con-

STRUCTED WILL ENABLE ONE TO DETERMINE THE MOST SATISFACTORY NUMBER OF TURNS TO USE ON THESE WINDINGS. IF COILS L_2 AND L_4 ARE COUPLED CLOSELY TO COIL L_3, THAT IS, WITH COIL L_2 WOUND RIGHT OVER THE TOP OF THE UPPER END OF COIL L_3 WITH A PIECE OF PAPER OFFERING THE SEPARATION AND COIL L_4 IS COUPLES IN LIKE MANNER TO THE LOWER END OF COIL L_3, THEN 25 TURNS WILL BE FOUND ABOUT RIGHT FOR COILS L_2 AND L_4. COIL L_1 CAN BE SEPARATED FROM L_2 BY ABOUT 1/8" TO ¼".

ALIGNING THE TUNING CIRCUITS

BY MEANS OF THE OSCILLATOR TRIMMER CONDENSER C_4, THE ALIGNMENT OF THE OSCILLATOR AT THE HIGH FREQUENCIES CAN BE ADJUSTED AND TRIMMER CONDENSER C_3 IS USED TO ALIGN THIS OSCILLATOR CIRCUIT AT THE LOWER FREQUENCIES. THESE CIRCUITS ARE ALL ALIGNED AFTER THE RECEIVER IS CONSTRUCTED. AT THAT TIME, THE GENERAL PRACTICE IS TO FIRST ALIGN THE INTERMEDIATE FREQUENCY STAGES WITH THE AID OF A MODULATED TEST OSCILLATOR ADJUSTED TO A FREQUENCY OF 175 KC. AFTER THIS, THE TRIMMER CONDENSERS OF THE PRE-SELECTOR R.F., 1ST DETECTOR AND OSCILLATOR ARE ADJUSTED FOR MAXIMUM RECEIVER RESPONSE WHEN THE SET IS TUNED TO RESONANCE WITH A MODULATED TEST OSCILLATOR GENERATING FIRST A LOW BROADCAST FREQUENCY, THEN A MEDIUM AND FINALLY A HIGH BROADCAST FREQUENCY-- THE TRIMMERS BEING ADJUSTED TO THE BEST AVERAGE SETTING FOR THE ENTIRE RANGE.

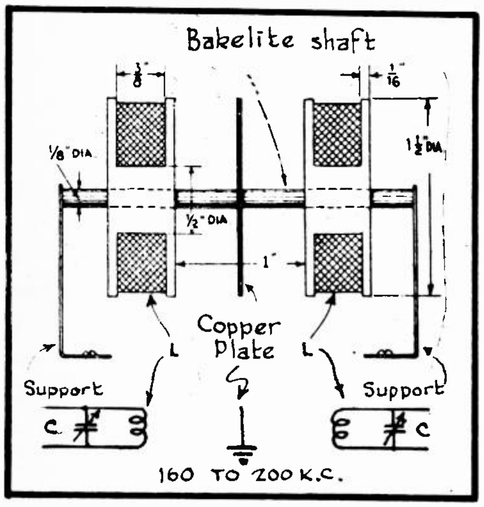

FIG. 19
Construction of the I.F. Transformer.

OF COURSE, THERE ARE VARIOUS TYPES OF OSCILLATOR CIRCUITS WHICH CAN BE USED IN THE CONSTRUCTION OF SUPERHETERODYNE RECEIVERS BUT IN ANY CASE, THE INFORMATION JUST GIVEN RELATIVE TO THE DESIGN OF ITS TUNED CIRCUIT WILL APPLY EQUALLY WELL TO ALL TYPES OF OSCILLATORS EMPLOYING PADDING CONDENSERS OF THIS FORM IN ORDER TO PROVIDE TRACKING.

NOW THAT YOU ARE FAMILIAR WITH A GOOD PRACTICAL SYSTEM OF DESIGNING THE OSCILLATOR AND FIRST DETECTOR CIRCUITS FOR SINGLE-CONTROL OPERATION, THE NEXT PORTION OF THE SUPERHETERODYNE RECEIVER, WHOSE CONSTRUCTION WE SHALL CONSIDER, IS THE INTERMEDIATE FREQUENCY AMPLIFIER.

I.F. TRANSFORMER CONSTRUCTION

FIG. 19 ILLUSTRATES THE CONSTRUCTIONAL FEATURES OF AN I.F. TRANSFORMER, WHICH CAN BE READILY CONSTRUCTED IN THE HOME WORK SHOP. THIS PARTICULAR UNIT IS ADAPTABLE TO OPERATING EFFICIENTLY WITHIN THE RANGE OF 160 TO 200 KC. AND CAN THUS BE ADJUSTED TO OPERATE AT THE POPULAR INTERMEDIATE FREQUENCY OF 175 KC. WITH MAXIMUM EFFICIENCY.

THE SPOOLS OR FORMS FOR THE WINDINGS MAY BE LATHE-TURNED WOOD OR BAKELITE, OR ELSE BUILT UP WITH INSULATING WASHERS AND RODS. AT ANY RATE, THE DIMENSIONS OF THE FORMS SHOULD BE AS INDICATED IN THE DRAWING OF FIG. 19. THE SUPPORTS MAY BE MADE OF BRASS STRIPS BENT TO THE REQUIRED SHAPE AND THE 1/8" DIAMETER MOUNTING ROD MAY BE BAKELITE OR

WOOD, BAKELITE BEING PREFERABLE.

THE COILS "L" (PRIMARY AND SECONDARY) SHOULD BOTH CONSIST OF 800 TURNS OF #36 B&S. SINGLE COTTON COVERED WIRE, "SCRAMBLE-WOUND". THIS SAME TRANSFORMER IS DIAGRAMATICALLY ILLUSTRATED IN THE LOWER PORTION OF FIG. 19, IN ORDER TO GIVE YOU A STILL CLEARER UNDERSTANDING OF THE UNIT.

THE CONDENSERS "C" IN THIS CASE SHOULD BE VARIABLE CONDENSERS OF THE TRIMMER TYPE, EACH WITH A CAPACITY RATING OF 140 MMFD. ONE OF THESE CONDENSERS IS CONNECTED ACROSS THE PRIMARY COIL AND THE OTHER ACROSS THE SECONDARY COIL AS ILLUSTRATED IN THE DIAGRAM OF FIG. 19 AND FOR GREATER SELECTIVITY, A GROUNDED COPPER PLATE CAN BE PLACED BETWEEN THE TWO COILS OF THE 1ST I.F. TRANSFORMER IN THE RECEIVER AS ALSO PICTURED FOR YOU IN FIG. 19. FOR THE SECOND AND THIRD I.F. TRANSFORMER OF ANY RECEIVER, HOWEVER, THE COPPER PLATE SHOULD BE ELIMINATED.

THE SELECTIVITY AND VOLUME ARE CONTROLLED BY THE SPACING BETWEEN THE COILS "L" ON EACH TRANSFORMER. THE GREATER THE DISTANCE BETWEEN THEM, THE BETTER WILL BE THE SELECTIVITY BUT THE AMPLIFICATION WILL BE LESS. IN SUPERHETERODYNE RECEIVERS EMPLOYING THREE I.F. TRANSFORMERS, IT IS GENERALLY THE PRACTICE TO MAKE THE 1ST I.F. TRANSFORMER QUITE SELECTIVE BY SEPARATING THE TWO COILS CONSIDERABLY AND USING THE COPPER DISC BETWEEN THEM. THE SECOND AND THIRD I.F. TRANSFORMERS IN THIS CASE HAVE THE TWO COILS MORE CLOSELY COUPLED AND NO COPPER DISC BEING USED. THIS PERMITS GREATER AMPLIFICATION IN THE LAST TWO I.F. TRANSFORMERS.

EACH OF THE I.F. TRANSFORMERS SHOULD BE PLACED IN AN INDIVIDUAL GROUNDED METAL SHIELD CAN AND BY MEANS OF A TEST OSCILLATOR ADJUSTED TO 175 KC., THE CONDENSERS "C" OF THE I.F. TRANSFORMERS CAN ALL BE USED TO ADJUST ALL OF THE I.F. TRANSFORMER COILS TO RESONATE AT EXACTLY 175 KC.

HAVING CONCLUDED THIS LESSON, YOU SHOULD NOW HAVE A CLEAR UNDERSTANDING OF THE DESIGN FEATURES AS USED IN R.F. BAND-PASS FILTER CIRCUITS AND THE SUPERHETERODYNE TYPE OF TUNING CIRCUIT. SO WITH THIS INFORMATION FRESH IN YOUR MIND, ANSWER THE EXAMINATION QUESTIONS AND WE WILL THEN CONTINUE OUR STUDY OF R.F. AMPLIFIERS IN THE FOLLOWING LESSON BY INVESTIGATING THE DESIGN FACTORS OF ALL-WAVE RECEIVERS ETC.

EXAMINATION QUESTIONS

LESSON NO. 43

"Being ignorant is not so much
a shame, as being unwilling to learn."

1. - What is the chief advantage of using a band-pass filter circuit in the R.F. amplifier?

2. - How does the increase and decrease of coupling between two tuned circuits affect the selectivity of the combination?

3. - Why is it that the selectivity curve, as plotted for a band-pass filter circuit, has two resonance peaks?

4. - In the case of a band-pass circuit, as illustrated in Fig. 7 of this lesson, how can the broadness of tuning be adjusted in order to bring about the desired results?

5. - How can the broadness of tuning be adjusted to the desired point in a band-pass arrangement of the type illustrated in Fig. 9 of this lesson?

6. - About how many turns of wire would you employ for the coupling coil in Fig. 11 of this lesson?

7. - Why are the .5 mfd by-pass condensers employed in the various circuits of Fig. 12 of this lesson?

8. - Describe how you would construct a band-pass circuit using a coupling condenser.

9. - Describe in what manner that you would design an oscillator coil for a superheterodyne receiver, so that the oscillator condenser may be one section of a ganged tuning condenser, having the same capacity rating as the other tuning condenser sections used for the first detector and pre-selector circuits.

10.- Describe briefly how an intermediate frequency transformer of the 175 Kc. type may be constructed.

WM. F LIESKE

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LESSON NO. 44

WINDING R. F. COILS

MEASURING INDUCTANCE AND CAPACITY

You are making rapid progress with your studies of R.F. amplifiers, so that you will shortly be qualified to design and construct really efficient amplifiers of this type.

Now we are ready to go about the task of actually winding R.F. transformers and the first coil type, which we shall consider is the popular solenoid type.

WINDING A SOLENOID TYPE COIL

Many coil winders, of course, have favorite tricks of their own which are gained from experience in this kind of work and after you have wound a number of coils, you will also no doubt, develope winding ideas of your own. Nevertheless, we will give you some suggestions at the present time relative to this work.

FIG. 1
Set-Up for Winding R. F. Transformer.

First, let us center our attention upon Fig. 2. Here we have a tubular winding form made of some such material as a rigid cardboard tube or bakelite. We begin by choosing a suitable point on this tube form at which we wish to start the winding and in this respect, it is timely to advise you never to start winding too near the end of the winding form.

At this point, where the winding is to start, make two small holes through the coil form as shown in Fig. 2. These holes need only be large enough to permit the coil wire to be threaded through them and they may be made approximately 1/16" apart.

COIL WIRE IS GENERALLY BOUGHT ON SPOOLS, SO TAKE HOLD OF THE FREE END OF THIS SPOOL OF WIRE AND THREAD IT ABOUT TWICE THROUGH THESE TWO FIRST HOLES OF YOUR WINDING FORM. THIS LOOP WILL SERVE AS THE ANCHORING POINT FOR THE BEGINNING OF YOUR WINDING, SO DRAW IT TIGHT, BEING CAREFUL, HOWEVER, THAT THE WIRE IS NOT BROKEN IN THE CASE VERY SMALL SIZE WIRE IS BEING USED. ALSO PROVIDE A SUFFICIENTLY LONG FREE END OF THE WINDING SO THAT YOU CAN MAKE THE PROPER ELECTRICAL CONNECTIONS TO IT LATER ON.

WHEN WINDING THE COIL BY HAND AND YOU ARE RIGHT HANDED, THEN HOLD THE COIL FORM IN YOUR LEFT HAND AT THE STARTING END AND WIND THE WIRE ON THE FORM IN THE DIRECTION INDICATED. DRAW WIRE FROM THE SPOOL AS IT IS NEEDED, BEING VERY CAREFUL THAT IT DOES NOT KINK AND DRAW THE TURNS UP TIGHT SO THAT THEY WON'T SLIP ON THE WINDING FORM. ALSO BE SURE THAT THE TURNS ARE ALL WOUND RIGHT NEXT TO EACHOTHER WITHOUT ANY SPACING BETWEEN THEM IN SUCH CASES WHERE THE COIL DESIGN CALLS FOR COILS OF THE NON-SPACE WOUND TYPE.

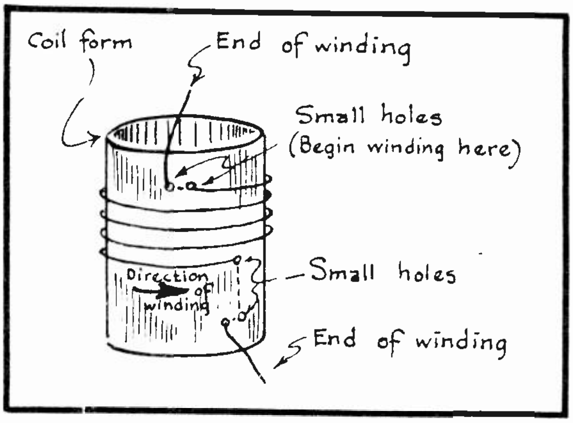

FIG. 2
An Example of Winding.

COUNT THE NUMBER OF TURNS AS YOU WIND, USING YOUR STARTING HOLES AS YOUR REFERENCE POINT. FINALLY, WHEN YOU HAVE APPLIED THE NUMBER OF TURNS CALLED FOR, MAKE ANOTHER SMALL HOLE IN THE WINDING FORM DIRECTLY AT THE POINT WHERE THE WINDING FINISHES. HOLD DOWN THE LAST TURN FIRMLY WITH THE THUMB OF YOUR LEFT HAND, SO THAT NO SLACK WILL DEVELOPE IN THE COIL AND THEN CUT THE WIRE FROM THE SPOOL, LEAVING A SUFFICIENT SURPLUS LENGTH FOR MAKING CONNECTIONS.

NOW PASS THE FINISHING END OF THE WIRE THROUGH THIS LAST HOLE, DRAWING IT TIGHT AND PULL IT DOWNWARDS ALONG THE INNER WALL OF THE COIL FORM. AT THE LOWER END OF THIS COIL FORM MAKE TWO MORE SMALL HOLES AND THREAD THE WIRE THROUGH THEM TIGHTLY-APPROXIMATELY TWICE. THUS THE FINISHING END OF THIS WINDING IS ALSO NOW ANCHORED AND YOU WILL HAVE A TIGHT, NEAT LOOKING WINDING.

LOCATING COIL TERMINALS

LET US CONSIDER FOR A MOMENT, THE MOST ADVANTAGEOUS POINTS AT WHICH SUCH WINDINGS SHOULD BE TERMINATED ON THE COIL FORM. THIS CAN PROBABLY BE ILLUSTRATED BEST BY MEANS OF THE ILLUSTRATION SHOWN YOU IN FIG. 3 WHERE WE HAVE A SHIELDED R.F. TRANSFORMER ASSEMBLY AS GENERALLY USED IN AMPLIFIERS EMPLOYING SCREEN-GRID CIRCUITS. IN THIS CASE, THE SHIELD CAN HAS BEEN PARTIALLY CUT-AWAY, SO THAT YOU CAN SEE THE ARRANGEMENT INSIDE.

NATURALLY, THE TYPE OF COIL MOUNTING TO BE USED ETC. SHOULD BE DECIDED UPON BEFORE WINDING THE COILS SO THAT THE COIL TERMINALS CAN BE LOCATED TO BEST SUIT THE PARTICULAR TYPE OF INSTALLATION. IN THE POPULAR METHOD OF FIG. 3, FOR EXAMPLE, WHERE THE CONTROL-GRID LEAD EMERGES FROM THE TOP OF THE SHIELD, IT IS LOGICAL THAT THE GRID END OF THE SECONDARY WINDING SHOULD TERMINATE AT THE UPPER END OF THE COIL FORM. TO FACILITATE WIRING, IT IS ADVISABLE TO MOUNT TERMINAL LUGS ON THE WINDING FORM AND

TO SOLDER, THE ENDS OF THE WINDING TO THESE. THUS THE PROPER CIRCUITWIRE CAN THEN LATER BE SOLDERED TO THIS SAME LUG VERY EASILY. IT IS ALSO ADVISABLE TO WRAP THE COIL WIRE AROUND THE LUG SEVERAL TIMES BEFORE SOLDERING IT TO THE LUG, FOR THIS WILL PREVENT THIS LEAD FROM BECOMING DETACHED WHEN MELTING THE SOLDER, AT THE TIME THE CIRCUIT WIRE IS SOLDERED TO THE LUG LATER ON. THIS IS JUST A MATTER OF CONVENIENCE.

IF SUB-PANEL WIRING IS USED FOR THE WIRING OF THE RECEIVER, AS IS GENERALLY THE CASE, THEN THE PRIMARY WINDING SHOULD TERMINATE AT THE LOWER END OF THE WINDING FORM AS ILLUSTRATED, AS SHOULD ALSO THE GROUND, FILAMENT OR CATHODE END OF THE SECONDARY. HERE TOO, SOLDERING LUGS WILL BE FOUND CONVENIENT. SO KEEP ALL OF THESE POINTS IN MIND WHEN CONSTRUCTING R.F. TRANSFORMERS AND YOU WILL DO A BETTER JOB.

A COIL WINDING MACHINE

IF YOU DO NOT HAVE OCCASSION TO WIND A GREAT NUMBER OF R.F. TRANSFORMERS, THEN THE HAND METHOD OF WINDING, AS JUST DESCRIBED, WILL BE FOUND SATISFACTORY ENOUGH BUT WINDING MANY COILS AT A TIME IN THIS WAY BECOMES RATHER TIRESOME. TO SPEED UP THIS WORK, A SIMPLE COIL WINDING MACHINE, AS ILLUSTRATED IN FIG. 4, WILL BE FOUND VERY HANDY. BY STUDYING FIG.4 IN CONJUNCTION WITH FIG. 5, YOU SHOULD OBTAIN A GOOD IDEA OF THE CONSTRUCTIONAL FEATURES OF THIS SIMPLE MACHINE, SO THAT YOU CAN READILY BUILD ONE FOR YOURSELF SHOULD YOU CHOOSE TO DO SO.

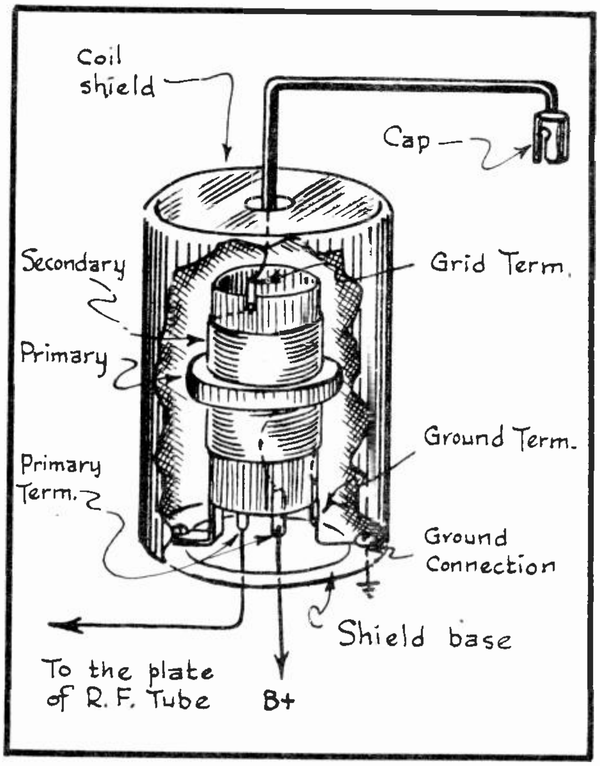

FIG. 3

Locating Coil Terminals for Screen Grid Circuits.

THIS APPARATUS CONSISTS ESSENTIALLY OF TWO BLOCKS OF WOOD SERVING AS BASES. TO THESE TWO BASES, YOU CAN FASTEN A PAIR OF STEEL STRAPS, SLIGHTLY SEPARATED FROM EACHOTHER SO AS TO FORM TWO RAILS. THE TWO UPRIGHTS CAN BE MADE FROM THIS SAME STEEL STOCK, BENDING THEM INTO RIGHT ANGLES, DRILLING A HOLE AT THEIR UPPER END TO RECEIVE THE SHAFT AND ANOTHER HOLE AT THE LOWER END TO RECEIVE THE HOLD-DOWN SOLTS.

THE CONE-SHAPED WEDGES CAN BE MADE FROM WOOD, BEING TURNED DOWN TO A CONICAL SHAPE IN A LATHE. A HOLE, LARGE ENOUGH TO PERMIT THESE WEDGES TO SLIP FREELY UPON THE SHAFT, IS DRILLED THROUGH THEIR CENTER. A CRANK IS FASTENED ON ONE END OF THE SHAFT.

TO USE THE APPARATUS, ILLUSTRATED IN FIG. 5, LOOSEN THE RIGHT HOLD-DOWN BOLT AND THE SET SCREW OF THE COLLAR, WHICH IS MOUNTED ON THE RIGHT END OF THE SHAFT. NOW SLIDE THE RIGHT UPRIGHT TOWARD THE RIGHT AND SLIP

THE RIGHT COLLAR AND WEDGE OFF THE SHAFT. THIS DONE, PLACE THE COIL FORM IN THE POSITION ILLUSTRATED IN FIG. 5 AND REPLACE THE RIGHT HAND WEDGE AND COLLAR. SLIDE THE RIGHT HAND WEDGE TOWARD THE LEFT FAR ENOUGH SO THAT ITS CONICAL SURFACE LOCKS TO THE HOLE IN THE COIL FORM AND LOCK IT IN POSITION WITH THE RIGHT HAND COLLAR. THE RIGHT HAND UPRIGHT CAN THEN BE MOVED UP AGAINST THE COLLAR AND ITS WING NUT TIGHTENED. THE COIL OR WINDING FORM IS THUS CENTRALLY WEDGED BETWEEN THE TWO CONES, SO THAT IT WILL ROTATE WHEN THE CRANK IS TURNED AS ILLUSTRATED IN FIG. 4 AND IF YOU WISH, YOU CAN MOUNT A VERTICAL STUD ON THE BASE OPPOSITE THE CRANK END OVER WHICH TO SLIP THE SPOOL OF WIRE SO THAT IT WON'T BE ROLLING ALL OVER THE WORK BENCH WHILE YOU ARE WINDING. WHEN THE WINDING HAS BEEN COMPLETED, THE COIL FORM CAN READILY BE REMOVED FROM THE WINDING MACHINE.

FIG. 4
A Practical Coil Winding Machine for Ordinary Use.

YOU WILL FIND A WINDING MACHINE BUILT UPON THIS PRINCIPLE TO SATISFACTORILY HANDLE A VARIETY OF COIL SIZES AND OF COURSE, YOU CAN CHANGE ANY OF ITS CONSTRUCTIONAL FEATURES TO SUIT YOURSELF.

NATURALLY, IN FACTORIES WHERE COILS ARE WOUND IN PRODUCTION LOTS, YOU WILL FIND THAT THE COILS ARE WOUND ON ELECTRICALLY OPERATED WINDING MACHINES WHICH OPERATE ON THE PRINCIPLE OF OUR MODERN LATHES.

AFTER THE COILS ARE WOUND, IT IS A COMMON PRACTICE TO COAT THEM WITH HIGH GRADE CLEAR VARNISH OR SHELLAC, SO AS TO PROTECT THEM AGAINST MOISTURE ABSORPTION. SPECIAL PREPARATIONS ARE ALSO AVAILABLE FOR THIS PURPOSE AND WHEN DRY, THE COIL IS NOT ONLY OFFERED THIS PROTECTIVE COATING BUT ITS GENERAL STRUCTURE IS MADE MORE RIGID AS WELL. IN ALL CASES, HOWEVER, YOU DO NOT FIND COILS "DOPED" IN THIS WAY.

THE "BASKET-WEAVE" COIL

YOU WILL PROBABLY ALSO BE INTERESTED IN BECOMING FAMILIAR WITH THE CONSTRUCTION OF COILS OTHER THAN THE PLAIN SOLENOID TYPE. SO LET US NEXT CONSIDER THE "BASKET-WEAVE" COIL.

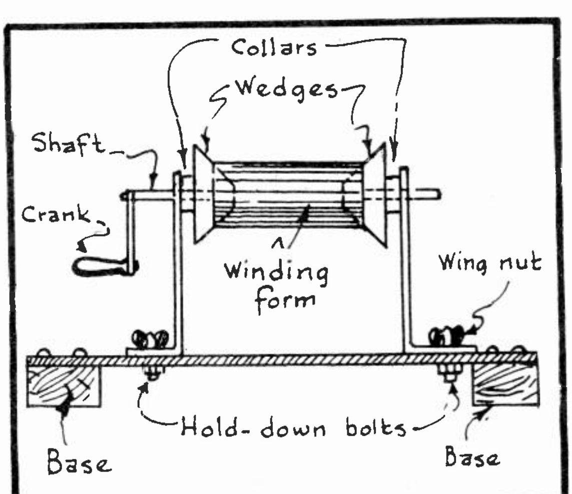

FIG. 5
Constructional Detail of Coil Winder.

THE SET-UP FOR WINDING A BASKET-WEAVE COIL IS ILLUSTRATED IN FIG. 6. IN THIS CASE, WE USE A DISC-SHAP-

ED PIECE OF WOOD ABOUT 3/4" THICK. HOLES ARE DRILLED AROUND THE FACE OF THIS DISC CLOSE TO THE OUTER EDGE AND INTO THESE HOLES WE INSERT WOODEN PEGS WHICH ARE ABOUT $1\frac{1}{2}$" LONG AND APPROXIMATELY 1/8" IN DIAMETER. THESE PEGS SHOULD FIT INTO THE HOLES RATHER TIGHT. THE GENERAL PRACTICE IS TO USE 13, OR 15 OF THESE PEGS FOR COILS WHOSE DIAMETER ACROSS OPPOSITE PEG CENTERS MEASURES RESPECTIVELY $2\frac{1}{2}$" AND $2\frac{5}{8}$".

WITH A SAW, WE CUT NOTCHES AROUND THE RIM OF THE WOODEN DISC NEXT TO EACH PEG AND BY MEANS OF A THREE-CORNERED FILE OR A KNIFE, THE ENTRANCE OF THE NOTCH CAN BE WIDENED SOMEWHAT. THESE NOTCHES SHOULD EXTEND ALL THE WAY TO THE HOLES IN WHICH THE PEGS ARE INSERTED.

THUS WITH THE WINDING FORM COMPLETED, IT CAN BE FASTENED TO SOME SORT OF A SUPPORT AS PICTURED IN FIG. 6 IN SUCH A WAY THAT THE WINDING FORM CAN BE ROTATED ABOUT ITS CENTER.

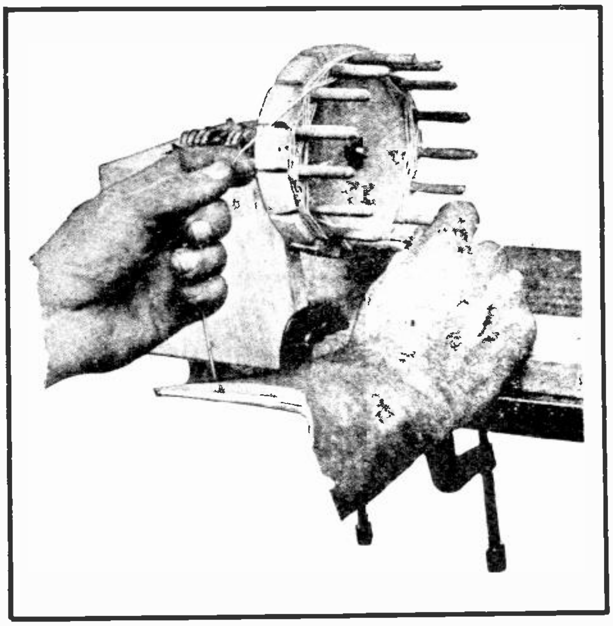

FIG. 6
Winding the Basket-Weave Coil.

TO START, ONE END OF THE WIRE CAN BE TEMPORARILY ANCHORED TO ONE OF THE PEGS. THE WINDING FORM IS THEN SLOWLY ROTATED AS THE FIRST TURN IS WOUND. NOTE THAT WE FIRST WIND OVER ONE PEG, THEN UNDER THE NEXT, OVER THE FOLLOWING PEG ETC. THEN DURING THE SECOND REVOLUTION OF THE WINDING FORM, THE SECOND TURN, IN OTHER WORDS, WE WILL WIND UNDER THE PEGS WHERE OUR PREVIOUS TURN WENT OVER THEM AND VICE VERSA. WE CONTINUE IN THIS WAY UNTIL THE REQUIRED NUMBER OF TURNS HAVE BEEN WOUND AND WE TEMPORARILY FASTEN THE END OF THE WINDING TO A PEG.

THE NEXT STEP IS TO REMOVE THE PEGS BUT WE DO THIS CAREFULLY BY REMOVING FIRST ONE OF THE PEGS TO WHICH NEITHER OF THE ENDS OF THE WINDING ARE FASTENED. AS SOON AS THIS PEG IS WITHDRAWN, WE TAKE A FLEXIBLE NEEDLE AND STRONG THREAD, INSERT THE NEEDLE THROUGH THE OPENING IN THE WINDING FROM WHICH THE PEG WAS REMOVED, THUS PULLING THE THREAD THROUGH. THIS IS ILLUSTRATED IN FIG. 7 AND IT IS FOR THE EASE IN THREADING THAT THE SLOTS ARE PROVIDED AROUND THE RIM OF THE FORM.

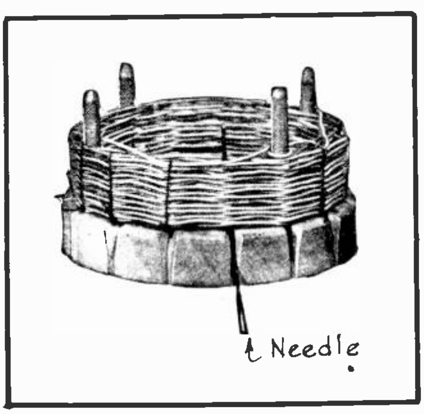

FIG. 7
Binding the Basket-Weave Coil.

THUS WITH THE THREAD DRAWN THROUGH THIS WINDING OPENING, WE TIE A LOOP, DRAWING IT TIGHT AND KNOTTING IT, AND IN THIS WAY, THE TURNS ARE FIRMLY FASTENED TOGETHER AT THIS POINT. WE REMOVE ONE PEG AT A TIME, IMMEDIATELY BINDING THE TURNS AT THAT POINT AS JUST DESCRIBED UNTIL ALL PEGS HAVE BEEN REMOVED.

A SATISFACTORY NEEDLE FOR THIS THREADING PURPOSE CAN BE MADE QUITE READILY BY TAKING A PIECE OF #20 B&S BARE OR ENAMELED COPPER WIRE, BENT DOUBLE SO AS TO FORM A LOOP AT ONE END. THE OTHER ENDS CAN BE CONNECTED TOGETHER WITH A DROP OF SOLDER, WHICH CAN BE DRESSED DOWN WITH EMERY CLOTH SO AS NOT TO PRODUCE ANY OBSTRUCTION WHEN THREADING WITH IT. A NEEDLE OF THIS TYPE IS QUITE FLEXIBLE AND THEREFORE LENDS ITSELF WELL TO WORKING IN AND AROUND ABRUPT CORNERS.

THE PEGS AT WHICH THE WINDING'S ENDS ARE FASTENED ARE REMOVED LAST. THUS THE COIL IS REMOVED FROM ITS FORM AND IT CAN THEN BE DOPED WITH AN INSULATIVE COMPOUND AS DESCRIBED RELATIVE TO SOLENOID WINDINGS AND WHEN DRY, THE COIL WILL BE RIGID SO THAT WHEN HANDLED WITH CONSIDERATION, THERE WILL BE LITTLE CHANCE OF ITS LOOSING ITS SHAPE.

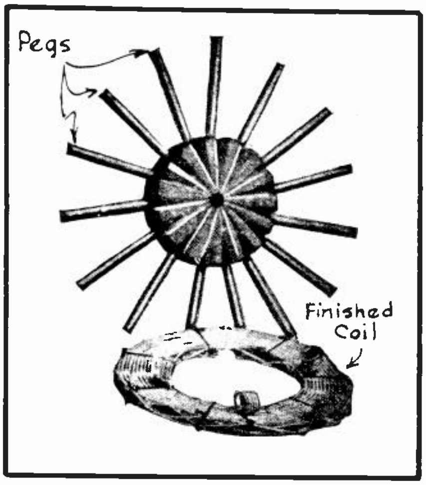

FIG. 8
The Spider-Web Coil and its Winding Form.

FOR A BASKET-WEAVE TYPE COIL, HAVING A DIAMETER OF $2\frac{1}{2}$" TO $2\frac{5}{8}$" AND 13 OR 15 PEGS AS MENTIONED PREVIOUSLY IN THIS DISCUSSION, APPROXIMATELY 80 TURNS WILL BE NEEDED FOR THE SECONDARY TO TUNE OVER THE BROADCAST BAND WHEN USED WITH A .00035 MFD. CONDENSER AND ABOUT 65 TURNS, WHEN USED WITH A .0005 MFD. TUNING CONDENSER. IN BOTH CASES, #24 B&S DOUBLE SILK COVERED WIRE CAN BE USED.

THE PRIMARY IS WOUND IN THE SAME MANNER AS THE SECONDARY, BEING WOUND NEXT TO THE SECONDARY ON THE SAME WINDING FORM BEFORE THE PEGS ARE REMOVED AND IT IS TIED TO THE SECONDARY BY MEANS OF THE SAME PIECE OF THREAD PREVIOUSLY DESCRIBED. THE NUMBER OF TURNS TO USE ON THE PRIMARY SHOULD BE APPROXIMATELY 1/3 OF THE NUMBER OF TURNS PLACED IN THE SECONDARY WINDING. IF A TENDENCY TOWARD OSCILLATION IS NOTICED, WHEN THE RECEIVER IS TESTED WITH THESE COILS, PEEL OFF SOME PRIMARY TURNS, PROBABLY SIX TURNS OR SO UNTIL OSCILLATION CEASES.

WINDING A "SPIDER WEB" COIL

THE SPIDER WEB COIL AND ITS WINDING FORM ARE SHOWN YOU IN FIG. 8. IN THIS CASE, WE AGAIN MAKE A DISC-SHAPED FORM WITH A MOUNTING HOLE AT ITS CENTER BUT THE PEGS, HOWEVER, ARE ALL INSERTED IN HOLES, WHICH ARE DRILLED AROUND THE RIM OF THE DISC. THE NOTCHES ARE CUT SO THAT THEY RADIATE FROM THE VARIOUS PEGS TOWARD THE CENTER.

THE COIL IS WOUND AROUND THE RIM OF THIS FORM IN MUCH THE SAME MANNER AS DESCRIBED RELATIVE TO THE BASKET WEAVE. THAT IS, WE WIND OVER ONE PEG, UNDER THE NEXT ETC. AND WHEN COMPLETE, THE COIL WILL BE "FLAT-SHAPED" AS SHOWN AT THE BOTTOM OF FIG. 8. HERE TOO, ONE PEG AT A TIME IS EXTRACTED FROM THE FORM AND THE TURNS ARE TIED TOGETHER WITH THREAD. THE FINISHED COIL IS THEN DOPED AS ALREADY PREVIOUSLY DESCRIBED.

TABLE I GIVES YOU WINDING SPECIFICATIONS FOR SPIDER WEB COILS TO BE USED WITH A .0005 MFD CONDENSER OVER THE BROADCAST BAND. THE NUMBER

OF SECONDARY TURNS IN THIS TABLE ARE ONLY APPROXIMATE BUT IF IT IS FOUND AFTER COMPLETION THAT THE COIL CAN BE TUNED TO FREQUENCIES BELOW THE BROADCAST BAND BUT NOT TO THE HIGHER FREQUENCY LIMIT OF THE BROADCAST BAND THEN 1 SECONDARY TURN AT A TIME CAN BE REMOVED, UNTIL THE DESIRED RESULTS ARE OBTAINED.

TABLE I

WINDING DATA FOR SPIDER - WEB COILS FOR BROADCAST BAND

WIRE SIZE	INSIDE DIAMETER	NUMBER OF PEGS	NO. OF TURNS WITH .0005 MFD. CONDENSER	NO. OF TURNS WITH .00035 MFD. CONDENSER
#24 D.S.C.	1	15	52	82
#20 D.C.C.	2"	17	46	77
#24 D.C.C.	1½"	11	50	80

THE NUMBER OF PRIMARY TURNS TO USE ON THE SPIDER WEB COIL SHOULD ALSO BE APPROXIMATELY 1/3 THE NUMBER OF TURNS AS ON THE SECONDARY, THE SAME AS DESCRIBED RELATIVE TO THE BASKET-WEAVE TYPE COIL.

THE HONEYCOMB COIL

FINALLY, IN FIG. 9, WE SEE THE HONEYCOMB COIL AND IN THIS CASE, THE COIL CONSISTS OF A WINDING MADE UP OF SEVERAL LAYERS, WITH EACH LAYER WOUND APPROXIMATELY AT RIGHT ANGLES TO THE LAYER BELOW IT. THIS TYPE OF COIL IS USED WHERE CONSIDERABLE INDUCTANCE IS DESIRED IN THE FORM OF A SMALL COMPACT WINDING. IN MODERN RADIO PRACTICE, THE HONEYCOMB COIL IS COMMONLY USED FOR THE PRIMARY WINDING OF R.F. TRANSFORMER, FOR I.F. TRANSFORMER WINDINGS ETC.

ALTHOUGH WE HAVE DISCUSSED SEVERAL DIFFERENT TYPES OF SECONDARY WINDINGS FOR R.F. TRANSFORMERS IN THIS LESSON, REMEMBER THAT THE SIMPLE SOLENOID TYPE IS THE MOST EFFICIENT OF ALL AND FOR GENERAL PURPOSES, YOU ARE ADVISED TO USE THIS TYPE IN PREFERENCE TO THE OTHER MORE COMPLICATED WINDINGS WHICH WERE DESCRIBED.

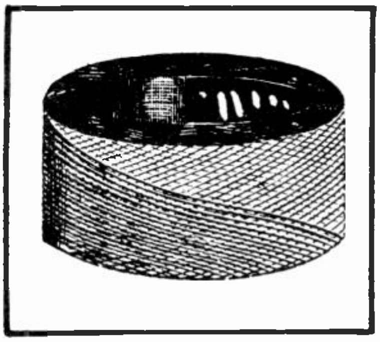

FIG. 9
The Honey comb Coil.

ALSO REMEMBER THAT WHEN CALCULATING SUCH SOLENOID WINDINGS TO MAKE USE OF THE DESIGNING DATA WHICH WAS FURNISHED YOU IN THE PREVIOUS LESSON. IN ADDITION, FOR QUICK REFERENCE, YOU CAN ALSO MAKE USE OF TABLES I AND II OF LESSON #11 FOR CONSTRUCTING COILS TO COVER THE BROADCAST BAND WITH EITHER A .00035 MFD. OR A .0005 MFD. TUNING CONDENSER.

SUGGESTIONS FOR PRIMARY WINDINGS

ALL OF OUR ATTENTION SO FAR HAS BEEN DIRECTED TOWARD THE DESIGN OF THE SECONDARY WINDING OF THE TRANSFORMER BUT FOR GOOD RESULTS, IT IS ALSO ESSENTIAL THAT THE PRIMARY WINDING OF THIS TRANSFORMER BE PROPERLY DESIGNED.

THE PRIMARY WINDING, OF COURSE, IS NOT GENERALLY INTENDED FOR TUNING PURPOSES AS IS THE SECONDARY. THE ESSENTIAL PURPOSE OF THE PRIMARY IS TO TRANSFER THE SIGNAL ENERGY FROM THE ANTENNA OR PLATE CIRCUIT OF ONE TUBE

TO THE GRID CIRCUIT OF THE SUCCEEDING TUBE BUT IN ORDER TO DO THIS EFFICIENTLY, IT IS NECESSARY THAT THE PROPER NUMBER OF TURNS OF WIRE ALSO BE USED ON THE PRIMARY WINDING.

FROM YOUR EARLY STUDIES OF TRANSFORMERS, YOU WILL RECALL THAT A GREATER VOLTAGE STEP-UP IS OBTAINED WHEN THE NUMBER OF SECONDARY TURNS IS LARGE IN COMPARISON TO THE NUMBER OF PRIMARY TURNS. ACCORDING TO THIS FACT, ONE WOULD NATURALLY ASSUME THAT WE SHOULD USE THE LEAST NUMBER OF TURNS POSSIBLE ON THE PRIMARY.

ALTHOUGH THIS RULE APPLIES QUITE WELL WITH IRON-CORE TRANSFORMERS, YET IT FALLS SHORT IN THE CASE OF AIR-CORE TRANSFORMERS DUE TO THE GREAT MAGNETIC LEAKAGE WHICH EXISTS BETWEEN THE PRIMARY AND SECONDARY WINDINGS OF THE AIR-CORE TRANSFORMER. FURTHERMORE, THE CHARACTERISTICS OF THE CIRCUIT IN WHICH THE PRIMARY WINDING IS CONNECTED ALSO HAS A PRONOUNCED EFFECT UPON THE DESIGN OF THE PRIMARY WINDING.

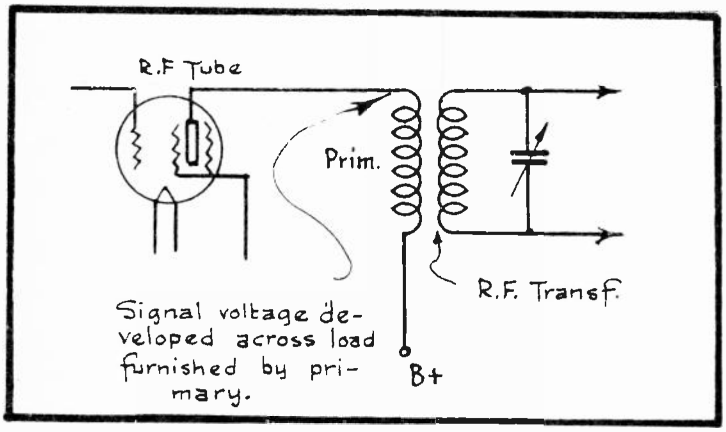

FIG. 10
Primary Winding as Load in Tube Plate Circuit.

THE PRIMARY WINDING, AS ILLUSTRATED IN FIG. 10, SERVES AS THE LOAD IN THE PLATE CIRCUIT OF THE R.F. AMPLIFIER TUBE. THE GREATER THE IMPEDANCE OFFERED BY THIS LOAD, THE GREATER WILL BE THE SIGNAL VOLTAGE DEVELOPED ACROSS ITS EXTREMETIES AND IN PRACTICE IT WORKS OUT THAT IN ORDER TO REALIZE 75% OF THE TUBE'S AMPLIFICATION FACTOR, THE LOAD IN THE TUBE'S PLATE CIRCUIT (PRIMARY WINDING IN THIS CASE) SHOULD OFFER AN IMPEDANCE EQUAL TO APPROXIMATELY 3 TIMES THAT OF THE TUBES PLATE RESISTANCE. (THE PLATE RESISTANCE OF A TUBE IS THE RESISTANCE WHICH THE PLATE CURRENT ENCOUNTERS WITHIN THE TUBE, BETWEEN THE PLATE AND CATHODE OR FILAMENT, AND IN LATER LESSONS YOU WILL RECEIVE MORE DETAILED INFORMATION REGARDING THIS TUBE CONSTANT AS WELL AS OTHER VALUABLE TUBE CONSTANTS). SO CONSIDERING CONDITIONS FROM THIS LATTER ANGLE, WE WANT A PRIMARY WINDING OF MANY TURNS SO AS TO INCREASE ITS INDUCTANCE AND LIKEWISE ITS IMPEDANCE.

FROM THE FOREGOING EXPLANATION, YOU WILL SEE THAT THE NET RESULT IS THAT ON ONE HAND, WE WANT MANY TURNS OF PRIMARY WINDING WHEREAS CONSIDERING CONDITIONS FROM THE OTHER POINT OF VIEW, WE WANT ONLY A FEW TURNS OF PRIMARY WINDING. HENCE THE ONLY THING TO DO IN THIS CASE IS TO COMPROMISE AND USE A MORE OR LESS AVERAGE NUMBER OF PRIMARY TURNS SO AS TO ATTAIN MAXIMUM AMPLIFICATION WITHOUT THE POSSIBILITY OF CIRCUIT OSCILLATION. FOR SCREEN GRID TUBES, IN WHICH THE PLATE RESISTANCE IS VERY HIGH, YOU WILL FIND THAT IT HAS BECOME THE GENERAL PRACTICE AMONG MANUFACTURERS TO CONSTRUCT THEIR PRIMARY R.F. TRANSFORMER WINDINGS WITH 40 OR MORE TURNS. FOR TUBES OF THE NONE SCREEN-GRID TYPE, WHEN USED AS AN R.F. AMPLIFIER, THEN BETWEEN 8 AND 15 TURNS OF PRIMARY ARE GENERALLY USED. THE REASON BEING THAT TUBES OF THIS LATTER TYPE HAVE A COMPARATIVELY LOWER PLATE RESISTANCE THAN DO THE SCREEN-GRID R.F. AMPLIFIER TUBES.

THE EFFECTS OF COUPLING

NOW THERE IS STILL ANOTHER IMPORTANT POINT RELATIVE TO THE DESIGN OF THE PRIMARY WINDING OF THE R.F. TRANSFORMER AND THAT IS THE MATTER OF COUPLING. IN OTHER WORDS, ONE MUST DECIDE AS TO HOW CLOSE TO PLACE THE PRIMARY WINDING TO THE SECONDARY OF THE R.F. TRANSFORMER, AS THIS POINT HAS A PRONOUNCED EFFECT UPON THE PERFORMANCE OF THE TRANSFORMER.

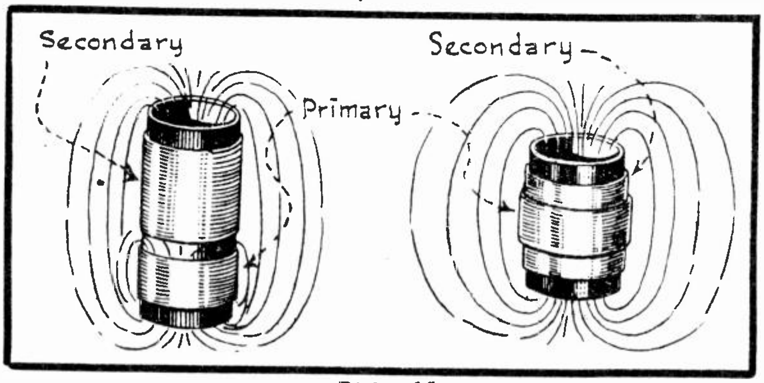

FIG. 11
Example of Loose and Close Coupling.

TWO TYPES OF COUPLING ARE ILLUSTRATED IN FIG. 11. AT THE LEFT, THE PRIMARY WINDING IS SPACED AT SOME DISTANCE FROM THE SECONDARY AND WE WOULD CLASSIFY THIS RELATION BETWEEN THE TWO WINDINGS AS BEING "LOOSE COUPLING".

IT IS OBVIOUS THAT THE FARTHER WE PLACE THE PRIMARY FROM THE SECONDARY, THE LOOSER WILL BE THE COUPLING. THIS IN TURN WILL MEAN THAT A LESS NUMBER OF THE PRIMARY WINDING'S LINES OF FORCE WILL LINK THE SECONDARY WINDING AND BECAUSE OF THIS FACT, THERE WILL BE LESS ENERGY TRANSFER BETWEEN THESE TWO WINDINGS AND THEREFORE THE AMPLIFICATION WILL DECREASE AS THE COUPLING IS MADE LOOSER. REMEMBER THIS.

NOW BESIDES AMPLIFICATION, THERE IS ALSO ANOTHER IMPORTANT RECEIVER QUALITY, WHICH IS AFFECTED BY THE COUPLING OF THE WINDINGS ON THE R.F. TRANSFORMER AND THAT IS SELECTIVITY. IT SO HAPPENS THAT THE LOOSER THE COUPLING BETWEEN THE PRIMARY AND SECONDARY WINDINGS, THE MORE SELECTIVE WILL BE THE CIRCUIT. THIS OF COURSE MEANS THAT IF YOU WANT THE RECEIVER TO TUNE SHARP, THEN YOU SHOULD USE LOOSE COUPLING ON THE R.F. TRANSFORMERS.

SO YOU SEE, HERE AGAIN WE HAVE TWO CONDITIONS WHICH WORK OPPOSITE TO EACHOTHER BECAUSE IF WE LOOSEN THE COUPLING SO AS TO INCREASE SELECTIVITY, WE ARE AT THE SAME TIME REDUCING THE AVAILABLE AMPLIFICATION AND VICE VERSA. HENCE, IN THIS CASE IT IS ALSO NECESSARY TO COMPROMISE AND TO USE A TYPE OF COUPLING WHICH WILL GIVE SATISFACTORY AMPLIFICATION AND SUFFICIENTLY SHARP TUNING.

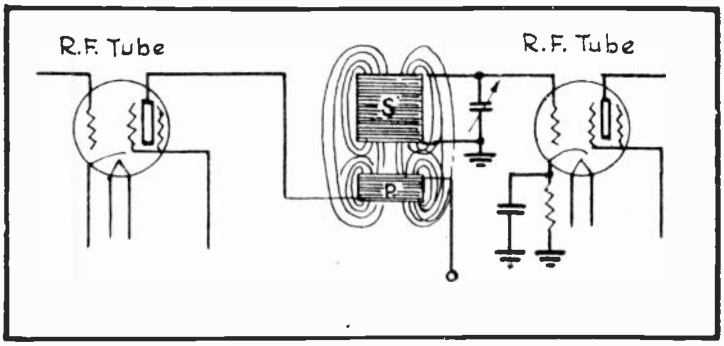

FIG. 12
Interaction Between Primary & Secondary Windings.

IN THIS RESPECT ONE SHOULD ALSO CONSIDER THE FACT THAT IT IS POSSIBLE TO COUPLE THE TRANSFORMER WINDINGS TOO LOOSE, WITH THE RESULT THAT THE RECEIVER WILL BECOME "OVER-SELECTIVE", THEREBY

PREVENTING RECEPTION OF THE HIGHER AUDIO FREQUENCIES. THIS WILL SERIOUSLY AFFECT THE RECEIVER'S TONE QUALITY AND SHOULD THEREFORE, BE GUARDED AGAINST. EXPERIMENT WILL SHOW WHAT EXTENT OF COUPLING GIVES BEST ALL AROUND PERFORMANCE FOR THIS PARTICULAR RECEIVER WHICH IS BEING DESIGNED AND CONSTRUCTED.

ANOTHER INTERESTING FEATURE RELATIVE TO COUPLING IS THAT THE AMPLIFICATION ONLY INCREASES UP TO A CERTAIN "CRITICAL VALUE" AS THE PRIMARY WINDING IS BROUGHT CLOSER TO THE SECONDARY. THIS IS DUE TO THE "INTERACTION" BETWEEN THESE TWO WINDINGS AS ILLUSTRATED IN FIG. 12. THAT IS, A MAGNETIC FIELD IS ALSO ESTABLISHED AROUND THE SECONDARY WINDING BY THE SIGNAL CURRENT FLOWING THROUGH IT AND THIS CURRENT WILL BE MAXIMUM AT RESONANCE. THIS RESULTING MAGNETIC FIELD TENDS TO OPPOSE THAT ESTABLISHED BY THE PRIMARY WINDING AND IF THE COUPLING IS TOO CLOSE, THEY REACT UPON EACHOTHER SO AS TO REDUCE THE EFFECTIVE FIELD AND THUS BRING ABOUT A REDUCTION IN AMPLIFICATION. AN EXAMPLE OF CLOSE COUPLING IS SHOWN AT THE RIGHT OF FIG. 11, WHERE THE PRIMARY IS WOUND DIRECTLY OVER THE SECONDARY WITH A PAPER OR OTHER INSULATION BETWEEN THEM.

THE MAIN OBJECT OF THE PRECEDING DISCUSSION ON COUPLING IS TO WARN YOU, SO THAT YOU WILL USE DISCRETION IN THIS RESPECT WHEN CONSTRUCTING R.F. TRANSFORMERS. IF YOU DIDN'T KNOW ANYTHING ABOUT THESE IMPORTANT EFFECTS OF COUPLING, IT IS OBVIOUS THAT YOU WOULDN'T BE QUALIFIED TO CONSTRUCT A REALLY EFFICIENT UNIT.

HIGH-GAIN TRANSFORMERS

YOU WILL ALSO REMEMBER THAT BESIDES THE CONVENTIONAL TYPE OF R.F. TRANSFORMERS, WE ALSO HAVE WHAT ARE KNOWN AS HIGH-GAIN OR CONSTANT-GAIN TYPE COILS AND WHICH WERE ALREADY DESCRIBED TO YOU IN LESSON #26. IN THIS CASE, THE INDUCTANCE VALUE OF THE PRIMARY WINDING IS QUITE HIGH SO THAT THE PRIMARY CIRCUIT RESONATES SLIGHTLY BELOW THE BROADCAST BAND SO THAT MAXIMUM GAIN THROUGH THE COIL CAN BE OBTAINED IN THE LOWER PORTION OF THE BROADCAST BAND. IN ADDITION, A CAPACITIVE COUPLING IS INTRODUCED BETWEEN THE PRIMARY AND SECONDARY WINDINGS SO THAT APPROXIMATELY THE SAME GAIN IS MAINTAINED AT THE HIGHER BROADCAST FREQUENCIES.

THERE IS NO NEED FOR GOING INTO FURTHER DETAILS AT THE PRESENT TIME REGARDING THESE COILS AS YOU ARE ALREADY ACQUAINTED WITH THEIR GENERAL CONSTRUCTION.

THE "WHEATSTONE BRIDGE"

NOW THAT YOU HAVE LEARNED HOW TO DETERMINE THE INDUCTIVE VALUE OF THE POPULAR SOLENOID TYPE COILS BY CALCULATION, AS WELL AS THE METHODS FOR WINDING VARIOUS COIL TYPES, YOU WILL AT THIS TIME NO DOUBT BE GREATLY INTERESTED IN THE MANNER BY WHICH INDUCTANCE CAN BE MEASURED WITH TESTING DEVICES. THE SIMPLEST METHOD OF MEASURING INDUCTANCE, WHERE THE EXPENSE OF ELABORATE TESTING EQUIPMENT IS PROHIBITIVE, IS BY USING A TESTING DEVICE KNOWN AS A "SLIDE-WIRE" WHEATSTONE BRIDGE. THIS SAME DEVICE CAN ALSO BE USED TO MEASURE RESISTANCE, INDUCTANCE OR CAPACITY AND THE CONSTRUCTION OF THIS APPARATUS IS CLEARLY ILLUSTRATED IN FIG. 13.

A WHEATSTONE BRIDGE OF THIS TYPE CAN BE CONSTRUCTED AT HOME VERY EASILY BY FOLLOWING FIG. 13 AND THE FOLLOWING SUGGESTIONS: THE BASE MAY

CONSIST OF A BOARD 45" LONG, 8" WIDE AND ABOUT $\frac{1}{2}$" THICK. MOUNT A METER STICK FIRMLY UPON THE UPPER FACE OF THE BASEBOARD AS SHOWN IN THE ILLUSTRATION AND THEN ARRANGE FIVE BRASS STRAPS, EACH $\frac{1}{2}$" WIDE AND $\frac{1}{4}$" THICK, IN THE FORM AS ALSO ILLUSTRATED AND FASTEN THEM FIRMLY TO THE FACE OF THE BASEBOARD WITH WOOD SCREWS.

STRAPS #1 AND #5 CAN BE 6" LONG, STRAPS #2 AND #4 CAN BE 10" LONG AND STRAP #3 CAN BE 15" LONG. MOUNT TERMINALS AT POINTS A, B, C, D, E, F, G AND H. CONNECT TERMINAL "A" TO THE BRASS STRAPS #4 AND #5 THROUGH A SINGLE POLE SWITCH, RUNNING THE CONNECTING WIRE ALONG THE UNDERSIDE OF THE BASE IN ORDER TO ADD TO THE APPEARANCE OF THE FACE. CONNECT TERMINAL "F" TO STRAPS #1 AND #2, ALSO RUNNING THIS CONNECTING WIRE ALONG THE UNDERSIDE OF THE BASE.

TERMINAL "H" IS CONNECTED TO STRAP #3 IN LIKE MANNER AND TERMINAL "G" IS CONNECTED TO A SLIDER BY MEANS OF A LONG FLEXIBLE INSULATED WIRE. THE SLIDER OR "STYLUS", AS IT IS SOMETIMES CALLED, MAY BE MADE FROM A PIECE OF 1/8" BRASS ROD ABOUT 3" LONG PROVIDED WITH A BAKELITE OR HARD RUBBER HANDLE. THE POINT OF THIS STYLUS SHOULD BE GROUND TO A "KNIFE EDGE".

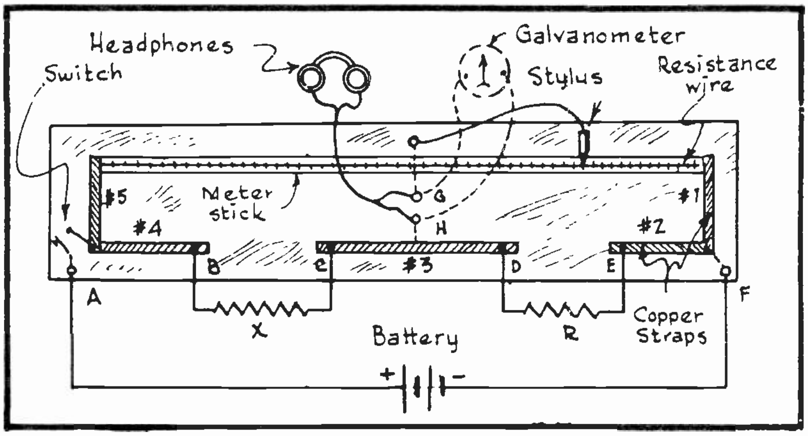

FIG. 13
The Wheatstone Bridge.

THE FINAL STEP IN THE CONSTRUCTION OF THIS APPARATUS IS TO STRETCH A PIECE OF RESISTANCE WIRE ACROSS THE LENGTH OF THE METER STICK. THIS WIRE MAY BE ANY HIGH-GRADE RESISTANCE ALLOY AND ALTHOUGH MANGANIN IS PREFERABLE, NICHROME OR ANY OTHER SUITABLE RESISTANCE ALLOY MAY BE SUBSTITUTED SATISFACTORILY. A #24 OR #28 B&S GAUGE WILL BE FOUND MOST CONVENIENT FOR THIS USE.

IT IS IMPORTANT THAT THIS RESISTANCE WIRE BE STRETCHED TAUT DIRECTLY ABOVE THE FACE OF THE METRIC SCALE, BEING MOUNTED SO THAT IT IS ELEVATED APPROXIMATELY 1/16" ABOVE THE METER SCALE.

HAVING CONSIDERED THE CONSTRUCTION OF THE "SLIDE-WIRE" WHEATSTONE BRIDGE, LET US NOW CONTINUE WITH THE EXPLANATION REGARDING ITS USE. WE SHALL BEGIN THIS EXPLANATION WITH THE APPLICATION OF THIS APPARATUS IN THE MEASUREMENT OF RESISTANCE AND THEN IN TURN FOR MEASURING INDUCTANCE AND CAPACITY.

MEASURING RESISTANCE

NOW THEN, FIG. 13 CLEARLY ILLUSTRATES THE "SET UP" FOR A RESISTANCE MEASUREMENT AND FOR THIS WORK, THE RESISTANCE TO BE MEASURED IS CONNECTED ACROSS TERMINALS B AND C AND WE REFER TO THIS UNKNOWN RESIS-

TANCE VALUE AS "X". THE NEXT STEP IS TO CONNECT A STANDARD RESISTANCE "R" ACROSS THE TERMINALS D AND E.

THE EXACT OHMIC VALUE OF THIS STANDARD RESISTANCE "R" MUST BE KNOWN BEFOREHAND. PRECISION TYPE NON-INDUCTIVE RESISTORS, WHICH ARE GUARANTEED TO BE ACCURATE TO WITHIN 1% OF THEIR RATED VALUE, CAN BE PURCHASED AND USED TO SERVE AS THE STANDARD RESISTANCE "R". SUCH RESISTORS ARE AVAILABLE IN A VAST NUMBER OF DIFFERENT VALUES AND FOR ANY "BRIDGE TEST," ONE SHOULD USE A RESISTANCE VALUE FOR R, WHICH IS ESTIMATED AS BEING AS EQUAL AS POSSIBLE TO THE VALUE OF THE UNKNOWN RESISTOR X.

BALANCING THE BRIDGE

PROCEED BY CONNECTING A PAIR OF HEADPHONES OR A GALVANOMETER ACROSS TERMINALS G AND H AND A BATTERY ACROSS TERMINALS A AND F. CLOSE THE SWITCH AND BRING THE SLIDER OR STYLUS INTO FIRM CONTACT AT VARIOUS POINTS ALONG THE TAUT RESISTANCE WIRE. IF USING THE GALVANOMETER, THIS INSTRUMENT WILL OFFER DIFFERENT READINGS AS THE STYLUS IS BROUGHT IN CONTACT WITH VARIOUS POINTS ALONG THE RESISTANCE WIRE, SO CONTINUE TESTING ALONG THIS RESISTANCE WIRE UNTIL YOU HAVE FINALLY LOCATED A POINT ON THIS WIRE WITH YOUR STYLUS AT WHICH THE GALVANOMETER READS ZERO. THE WHEATSTONE BRIDGE IS NOW SAID TO BE IN A STATE OF BALANCE, SO NOTE CAREFULLY AT WHICH MARK OF THE METER STICK AT WHICH THE STYLUS MAKES CONTACT WITH THE RESISTANCE WIRE IN ORDER TO CAUSE THE GALVANOMETER TO READ ZERO.

IF USING HEADPHONES INSTEAD OF THE GALVONOMETER, YOU WILL HEAR CLICKS OF VARYING INTENSITY AS THE STYLUS IS BROUGHT IN CONTACT WITH VARIOUS POINTS ALONG THE METER SCALE. IN THIS CASE, CONTINUE CONTACTING THE STYLUS AT DIFFERENT POINTS ALONG THE METER SCALE UNTIL YOU LOCATE THE POINT AT WHICH NO CLICK IS HEARD IN THE HEADPHONES UPON MAKING CONTACT. THE WHEATSTONE BRIDGE WILL NOW BE IN A STATE OF BALANCE, SO CAREFULLY TAKE NOTE OF THE STYLUS POSITION AT THIS INSTANT WITH RESPECT TO THE METRIC SCALE.

LET US ASSUME THAT UNDER THE CONDITIONS OF AN ACTUAL TEST, THE WHEATSTONE BRIDGE IS BALANCED UNDER THE CIRCUMSTANCES ILLUSTRATED IN FIG. 14. HERE THE STANDARD RESISTOR "R" HAS A VALUE OF 10 OHMS AND THE BRIDGE IS BROUGHT TO A STATE OF BALANCE WITH THE STYLUS OR SLIDER CONTACTING POINT "A" ON THE RESISTANCE WIRE.

CALCULATING RESISTANCE

NOW THEN, TO CALCULATE THE VALUE OF THE UNKNOWN RESISTOR "X", WE EMPLOY THE FOLLOWING MATHEMATICAL RELATION, $X = \frac{RS}{T}$. PUTTING THIS MATHEMATICAL FORMULA IN WORDS, IT HAS THE FOLLOWING MEANING: TO FIND THE VALUE IN OHMS OF THE UNKNOWN RESISTOR "X", MULTIPLY THE OHMIC VALUE OF THE STANDARD RESISTOR "R" BY LENGTH "S" OF THE RESISTANCE WIRE (S IS EQUAL TO THE DISTANCE FROM THE ZERO POINT ON THE METRIC SCALE TO THE POINT "A" AT WHICH THE STYLUS TOUCHES THE WIRE IN ORDER TO BALANCE THE SYSTEM); DIVIDE THIS PRODUCT BY "T" (THE DISTANCE FROM POINT "A" IN FIG. 14 TO THE OTHER EXTREMETY OF THE METRIC SCALE).

AS A PRACTICAL EXAMPLE, LET US SUPPOSE THAT THE STANDARD RESISTOR "R" IN FIG. 14 HAS A VALUE OF 10 OHMS, DISTANCE "S" IS EQUAL TO 40 CM. AND DISTANCE "T" TO 60 CM., WITH THE SYSTEM IN A STATE OF BALANCE. APPLY-

ING OUR FORMULA $X = \frac{R\ S}{T}$ TO THIS PARTICULAR EXAMPLE, WE HAVE: $X = \frac{10 \times 40}{60} = \frac{400}{60} = 6.66$ OHMS.

THE SIZE BATTERY TO USE FOR THIS TEST WILL BE GOVERNED BY THE RESISTANCE VALUES IN THE SYSTEM. THE PRACTICAL THING TO DO IS TO USE A BATTERY VOLTAGE WHICH WILL GIVE A LEGIBLE READING ON THE GALVANOMETER AND A DISTINCT CLICK IN THE HEADPHONES WHEN THE SYSTEM IS NOT BALANCED. ORDINARILY, A $4\frac{1}{2}$ VOLT "C" BATTERY WILL SERVE THE PURPOSE.

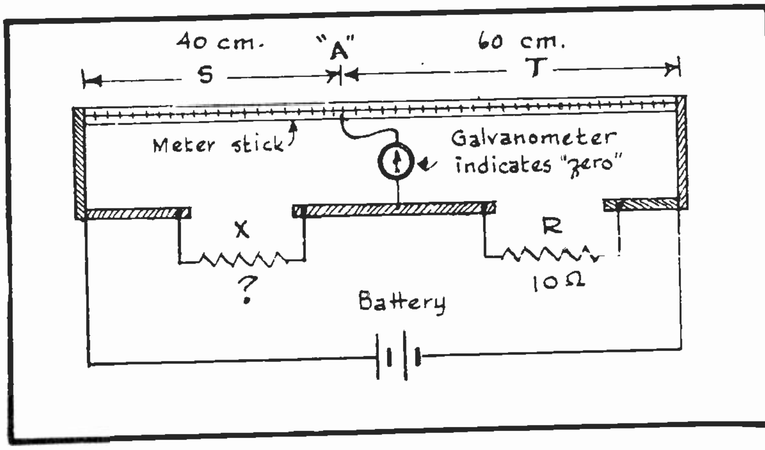

FIG. 14
Data for Calculating Resistance.

MEASURING INDUCTANCE

FIG. 15 SHOWS YOU HOW TO SET UP THE BRIDGE FOR MEASURING INDUCTANCE. IN THIS CASE, THE UNKNOWN INDUCTANCE "Lx" IS CONNECTED ACROSS THE SAME TERMINALS ACROSS WHICH THE UNKNOWN RESISTANCE WAS FORMERLY CONNECTED FOR THE RESISTANCE MEASUREMENT AND A STANDARD INDUCTANCE OF KNOWN INDUCTIVE VALUE "L s" IS CONNECTED TO THE BRIDGE AS ALSO PICTURED IN FIG. 15.

NOW INSTEAD OF CONNECTING A BATTERY DIRECTLY ACROSS THE BRIDGE, WE NEED A SOURCE OF A.C., HAVING APPROXIMATELY A 1000 CYCLE FREQUENCY. THIS A.C. SUPPLY CAN BE OBTAINED BY CONNECTING AN ORDINARY BUZZER IN SERIES WITH TWO SERIES CONNECTED No.6 DRY CELLS AND IN TURN CONNECTING THIS COMBINATION ACROSS THE PRIMARY WINDING OF A TRANSFORMER. THIS TRANSFORMER MAY BE AN ORDINARY TELEPHONE TRANSFORMER OR ELSE IT CAN BE CONSTRUCTED BY WINDING A PRIMARY OF 100 TURNS AND A SECONDARY OF 1000 TURNS AROUND AN IRON CORE. THE WIRE SIZE IS NOT CRITICAL. THE SECONDARY WINDING OF THIS TRANSFORMER IS THEN CONNECTED ACROSS

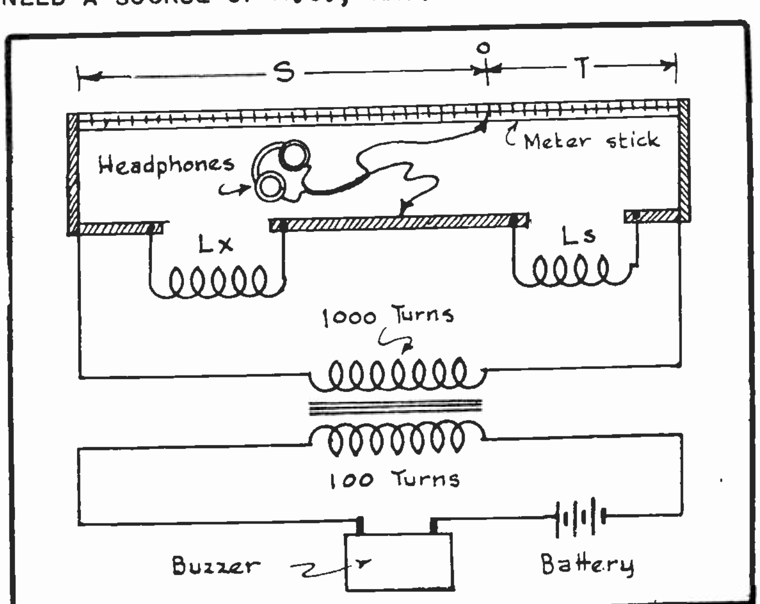

FIG. 15
Measuring Inductance.

THE BRIDGE CIRCUIT AS SHOWN AND IN THIS WAY AN A.C. SUPPLY OF APPROXIMATELY 1000 CYCLES IS APPLIED ACROSS THE BRIDGE CIRCUIT.

WITH THE SET-UP AS ILLUSTRATED IN FIG. 15, A DECIDED BUZZING SOUND WILL BE HEARD IN THE HEADPHONES AS THE SLIDER MAKES CONTACT WITH VARIOUS POINTS ON THE RESISTANCE WIRE. LOCATE THE POSITION ON THIS WIRE WHERE THE MINIMUM BUZZING SOUND IS DETECTED IN THE HEADPHONES. THIS INDICATES THAT THE BRIDGE IS BALANCED, SO CAREFULLY TAKE NOTE OF THE SLIDER'S POSITION OVER THE METRIC SCALE AT THIS INSTANT.

THE INDUCTIVE VALUE OF L X IN FIG. 15 CAN NOW BE DETERMINED BY USING THE FOLLOWING FORMULA: $Lx = \frac{S}{T} \times Ls$ IN WORDS, THIS MEANS THAT TO FIND THE VALUE OF THE INDUCTANCE, DIVIDE LENGTH "S" OF FIG. 15 BY LENGTH T AND MULTIPLY THIS QUOTIENT BY THE INDUCTIVE VALUE OF THE KNOWN INDUCTANCE "Ls". THE ANSWER WILL BE EXPRESSED IN THE SAME INDUCTANCE UNITS AS USED FOR Ls.

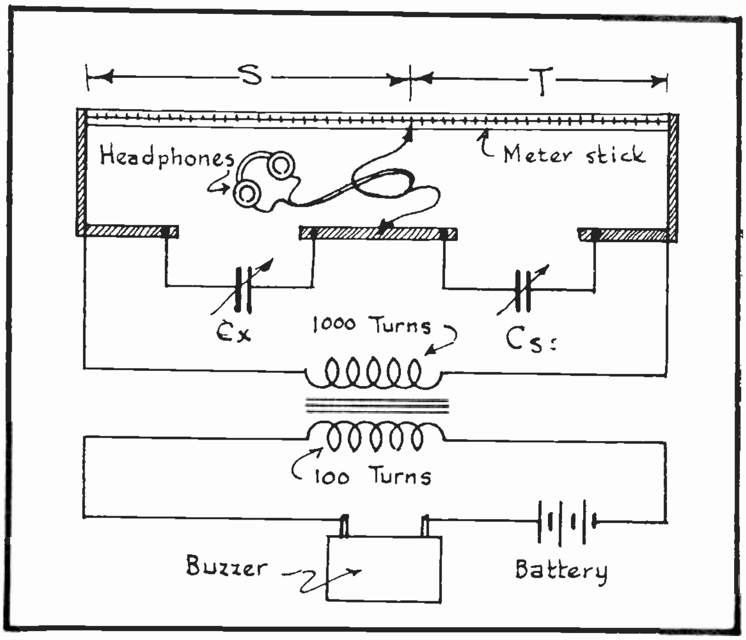

FIG. 16

Measuring Capacity of a Variable Condenser.

AS A PRACTICAL EXAMPLE, LET US ASSUME THE STANDARD INDUCTANCE Ls IN FIG. 15 AS HAVING A VALUE OF 130 MICROHENRIES AND THE BRIDGE BEING IN A STATE OF BALANCE WITH THE SLIDER CONTACTING THE RESISTANCE WIRE OVER THE 60 CM. MARK. DISTANCE "S" THUS BECOMES 60 CM. AND "T" IS 40 CM. THENCE BY APPLYING THE FORMULA $Lx = \frac{S}{T} \times Ls$, WE HAVE $Lx = \frac{60}{40} \times 130 = 1.5 \times 130 = 195$ MICROHENRIES. HENCE COIL Lx HAS AN INDUCTANCE OF 195 MICROHENRIES.

THE MOST CONVENIENT INDUCTANCE STANDARD, Ls IN FIG. 15, IS GENERALLY A WELL CONSTRUCTED VARIOMETER. THIS MAY BE MOUNTED WITH A VERNIER DIAL (GEARED DIAL MOVEMENT), THE UNIT BEING PREVIOUSLY CALIBRATED WITH A CURVE PLOTTED BY SOME TESTING LABORATORY AND SHOWING THE INDUCTANCE FOR ANY DIAL SETTING. THIS FORM OF STANDARD INDUCTANCE WILL SERVE WELL FOR MOST INDUCTIVE MEASUREMENTS CONCERNING R.F. COILS.

MEASURING CONDENSER CAPACITY

THE BRIDGE ASSEMBLY CAN ALSO BE USED FOR MEASURING THE CAPACITY OF UNKNOWN CONDENSERS. FOR THIS WORK, WE USE THE SAME SET UP AS WHEN MEASURING INDUCTANCE AND AS ILLUSTRATED IN FIG. 15, ONLY THAT THE UNKNOWN CONDENSER AND A CALIBRATED STANDARD CONDENSER ARE CONNECTED INTO THE CIRCUIT AS SHOWN YOU IN FIG. 16.

IN THIS CASE, THE STANDARD CONDENSER CAN BE A GOOD VARIABLE AIR CONDENSER OF LOW DIELECTRIC LOSS AND EQUIPPED WITH A VERNIER DIAL FOR WHICH A GRAPH HAS BEEN PLOTTED IN ORDER TO SHOW THE EXACT CAPACITY OF THE STANDARD CONDENSER CORRESPONDING TO ANY DIAL SETTING.

THE BRIDGE IS BALANCED BY ADJUSTING THE SLIDER TO THE POINT WHERE THE LEAST BUZZING SOUND IS HEARD IN THE HEADPHONES. THE CAPACITY OF THE UNKNOWN CONDENSER IS THEN FOUND BY USING THE FORMULA $Cx = \frac{Cs\ T}{S}$ AS APPLIED TO FIG. 16.

LET US SUPPOSE, FOR EXAMPLE, THAT THE STANDARD CONDENSER IN FIG. 16 IS ADJUSTED TO A CAPACITY OF .00025 MFD. AND THAT THE BRIDGE IS BALANCED WITH THE SLIDER CONTACTING THE RESISTANCE WIRE AT THE 65 CM. MARK OF THE METRIC SCALE. THIS MEANS THAT DISTANCE S = 65 CM. AND T = 35 CM. APPLYING THE CONDENSER FORMULA, WE HAVE $Cx = \frac{.00025 \times 35}{65} = \frac{.00875}{65} = .00013$ APPROXIMATELY. THUS, THE UNKNOWN CONDENSER IS FOUND TO HAVE A CAPACITY OF ABOUT .00013 MFD.

WE HAVE NOW CONSIDERED R.F. TRANSFORMER DESIGN AND THE APPLICATIONS OF THE WHEATSTONE BRIDGE QUITE THOROUGHLY, SO WITH THIS INFORMATION ADDED TO YOUR GROWING RADIO KNOWLEDGE, WE SHALL CONCLUDE THIS LESSON.

ALTHOUGH WE HAVE BY NO MEANS COMPLETED ALL OF OUR STUDIES PERTAINING TO R.F. AMPLIFIERS, YET WE SHALL LEAVE THIS SUBJECT FOR A LITTLE WHILE AND GO INTO A.F. AMPLIFIERS MORE THOROUGHLY. BY THUS HAVING A CHANGE OF SUBJECT FOR AWHILE, WE CAN PREVENT YOUR STUDIES FROM BECOMING TIRESOME AND MONOTENOUS, WHILE AT THE SAME TIME ENABLING YOU TO ADVANCE THROUGH THE ENTIRE RADIO FIELD AS A WHOLE MORE RAPIDLY AND IN EASY, LOGICAL STEPS.

Examination Questions

LESSON NO. 44

There is only one royal road to success -- thorough, practical training. It is foolish to depend upon luck, or chance. The wise man plans ahead definitely, then, come what may, he follows his plans without deviating.

1. - Describe in detail how you would go about the task of winding a solenoid type R.F. coil?

2. - What important points should be taken into consideration as regards placement of the terminal lugs on an R.F. transformer?

3. - Describe how a basket-weave coil may be wound?

4. - What are some of the more important points to be considered relative to the primary winding of R.F. transformers of the solenoid type?

5. - Describe the construction of a Wheatstone Bridge.

6. - Explain how the value of an unknown resistor may be measured by means of a Wheatstone Bridge.

7. - How can the inductance of a winding be measured with a Wheatstone Bridge?

8. - Explain how the value of an unknown condenser may be measured by means of a Wheatstone Bridge.

9. - Describe a simple coil winding machine.

10.- What type of R.F. transformer secondary winding is most efficient?

WM. F. LIESKE

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Established 1905

Los Angeles, California

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LESSON NO. 45

• A.F. AMPLIFIER DESIGNING FACTORS •

You have been associated with audio frequency amplifiers a great deal throughout your radio studies up to this time but still there are many important things which we have as yet not considered in great detail regarding this most valuable member of the radio family. So much depends upon the A.F. amplifier in public address installations, as well as in radio receivers, that it is absolutely necessary for you to become thoroughly familiar with this unit.

In order to fully master this subject, you should become acquainted with the more important designing factors involved in the construction of audio frequency amplifiers, in addition to the correct procedures of servicing them. We have considered the operation and servicing of audio amplifiers quite thoroughly and so now we want to tell you about many of the FINER POINTS concerning them — things with which only the EXPERT radiomen are familiar. We assure you that you are going to find this study exceptionally interesting, as well as exceedingly beneficial.

FIG. 1
At Switch Board of a Centralized Public Address Installation.

TUBE "PLATE RESISTANCE"

Now then, the first point, which we are going to discuss with you, will be some additional vacuum tube characteristics. The first of these is the tube characteristic known as the "PLATE RESISTANCE" and although you have already been introduced to this tube constant, we are now going to consider it in greater detail.

The opposition offered to the flow of a direct current by the space between the plate of a tube and the electron emittor, which may be either the filament or

CATHODE, IS KNOWN AS THE TUBE'S "PLATE RESISTANCE" OR BETTER STILL, ITS "D.C. PLATE RESISTANCE". IT IS OF COURSE UNDERSTOOD THAT THE ELECTRON STREAM BETWEEN THE PLATE AND FILAMENT OR CATHODE "BRIDGES" THE SPACE BETWEEN THESE TWO ELEMENTS SO THAT A DIRECT CURRENT CAN ACTUALLY PASS BETWEEN THEM.

OHM'S LAW CAN QUITE EASILY BE APPLIED TO DETERMINE THE D.C. PLATE RESISTANCE OF ANY TUBE. IT CAN BE APPLIED IN THE FORM OF $R = \frac{Ep}{Ip}$ WHERE "Ep" IS THE D.C. VOLTAGE APPLIED TO THE PLATE AND "Ip" THE CURRENT FLOWING THROUGH THE PLATE CIRCUIT.

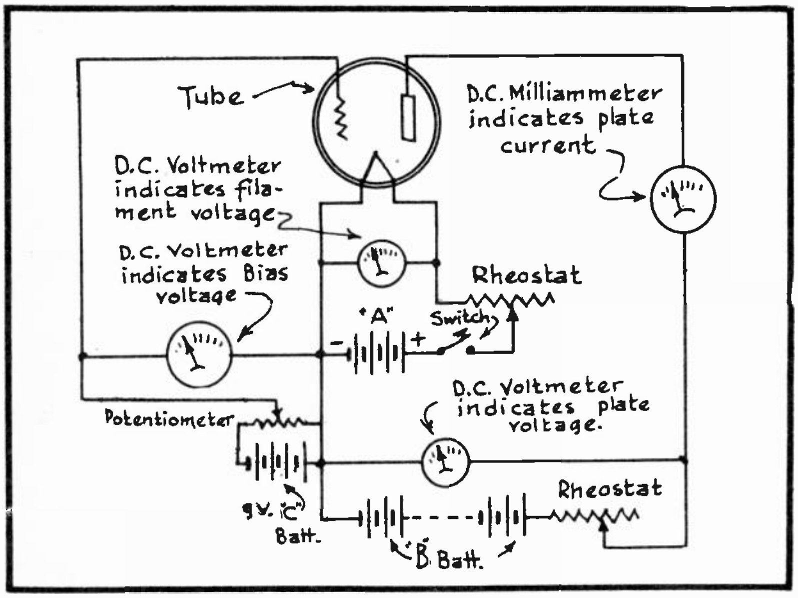

FIG. 2
Circuit For Determining Tube Characteristics.

TUBE "PLATE IMPEDANCE"

NOW UNDER ACTUAL RECEIVER OPERATION, THE SO CALLED D.C. PLATE CURRENT IS CONSTANTLY CHANGING IN VALUE DUE TO THE A.C. SIGNALS WHICH ARE IMPRESSED UPON THE TUBE'S GRID, THEREFORE WE HAVE ANOTHER TUBE CHARACTERISTIC TO CONSIDER, NAMELY THAT KNOWN AS THE TUBE'S "PLATE IMPEDANCE" OR A.C. RESISTANCE. THIS CHARACTERISTIC IS EVEN MORE IMPORTANT THAN A TUBE'S D.C. PLATE RESISTANCE BECAUSE THIS IS THE CONDITION WHICH ACTUALLY EXISTS IN AN OPERATING RECEIVER.

IN OTHER WORDS, A TUBE'S PLATE RESISTANCE GOVERNS THE STEADY PLATE CURRENT FLOW WHEN NO SIGNAL VOLTAGE IS BEING APPLIED TO THE GRID, THAT IS, WHEN THE GRID VOLTAGE IS STEADY. THE TUBE'S PLATE IMPEDANCE, ON THE OTHER HAND, GOVERNS THE VARYING PLATE CURRENT FLOW WHEN A VARYING SIGNAL VOLTAGE IS APPLIED TO THE GRID. THEREFORE, SINCE THE LATTER CONDITION EXISTS UNDER ACTUAL OPERATION, IT IS PERFECTLY CLEAR THAT THIS CHARACTERISTIC IS THE MORE IMPORTANT OF THE TWO. UNFORTUNATELY, IT HAS BECOME A COMMON PRACTICE TO REFER TO A TUBE'S "PLATE IMPEDANCE" AS ITS "PLATE RESISTANCE", WHICH IS REALLY INCORRECT BUT WE WANT YOU TO BE ABLE TO DISTINGUISH CLEARLY THE MEANING BETWEEN THESE TWO UNLIKE TERMS.

THE FORMULA FOR DETERMING A TUBE'S PLATE IMPEDANCE IS:

$$Rp = \frac{\text{CHANGE IN PLATE VOLTAGE}}{\text{CHANGE PRODUCED IN PLATE CURRENT.}}$$

WHERE "Rp" SIGNIFIES THE PLATE IMPEDANCE OF A TUBE.

IN FIG. 2 YOU WILL SEE A CIRCUIT ARRANGEMENT BY MEANS OF WHICH THE PLATE IMPEDANCE OF A TUBE CAN BE DETERMINED. FOR EXAMPLE, LET US SUPPOSE THAT THE TUBE BEING TESTED IN FIG. 2 BE A TYPE -01A AND THAT WE ADJUST

THE VOLTAGES TO THE VALUES RECOMMENDED TO ENABLE THIS TUBE TO OPERATE AS AN EFFICIENT AMPLIFIER. ACCORDING TO THE TUBE SPECIFICATIONS GIVEN YOU IN EARLIER LESSONS, THIS PARTICULAR TYPE OF TUBE WILL OPERATE BEST AS AN AMPLIFIER WITH A PLATE VOLTAGE OF 135 VOLTS, A GRID BIAS OF -9 VOLTS AND A FILAMENT VOLTAGE OF 5 VOLTS.

WITH THE VALUES OF FIG. 2 THUS ADJUSTED, LET US ASSUME THAT THE MILLIAMMETER IN THE PLATE CIRCUIT REGISTERS 3 MILLIAMPERES. NOW WE WILL READJUST THE PLATE CIRCUIT RHEOSTAT UNTIL THE PLATE VOLTAGE DROPS TO 125 VOLTS. LET US FURTHER SUPPOSE THAT THE MILLIAMMETER AT THIS TIME INDICATES A PLATE CURRENT OF 2 MILLIAMPERES.

FROM THIS DATA, WE CAN VERY READILY DETERMINE THE TUBE'S PLATE IMPEDANCE BY SUBSTITUTING THE VALUES WHICH WE HAVE JUST FOUND INTO THE FORMULA WHICH WAS GIVEN YOU A FEW MOMENTS AGO. THE CHANGE IN PLATE VOLTAGE IN THIS CASE WILL BE 135 VOLTS MINUS 125 VOLTS OR 10 VOLTS, WHILE THE RESULTING CHANGE IN PLATE CURRENT WILL BECOME 3 MILLIAMPERES MINUS 2 MILLIAMPERES OR EXACTLY 1 MILLIAMPERE. WHEN USING THIS PLATE CURRENT CHANGE IN THE FORMULA, IT SHOULD BE CONVERTED TO AMPERES. WE THEREFORE HAVE $R_P = \frac{10 \text{ VOLTS}}{.001 \text{ AMPERE}} = 10,000$ OHMS AS THE PLATE IMPEDANCE FOR THIS PARTICULAR TUBE.

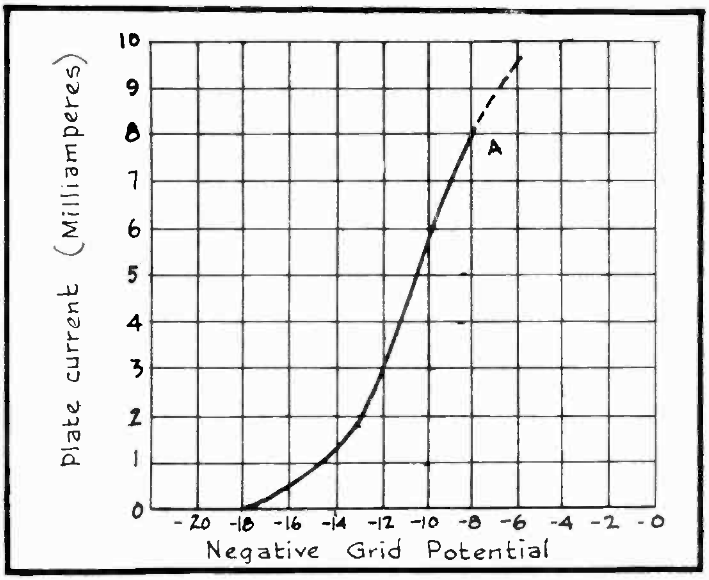

FIG. 3
A Typical Tube Characteristic Curve.

"MUTUAL CONDUCTANCE" OF TUBES

THE NEXT TUBE CHARACTERISTIC WHICH WE WANT TO DISCUSS WITH YOU IS THAT KNOWN AS THE TUBE'S "MUTUAL CONDUCTANCE". THIS CHARACTERISTIC IS A VERY IMPORTANT ONE IN DETERMINING THE MERIT OF A TUBE TO OPERATE AS AN AMPLIFIER. THIS QUALITY OF A TUBE DEPENDS UPON HOW MUCH PLATE CURRENT CHANGE IS PRODUCED BY A GIVEN GRID VOLTAGE CHANGE. THE MUTUAL CONDUCTANCE OF A TUBE IS MEASURED BY THE UNIT "MHO", WHICH YOU WILL IMMEDIATELY RECOGNIZE AS BEING THE WORD "OHM" SPELLED BACKWARDS. THE TERM "MHO" IS ALSO EMPLOYED AS THE UNIT REFERING TO CONDUCTANCE OF RESISTANCES AND IN THIS CASE IS SIMPLY EQUAL TO THE NUMBER 1 DIVIDED BY THE RESISTANCE VALUE. FOR EXAMPLE, IF A CERTAIN ELECTRICAL CONDUCTOR HAS A RESISTANCE OF 20 OHMS, THEN ITS CONDUCTANCE WILL BE $\frac{1}{20}$ OR .05 MHO. ETC.

RETURNING TO TUBES, THE MUTUAL CONDUCTANCE OF THE TUBE IS FOUND BY USING THE FORMULA:

$$G_M = \frac{\text{CHANGE IN PLATE CURRENT PRODUCED (EXPRESSED IN AMPERES)}}{\text{CHANGE IN GRID POTENTIAL PRODUCING THIS PLATE CURRENT CHANGE}}$$

(NOTE THAT THE EXPRESSION "MUTUAL CONDUCTANCE" IS GENERALLY SIMPLY IN-

DICATED BY THE TERM "GM")

THE DATA REQUIRED TO COMPLETE THIS CALCULATION CAN ALSO BE OBTAINED FROM THE TESTING APPARATUS OUTLINED IN FIG. 2. FOR EXAMPLE, IF THE PARTICULAR TUBE IS TO BE OPERATED AT A PLATE VOLTAGE OF 180 VOLTS, A FILAMENT VOLTAGE OF 5 VOLTS AND A GRID BIAS VOLTAGE OF -13.5 VOLTS, THEN INSERT THE TUBE IN THE CIRCUIT OF FIG. 2, ADJUST THE FILAMENT VOLTAGE TO THE REQUIRED VALUE, ADJUST THE PLATE CIRCUIT RHEOSTAT SO THAT THE PLATE VOLTAGE WILL BE EXACTLY 180 VOLTS. CONTINUE BY ADJUSTING THE GRID CIRCUIT POTENTIOMETER SO THAT A BIAS VOLTAGE OF -13 VOLTS WILL BE IMPRESSED UPON THE TUBE'S GRID AND NOTE THE PLATE CURRENT INDICATED BY THE MILLIAMMETER. LET US SUPPOSE THAT THE MILLIAMMETER INDICATES 5.5 MILLIAMPERES AT THIS TIME.

NOW ADJUST THE GRID BIAS VOLTAGE TO -14 VOLTS AND AGAIN NOTE THE READING OF THE MILLIAMMETER, WHICH WE WILL ASSUME TO BE 4.5 MILLIAMPERES. FROM THIS TEST, WE HAVE FOUND THAT A GRID VOLTAGE CHANGE OF 1 VOLT (14 MINUS 13) HAS PRODUCED A PLATE CURRENT CHANGE OF 1 MILLIAMPERE (5.5 MINUS 4.5) OR .001 AMPERE.

SUBSTITUTING THESE VALUES IN OUR FORMULA WE HAVE:

$G_M = \frac{.001}{1} = .001$ MHOS OR 1,000 MICHROMHOS. (1 MHO IS EQUAL TO 1,000,000 MICROMHOS).

CHARACTERISTIC CURVES OF TUBES

IT IS A COMMON PRACTICE TO ILLUSTRATE TUBE CHARACTERISTICS BY MEANS OF A GRAPH AS THE ONE SHOWN YOU IN FIG. 3. THE LINE WHICH IS DRAWN THRU THE VARIOUS POINTS ON THIS CROSS-RULED PAPER IS KNOWN AS THE "GRID POTENTIAL - PLATE CURRENT CURVE" AND IT IS PLOTTED FROM OATA OBTAINED IN THE FOLLOWING MANNER:

THE TUBE TO BE TESTED IS INSERTED IN THE TEST CIRCUIT OF FIG.2. THE PLATE VOLTAGE AND FILAMENT VOLTAGE ARE THEN ADJUSTED TO THE VALUEAT WHICH THE TUBE IS INTENDED TO BE OPERATED. VARIOUS NEGATIVE GRID POTENTIALS ARE THEN APPLIED AND THE CORRESPONDING PLATE CURRENT NOTED. LET US ASSUME THAT THE DATA THUS FOUND IS AS TABULATED IN TABE I.

TABLE I

NEGATIVE GRID POTENTIAL	CORRESPONDING PLATE CURRENT
-18 VOLTS	0 MA.
-17 VOLTS	.25 MA.
-16 VOLTS	.5 MA.
-15 VOLTS	.75 MA.
-14 VOLTS	1.25 MA.
-13 VOLTS	1.75 MA.
-12 VOLTS	3.00 MA.
-11 VOLTS	4.5 MA.
-10 VOLTS	5.75 MA.
-9 VOLTS	7.00 MA.
-8 VOLTS	8.00 MA.

HAVING OBTAINED THIS DATA, WE WOULD PROCEED BY PLOTTING THESE VALUES ON OUR GRAPH. THE NEGATIVE GRID POTENTIALS, YOU WILL NOTE IN FIG. 3 ARE SCALED HORIZONTALLY FROM RIGHT TO LEFT ALONG THE BOTTOM OF THE GRAPH, WHILE THE PLATE CURRENT VALUES ARE SCALED ALONG THE LEFT EDGE FROM THE BOTTOM TOWARDS THE TOP OF THE GRAPH.

SINCE WE FOUND FROM OUR EXPERIMENT THAT NO PLATE CURRENT FLOWS WHEN A NEGATIVE POTENTIAL OF -18 VOLTS IS APPLIED TO THE TUBE'S GRID, WE MARK OUR FIRST POINT ON THE HORIZONTAL "0" PLATE CURRENT LINE WHERE THE -18 VOLTS VERTICAL

LINE CROSSES IT. ALL OTHER POINTS ARE LOCATED ON THIS GRAPH IN A SIMILAR MANNER AND ARE THEN CONNECTED TOGETHER WITH A LINE, THEREBY RESULTING IN THE CHARACTERISTIC CURVE.

AS YOU WILL OBSERVE IN FIG. 3, THE CURVE FOR THIS TUBE, WHEN OPERATING AT THE PLATE VOLTAGE USED FOR THE TEST, SLOPES QUITE GRADUALLY AT THE HIGHER NEGATIVE GRID VOLTAGES BUT THEN SUDDENLY COMMENCES A STEEP UPWARD CLIMB IN THE FORM OF A STRAIGHT LINE AS THE NEGATIVE GRID POTENTIAL IS REDUCED AND THEN COMMENCES TO BEND AGAIN AT ITS UPPER END.

THE TUBE OPERATING AS AN AMPLIFIER

THE GRAPH, WHICH HAS BEEN PREPARED FOR YOU IN FIG. 4, SHOWS YOU HOW A STUDY OF A TUBE'S GRID POTENTIAL-PLATE CURRENT CHARACTERISTIC CURVE ENABLES ONE TO ANALYZE A TUBE'S BEHAVIOR AS AN AMPLIFIER. HERE FOR EXAMPLE, THE CHARACTERISTIC CURVE WAS PLOTTED FOR THE TUBE WHILE OPERATING AT A PLATE VOLTAGE OF 135 VOLTS AND WITH A BIAS VOLTAGE OF -9 VOLTS APPLIED TO THE GRID.

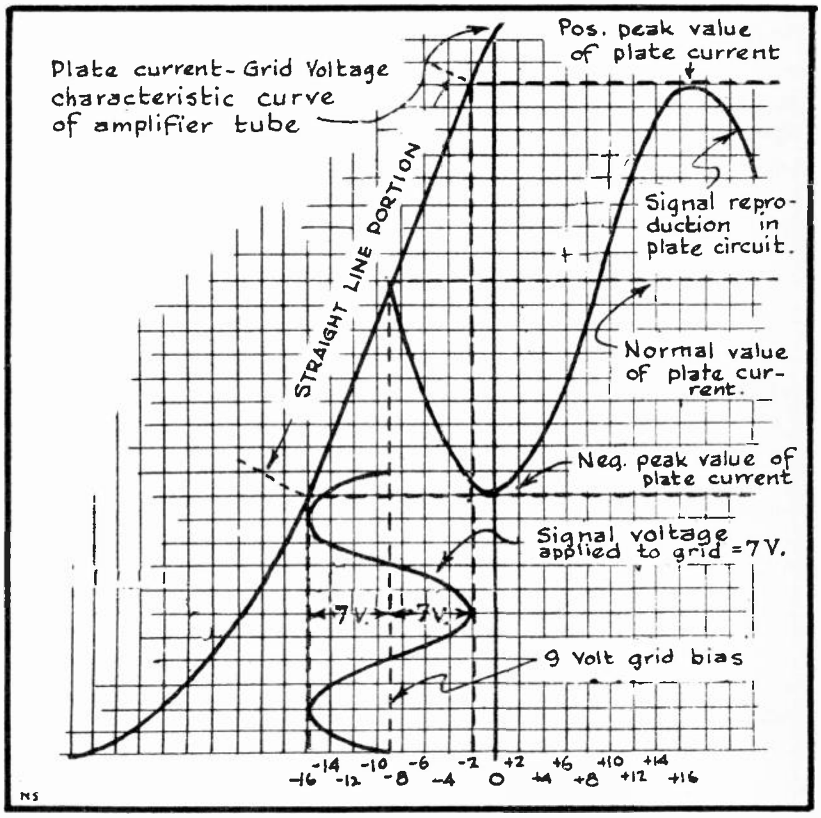

FIG. 4

Graphic Representation of a Tube Operating as Amplifier.

NOW IF AN A.C. SIGNAL VOLTAGE OF 7 VOLTS MAXIMUM INTENSITY SHOULD BE IMPRESSED UPON THE GRID OF THIS TUBE, THE GRID WOULD BE SWUNG BETWEEN THE LIMITS OF -2 VOLTS AND -16 VOLTS OR 7 VOLTS EACH WAY FROM THE FIXED BIAS VOLTAGE OF -9 VOLTS. THIS A.C. SIGNAL VOLTAGE OF 7 VOLTS, AS APPLIED TO THE GRID OF THIS TUBE, IS CLEARLY ILLUSTRATED FOR YOU IN FIG. 4. ALSO OBSERVE IN THIS GRAPHIC ILLUSTRATION THAT THE BIAS VOLTAGE IS SUFFICIENTLY GREAT TO PREVENT THE MAXIMUM SIGNAL VOLTAGE FROM EVER ACTUALLY CAUSING THE GRID TO ASSUME A POSITIVE POTENTIAL. THIS IS AN IMPORTANT POINT BECAUSE IF THE GRID IS EVER PERMITTED TO TAKE ON A POSITIVE POTENTIAL, GRID CURRENTS WILL FLOW AND THE SOUNDS AS REPRODUCED BY THE SPEAKER WILL BECOME DISTORTED.

NOW THEN BY PROJECTING THE PEAK VALUES OF THE A.C. GRID CIRCUIT SIGNAL UP TO THE TUBE'S CHARACTERISTIC CURVE AS DONE BY THE DOTTED VERTICAL LINES IN FIG. 4, WE FIND THAT THIS PROJECTION FALLS ON THE "STRAIGHT LINE PORTION" OF THE CURVE. FURTHERMORE, BY PROJECTING HORIZONTAL LINES FROM THESE POINTS OF INTERSECTION ON THE TUBE CURVE AND PLOTTING PLATE CURRENT VALUES CORRESPONDING TO THE SIGNAL VOLTAGE CHANGES, WE FIND THAT THE

PLATE CURRENT CURVE (CHANGES OF PLATE CURRENT ABOVE AND BELOW ITS NORMAL VALUE AS CAUSED BY THE A.C. SIGNAL VOLTAGES BEING APPLIED TO THE TUBE'S GRID) WILL BE AN EXACT DUPLICATION OF THE A.C. SIGNAL VOLTAGE CURVE ONLY GREATER IN MAGNITUDE. NOTE THE CLOSE RESEMBLANCE BETWEEN THESE TWO CURVES IN FIG. 4. WHENEVER A TUBE IS CORRECTLY FUNCTIONING AS AN AMPLIFIER, FREE FROM DISTORTION, THE PLATE CURRENT CURVE WILL ALWAYS BE A MAGNIFIED BUT EXACT REPRODUCTION OF THE GRID CIRCUIT SIGNAL VOLTAGE CURVE.

QUITE OFTEN, ENGINEERS SPEAK OF THE CONDITION ILLUSTRATED IN FIG.4 BY SAYING THAT "AS AN AMPLIFIER, THE TUBE OPERATES ON THE STRAIGHT PORTION OF ITS CHARACTERISTIC CURVE." REMEMBER THIS BECAUSE YOU WILL HEAR THIS EXPRESSION USED QUITE OFTEN.

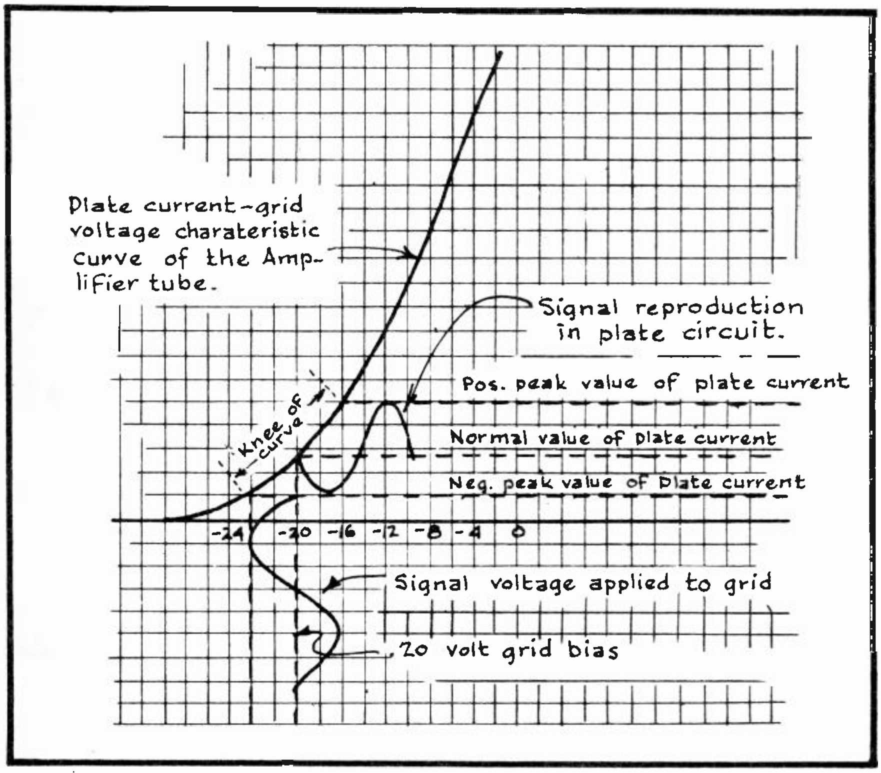

FIG. 5
Distortion Produced by Amplifier Tube.

TUBE DISTORTION

IN ORDER TO GIVE YOU SOMEWHAT OF AN IDEA AS TO WHAT TAKES PLACE WHEN THE AMPLIFIER TUBE IS OPERATED AT THE CURVED PORTION OR "KNEE" OF THE CURVE, WE HAVE PREPARED THE GRAPH OF FIG.5 FOR YOU. HERE YOU WILL SEE THAT THE PLATE CURRENT CURVE IS NOT AN EXACT REPRODUCTION OF THE GRID CIRCUIT A.C. SIGNAL. TO BE EXACT, THE POSITIVE HALF OF THE PLATE CURRENT CURVE IS OF GREATER MAGNITUDE THAN THE NEGATIVE HALF OF THIS SAME CURVE AND THIS IS WHAT CAUSES DISTORTION IN THE SOUNDS PRODUCED BY THE SPEAKER.

YOU SEE, WHAT REALLY IS HAPPENING IN THE GRAPH OF FIG. 5 IS THAT UPON PROJECTING THE HORIZONTAL PLATE CURRENT LIMITING LINES FROM THE TUBE'S CURVE, THESE LINES DO NOT REMAIN EQUALLY DISTANT APART. THE REASON IS OBVIOUS, SIMPLY BECAUSE OF THE CONSTANTLY CHANGING SLOPE OF THE TUBES CURVE AT THE "KNEE".

THUS, YOU SEE, THAT AS AN AMPLIFIER, THE TUBE SHOULD NEVER BE PERMITTED TO OPPERATE AT THE CURVED PORTION OF ITS GRID POTENTIAL-PLATE CURRENT CURVE. TO PREVENT SUCH A POSSIBILITY, IS A SIMPLE MATTER, FOR BY CHOOSING THE PROPER VALUES FOR THE GRID BIAS AND PLATE VOLTAGES, THIS IS IMPOSSIBLE. THE PLATE AND GRID VOLTAGE VALUES SPECIFIED IN TUBE TABLES,

FOR OPERATING THE VARIOUS TYPES OF TUBES AS AMPLIFIERS, HAVE ALL CAREFULLY BEEN DETERMINED BY THE MANY TUBE MANUFACTURERS SO THAT THESE SPECIFIC TUBES WILL OPERATE AT MAXIMUM EFFICIENCY AND ON THE STRAIGHT PORTION OF THEIR GRID POTENTIAL-PLATE CURRENT CHARACTERISTIC CURVE. SO ALL THAT YOU HAVE TO DO IS TO OPERATE THE AMPLIFIER TUBES AT THE VOLTAGE SPECIFIED IN THESE TABLES.

ALTHOUGH YOU DO NOT NECESSARILY REQUIRE A KNOWLEDGE OF AMPLIFIER TUBE CHARACTERISTIC CURVES IN ORDINARY SERVICE WORK, YET YOU WILL FREQUENTLY COME ACROSS THEM IN RADIO ENGINEERING LITERATURE. SO BY NOW HAVING LEARNED SOMETHING ABOUT THEM, YOU WILL BE BETTER ABLE TO FULLY UNDERSTAND ANY LITERATURE WHERE REFERENCE IS MADE TO SUCH CURVES OR TO TERMS ASSOCIATED WITH THEM.

RESISTANCE-CAPACITY COUPLED AMPLIFIERS

NOW LET US CONTINUE BY CONSIDERING THE DESIGNING FACTORS INVOLVED IN RESISTANCE-CAPACITY COUPLED AMPLIFIERS. A TYPICAL CIRCUIT OF THIS FORM IS LAID OUT FOR YOU IN FIG. 6.

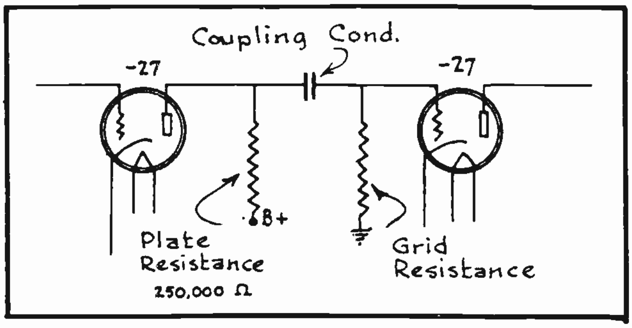

FIG. 6
Resistance-Capacity Coupling.

VOLTAGE AMPLIFICATION

THE FIRST POINT IN WHICH WE ARE INTERESTED RELATIVE TO THIS CIRCUIT IS THE VOLTAGE AMPLIFICATION, WHICH CAN BE REALIZED FROM A CIRCUIT OF THIS TYPE. TO DETERMINE THIS VALUE WE USE THE FORMULA:

$$\text{Voltage Amplification} = \frac{\text{Load resistance} \times \text{Effective Amplification factor of the tube}}{\text{Load Resistance} + \text{plate Impedance of the tube.}}$$

EXPRESSED IN WORDS, THIS FORMULA TELLS US THAT IN ORDER TO DETERMINE THE VOLTAGE AMPLIFICATION OBTAINED FROM A RESISTANCE-CAPACITY COUPLED STAGE, WE MULTIPLY THE LOAD RESISTANCE (RESISTANCE IN THE TUBE'S EXTERNAL PLATE CIRCUIT) BY THE EFFECTIVE AMPLIFICATION FACTOR OF THE TUBE AND THEN IN TURN DIVIDE THE PRODUCT THUS OBTAINED BY THE SUM OF THE LOAD RESISTANCE AND THE TUBE'S PLATE IMPEDANCE.

FOR GENERAL CALCULATIONS, THE LOAD RESISTANCE OF THE TUBE CAN BE CONSIDERED AS THE OHMIC RESISTANCE OF THE PLATE RESISTOR, WHICH IN THE CASE OF FIG. 6 IS 250,000 OHMS.

THE RATED AMPLIFICATION FACTOR OF A TUBE IS NOT FULLY REALIZED UNDER ACTUAL OPERATING CONDITIONS. THIS IS TAKEN INTO ACCOUNT IN THE FORMULA, WHERE YOU WILL NOTE THAT THE TUBE'S EFFECTIVE AMPLIFICATION FACTOR IS SPECIFIED. IT HAS BECOME THE GENERAL PRACTICE TO CONSIDER THE EFFECTIVE AMPLIFICATION FACTOR AS BEING EQUAL TO APPROXIMATELY 90% OF THE RATING AS GIVEN BY THE TUBE MANUFACTURER. IN OTHER WORDS, THE TYPE -27 TUBE IS RATED AS HAVING AN AMPLIFICATION FACTOR OF 9. ITS EFFECTIVE AMPLIFICATION

FACTOR WOULD THEREFORE BE CONSIDERED AS BEING .9 X 9 OR APPROXIMATELY 8.

WITH THIS MATTER TAKEN CARE OF, LET US PROCEED BY CALCULATING THE VOLTAGE AMPLIFICATION WHICH IS OFFERED BY THE STAGE OF FIG. 6. FOR THIS PROBLEM, THE LOAD RESISTANCE WILL BE 250,000 OHMS; THE EFFECTIVE AMPLIFICATION FACTOR WILL BE 8 AND THE PLATE IMPEDANCE ("RESISTANCE") AS FOUND IN A TABLE OF TUBE CONSTANTS WILL BE 9,000 OHMS, WHEN OPERATING THE TUBE AT A PLATE VOLTAGE OF 135 VOLTS AND A GRID BIAS OF -9 VOLTS.

SUBSTITUTING THESE VALUES IN OUR FORMULA WE HAVE:

$$\text{Voltage Amplification} = \frac{250{,}000 \times 8}{250{,}000 + 9000} = 7.7$$

THIS MEANS THAT THE SIGNAL VOLTAGE OBTAINED ACROSS THE OUTPUT OF THIS PARTICULAR STAGE WILL BE 7.7 TIMES OR SLIGHTLY MORE THAN $7\frac{1}{2}$ TIMES THE SIGNAL VOLTAGE IMPRESSED ACROSS THE GRID CIRCUIT OF THIS SAME TUBE. THAT IS TO SAY, IF A SIGNAL VOLTAGE OF .5 VOLT BE APPLIED ACROSS THE GRID CIRCUIT OF THE TUBE, THE SIGNAL VOLTAGE AVAILABLE ACROSS THE PLATE RESISTOR OF THIS SAME TUBE WILL BE APPROXIMATELY 3.85 VOLTS (7.7 X .5)

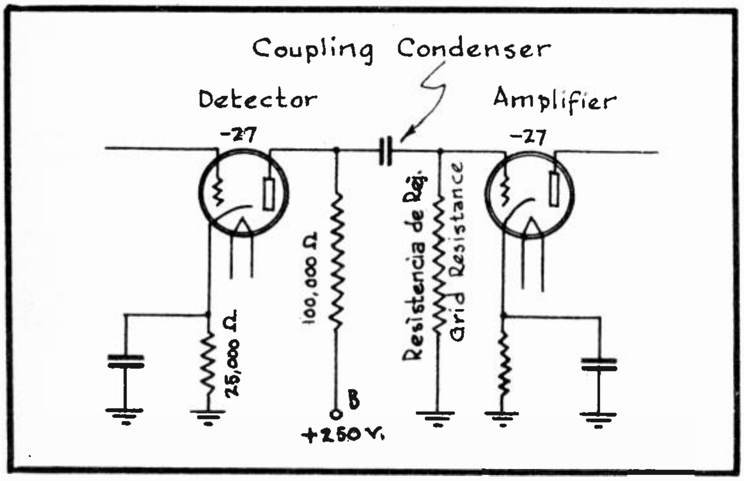

FIG. 7
Voltage Distribution in Circuit.

THE PLATE CIRCUIT RESISTOR

NOW LET US CONSIDER THE VALUE OF THE PLATE RESISTOR IN GREATER DETAIL. TO BEGIN WITH, THE GREATER THE VALUE OF THIS RESISTOR, THE GREATER WILL BE THE AMPLIFICATION REALIZED FROM THE TUBE IN WHOSE CIRCUITED IT IS INSERTED. HOWEVER, SINCE THE PLATE CURRENT MUST FLOW THROUGH THIS LOAD RESISTOR, CONSIDERABLE OF THE "B" VOLTAGE WILL BE DISSIPATED ACROSS THIS RESISTOR AND WILL IN THIS WAY REDUCE THE VOLTAGE EFFECTIVE AT THE PLATE OF THE TUBE.

TO MAKE THIS IMPORTANT POINT STILL CLEARER, LET US RESORT TO A PRACTICAL EXAMPLE. FOR INSTANCE, IN FIG. 7, A TYPE -27 TUBE IS BEING OPERATED AS A POWER DETECTOR AND FOR THE PARTICULAR RECEIVER IN WHICH THIS CIRCUIT IS BEING USED, THE PLATE VOLTAGE REQUIRED AT THE TUBE IS APPROXIMATELY 150 VOLTS, WITH A GRID BIAS OF -20 VOLTS.

BEAR IN MIND THAT THIS TUBE IN FIG. 7 IS BEING OPERATED AS A POWER DETECTOR AND AS SUCH, THE TUBE'S PLATE IMPEDANCE BECOMES MUCH GREATER THAN WHEN USING THIS SAME TUBE AS AN AMPLIFIER OR GRID CONDENSER AND LEAK TYPE DETECTOR AND BECAUSE OF THIS, THE PLATE CURRENT PASSED BY THE TUBE, WILL BE MUCH LESS THAN THAT SPECIFIED IN TUBE TABLES WHEN THE PARTICULAR TUBE IS CONSIDERED AS OPERATING UNDER AMPLIFIER CONDITIONS.

IN THE PARTICULAR CIRCUIT OF FIG. 7, THE PLATE CURRENT FLOWING THROUGH THE DETECTOR TUBE WILL ONLY BE ABOUT .8 MILLIAMPERE. THIS .8 MA. WILL THEREFORE FLOW THROUGH THE 100,000 OHM PLATE RESISTOR AND AS A RE-

SULT, 80 VOLTS WILL BE DISSIPATED OR LOST ACROSS THIS RESISTOR (E = I X R = .0008 AMPERE X 100,000 OHMS = 80 VOLTS). HENCE IF THE AVAILABLE "B" VOLTAGE IS 250 VOLTS, ONLY 250 MINUS 80 OR 170 VOLTS WILL REACH THE PLATE OF THE DETECTOR TUBE. THEN SINCE THIS SAME .8 MA. WILL ALSO FLOW THROUGH THE 25,000 OHM BIAS RESISTOR, AN ADDITIONAL 20 VOLTS WILL BE DISSIPATED HERE SO THAT THE ACTUAL EFFECTIVE PLATE VOLTAGE (ACROSS PLATE AND CATHODE) WILL BE 170 MINUS 20 OR 150 VOLTS. SO YOU SEE, BY USING THE VALUES HERE SPECIFIED, EVERYTHING WORKS OUT SATISFACTORILY FOR THIS PROBLEM. NEVERTHELESS, ALL VALUES WOULD BE UPSET BY USING A PLATE RESISTOR OF A DIFFERENT OHMIC VALUE.

FREQUENCY CHARACTERISTIC OF RESISTANCE-CAPACITY COUPLING

NOW LET US CONSIDER THE FREQUENCY CHARACTERISTIC OF SUCH AN AMPLIFIER STAGE AS ILLUSTRATED IN FIG. 7. THIS DEPENDS PRIMARILY UPON TWO THINGS, NAMELY THE CAPACITIVE VALUE OF THE COUPLING CONDENSER AND THE RESISTANCE VALUE OF THE LEAK RESISTOR, WHICH IS CONNECTED ACROSS THE GRID CIRCUIT OF THE FOLLOWING TUBE.

IN ORDER THAT SUCH A RESISTANCE-CAPACITY COUPLED AMPLIFIER STAGE MAY HANDLE THE LOWER AUDIO FREQUENCIES SATISFACTORILY, A DEFINITE RELATION MUST EXIST BETWEEN THE COUPLING CONDENSER AND THE GRID LEAK RESISTOR. WE CALL THIS IMPORTANT RELATION THE "TIME CONSTANT" AND IT IS FOUND BY MULTIPLYING THE COUPLING CONDENSER CAPACITY EXPRESSED IN FARADS BY THE GRID LEAK RESISTOR EXPRESSED IN OHMS. TO ENABLE THIS TYPE OF COUPLING TO HANDLE AUDIO FREQUENCIES DOWN TO 50 CYCLES, THE TIME CONSTANT SHOULD NOT BE GREATER THAN 0.0065.

IT IS EASY TO SEE THAT THE GREATER THE VALUE OF THE COUPLING CONDENSER, THE EASIER WILL IT BE FOR THE LOWER AUDIO FREQUENCIES TO PASS THRU IT AND THEREBY ACT UPON THE GRID OF THE FOLLOWING TUBE. HOWEVER, BY CHOOSING TOO GREAT A VALUE FOR THE COUPLING CONDENSER, THERE IS DANGER OF MOTOR-BOATING TO OCCUR, THAT IS, A "PUTT-PUTT" SOUND LIKE THAT OF A MOTOR BOAT EXHAUST COMING FROM THE SPEAKER. WHILE ON THE OTHER HAND, TOO SMALL A CAPACITIVE VALUE FOR THE COUPLING CONDENSER WILL PREVENT THE LOWER AUDIO FREQUENCIES TO BE APPLIED TO THE GRID OF THE FOLLOWING TUBE FOR FURTHER AMPLIFICATION.

THE GREATER THE VALUE OF THE GRID LEAK, THE LESS WILL BE THE SIGNAL VOLTAGE LOST THROUGH IT AND THE BETTER WILL BE THE AMPLIFICATION OF THE LOWER FREQUENCIES. HOWEVER, HERE AGAIN AN EXCESSIVELY HIGH VALUE FOR THE LEAK RESISTOR IS APT TO CAUSE BLOCKING OF THE TUBE IN WHOSE CIRCUIT IT IS CONNECTED. THAT IS, IF THE LEAK RESISTOR HAS TOO MUCH RESISTANCE, ELECTRONS WILL NOT BE ABLE TO DRAIN OFF THE GRID AND WOULD FINALLY ACCUMULATE TO SUCH AN EXTENT AS TO STOP THE ELECTRON STREAM THROUGH THE TUBE ALTOGETHER, THEREBY PREVENTING ITS CONTINUED OPERATION AND AT WHICH TIME, WE WOULD SPEAK OF THE TUBE AS BEING BLOCKED.

YOU WILL FIND TABLE II HANDY, IN THAT BY REFERRING TO IT, YOU CAN QUICKLY DETERMINE WHAT COUPLING CONDENSER AND GRID LEAK COMBINATION WILL OFFER GOOD RESULTS. THIS TABLE, YOU WILL NOTE, IS BASED ON THE RULE WHICH WAS JUST GIVEN YOU IN REGARDS TO THE TIME CONSTANT NOT EXCEEDING A VALUE OF .0065 IN ORDER THAT FREQUENCIES AS LOW AS 50 CYCLES MAY BE AMPLIFIED.

OF COURSE, IT IS UNDERSTOOD THAT YOU WILL FIND CONDENSER AND LEAK

RESISTOR VALUES USED IN MANY COMMERCIAL CIRCUITS WHERE THE TIME CONSTANT IS CONSIDERABLY LESS THAN .0065 AND IN SUCH CASES, THE DESIGNERS HAVE CHOSEN SUCH VALUES IN ORDER TO OBTAIN STILL GREATER EMPHASIS OF THE LOWER NOTES. IT IS THUS UNDERSTOOD THAT IN DESIGN WORK OF THIS NATURE, THE DESIGNER SHOULD USE HIS OWN DISCRETION IN CHOOSING THE CIRCUIT VALUES TO OBTAIN THE DESIRED FREQUENCY CHARACTERISTIC.

TABLE II

COUPLING CONDENSER AND LEAK RESISTOR RELATIONS
TO AMPLIFY DOWN TO 50 CYCLES

GRID LEAK RESISTANCE	CORRESPONDING COUPLING COND.
1 MEGOHM OR 1,000,000 OHMS	---------- 0.0065 MFD.
3/4 MEGOHM OR 750,000 OHMS	---------- 0.0087 MFD.
1/2 MEGOHM OR 500,000 OHMS	---------- 0.013 MFD.
1/4 MEGOHM OR 250,000 OHMS	---------- 0.026 MFD.
1/10 MEGOHM OR 100,000 OHMS	---------- 0.065 MFD.

TUBE MANUFACTURERS GENERALLY SPECIFY WHAT GRID RESISTOR IS MOST DESIRABLE FOR THEIR PARTICULAR TUBE FOR BEST PERFORMANCE. WITH THIS VALUE KNOWN, THE COUPLING CONDENSER VALUE CAN BE CHOSEN ACCORDING TO THE METHOD JUST DESCRIBED.

PREVENTING MOTORBOATING

IN FIG. 8 YOU ARE SHOWN A METHOD WHICH IS FREQUENTLY EMPLOYED TO PREVENT MOTORBOATING IN RESISTANCE-CAPACITY COUPLED A.F. AMPLIFIERS. HERE YOU WILL OBSERVE, THAT A SEPARATE RESISTOR R2 IS CONNECTED IN SERIES WITH THE PLATE LOAD RESISTOR R_1 AND B+. BYPASS CONDENSERS C_1 AND C_2 ARE THEN CONNECTED BETWEEN GROUND AND EACH END OF R_2. THIS RESISTOR-CONDENSER COMBINATION R_2-C_1-C_2 SERVES AS A FILTER SO AS TO REDUCE UNDESIRED COUPLING BETWEEN THIS A.F. STAGE AND OTHER PARTS OF THE CIRCUIT WHICH MAY BE LIKELY TO CAUSE A LOW FREQUENCY OSCILLATION.

THE VALUES FOR C_1 AND C_2 MAY BE FROM 1 TO 2 MFD. WHILE R_2 MAY BE FROM ABOUT 25,000 OHMS TO 100,000 OHMS OR EVEN MORE.

A PRACTICAL A.F. AMPLIFIER DESIGN PROBLEM

HAVING CONSIDERED THE VARIOUS SECTIONS OF THE A.F. AMPLIFIER INDIVIDUALLY, LET US NOW GO A STEP FARTHER BY INVESTIGATING THE METHOD OF DESIGNING AN A.F. AMPLIFIER IN ITS COMPLETE FORM. THIS AMPLIFIER IS TO BE A.C. OPERATED.

POWER OUTPUT REQUIREMENTS

OUR FIRST PROBLEM IN THIS RESPECT WILL BE TO DETERMINE THE AMOUNT OF POWER REQUIRED FROM THE AMPLIFIER'S FINAL OR POWER STAGE AND WHICH IS TO BE UTILIZED FOR LOUD SPEAKER OPERATION. THE AMOUNT OF THIS POWER OUTPUT WILL OF COURSE DEPEND UPON THE EFFICIENCY OF THE LOUD SPEAKER AND THE AMOUNT OF ACOUSTICAL (SOUND) ENERGY THAT THE SPEAKER MUST CREATE IN THE ROOM IN WHICH IT IS BEING OPERATED.

YOU WILL NO DOUBT GAIN SOMEWHAT OF AN IDEA AS TO THE REQUIRED SPEAKER ENERGY BY COMPARING IT WITH THE ENERGY EXPENDED BY THE HUMAN VOICE WHILE SPEAKING. THE AVERAGE POWER OF NORMAL SPEECH HAS BEEN ESTIMATED TO BE EQUIVALENT TO A POWER ELECTRICALLY EXPRESSED AS 10 MICROWATTS (0.000010 WATTS).

NOW THE MOST TRYING TEST IS GIVEN A LOUD SPEAKER DURING THE TIME THAT IT IS CALLED UPON TO REPRODUCE FAITHFULLY THE SOUNDS AS EMITTED BY A COMPLETE ORCHESTRA, FOR HERE THE RANGE IN VOLUME IS VERY GREAT — RANGING FROM PIANISSIMO PASSAGES WHICH ARE HARDLY AUDIBLE, TO FORTISSIMO PASSAGES WHICH ARE VERY LOUD. BASED UPON SUCH CONSIDERATIONS, ONE CAN ASSUME THAT THE MINUMUM POWER REQUIRED FROM THE LOUD SPEAKER WHILE REPRODUCING THE VERY SOFT TONES WILL BE ABOUT 3 MICROWATTS, WHEREAS THE POWER REQUIRED FOR THE REPRODUCTION OF THE LOUDEST ORCHESTRAL TONES WILL BE APPROXIMATELY 10,000 TIMES AS GREAT OR 30,000 MICROWATTS (0.03 WATTS).

UNDER SUCH AVERAGE CONDITIONS, NOT ONLY WILL THE LOUD SPEAKER BE CALLED UPON TO DELIVER A POWER ENERGY EQUIVALENT TO 0.03 WATTS BUT MUST DO SO WITHOUT DISTORTION. IN OTHER WORDS, "OVERLOADING" OF THE SPEAKER CANNOT BE TOLERATED, SO TO BE ON THE SAFESIDE IT IS ADVISABLE TO ASSUME THE REQUIRED POWER TO BE TWICE AS GREAT AS ACTUALLY NEEDED. THIS MEANS THAT WE WILL CONSIDER THE LOUDSPEAKER AS HAVING TO DELIVER 0.06 WATTS OF ENERGY.

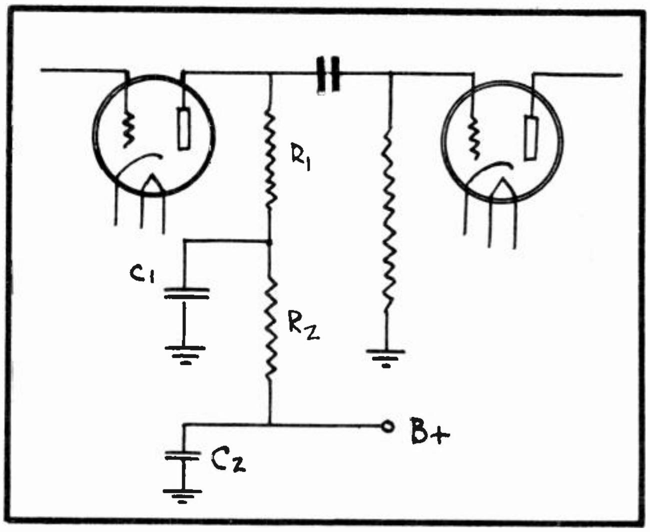

FIG. 8
Anti-Motorboat Circuit.

OUR PRESENT DAY LOUDSPEAKERS, ALTHOUGH CAPABLE OF OFFERING FINE TONE QUALITY, ARE NEVERTHELESS STILL QUITE INEFFECIENT AS REGARDS POWER LOSSES IN THEIR MOVEMENT ETC. ASSUMING THE PARTICULAR SPEAKER WHICH WE ARE TO USE AS HAVING A RATED EFFICIENCY OF 2%, WE CAN READILY CALCULATE THE NECESSARY POWER TO BE DELIVERED TO THE SPEAKER BY USING THE FORMULA:

$$\text{Power into speaker} = \frac{\text{Output power}}{\text{Efficiency}}$$

HERE WE HAVE ALREADY DETERMINED THE OUTPUT POWER AS BEING 0.06 WATTS AND THE EFFICIENCY IS KNOWN TO BE 2%. EXPRESSED AS A DECIMAL FRACTION, 2% IS EQUIVALENT TO 0.02. SUBSTITUTING THESE VALUES INTO THE FORMULA, WHICH WAS JUST GIVEN YOU, WE HAVE:

$$\text{Power into speaker} = \frac{0.06}{0.02} = 3 \text{ watts}$$

THUS, WE HAVE DETERMINED THAT THE AMPLIFIER FOR THIS PARTICULAR JOB MUST HAVE AN UNDISTORTED OUTPUT OF 3 WATTS TO BE DELIVERED TO THE SPEAKER. REMEMBER THAT THIS UNDISTORTED OUTPUT POWER RATING MEANS THAT THIS AMOUNT OF POWER IS TO BE HANDLED WITH EASE—AN ADEQUATE MARGIN OF SAFETY BEING ALLOWED AS ALREADY SPECIFIED, SO THAT THERE WILL BE NO POSSIBILITY OF DISTORTION BEING CAUSED BY OVER-LOADING.

IN PRACTICE, YOU WILL FIND MOST ELECTRODYNAMIC SPEAKERS CAPABLE OF

SATISFACTORILY HANDLING AN AMPLIFIER OUTPUT OF 3 WATTS, WHILE SOME OF THE LARGER UNITS CAN STAND 5 WATTS AND OVER. THIS MEANS THAT TWO 3-WATT SPEAKERS CONNECTED IN PARALLEL FOR PUBLIC ADDRESS WORK WILL REQUIRE 6 WATTS, THREE SUCH SPEAKERS 9 WATTS ETC.

ONE SET OF HEADPHONES WILL HANDLE FROM 0.004 TO 0.006 WATTS OF AMPLIFIER OUTPUT, WHILE THE AVERAGE MAGNETIC SPEAKER WILL TAKE FROM 150 TO 300 MILLIWATTS.

THE CHOICE OF POWER TUBES

HAVING NOW DETERMINED THE OUTPUT POWER REQUIRED FROM OUR AMPLIFIER, THE NEXT STEP WILL BE TO CHOOSE A TYPE OF COMMERCIAL POWER TUBE WHICH WILL DELIVER THIS OUTPUT OF 3 WATTS WITHOUT DISTORTION. BY REFERRING TO PREVIOUS LESSONS CONTAINING INFORMATION ON A.C. TUBE CHARACTERISTICS YOU WILL FIND THAT A TYPE -50, AS WELL AS SEVERAL OTHER TYPES OF POWER TUBES ARE CAPABLE OF FULFILLING THIS REQUIREMENT.

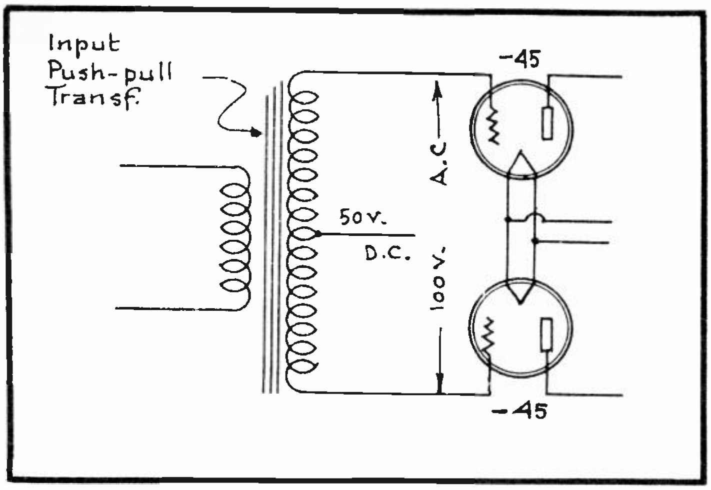

FIG. 9
The Power Stage.

BY STILL FURTHER STUDYING THESE TUBE CONSTANTS, YOU WILL FIND THAT A TYPE -45 POWER TUBE WILL FURNISH AN UNDISTORTED OUTPUT OF 1.6 WATTS. TWO TUBES OF THIS TYPE WHEN CONNECTED IN A PUSH-PULL ARRANGEMENT WILL HANDLE SLIGHTLY MORE THAN TWICE THIS POWER OR AT LEAST 3.2 WATTS, WHICH ALSO MEETS OUR REQUIREMENTS SATISFACTORILY. FOR THE SAKE OF A DEFINITE PROBLEM, LET US SUPPOSE THAT WE DECIDE TO USE A PAIR OF -45'S IN A PUSH-PULL POWER STAGE.

AS WAS ALREADY TOLD YOU PREVIOUSLY — IN ORDER TO AVOID THE POSSIBILITY OF DISTORTION DUE TO TUBE OVERLOADING, THE SIGNAL PEAK VOLTAGE AS APPLIED TO THE TUBE'S GRID SHOULD NOT EXCEED THIS SAME TUBE'S GRID BIAS VOLTAGE. MANUFACTURER'S, YOU WILL REMEMBER, SPECIFY A GRID BIAS VOLTAGE OF MINUS 50 VOLTS FOR THE -45 TUBE AND THEREFORE THE A.C. SIGNAL VOLTAGE AS APPLIED TO THIS TUBE'S GRID SHOULD NOT EXCEED A 50 VOLT PEAK VALUE. HOWEVER, WHEN CONNECTING THESE TUBES IN PUSH-PULL, THE ALLOWABLE SIGNAL VOLTAGE FROM GRID TO GRID IS 100 PEAK VOLTS (50 VOLTS FROM EACH GRID TO THE CENTER TAP OF THE INPUT PUSH-PULL TRANSFORMER'S SECONDARY WINDING).

BY REFERRING TO FIG. 9, YOU WILL BE ABLE TO MORE CLEARLY VISUALIZE THE CONDITIONS AS THEY REALLY ARE. NOTICE HERE THAT WITH THE 3 WATTS AVAILABLE ACROSS THE OUTPUT, A SIGNAL OF 100 VOLTS A.C. PEAK VALUE IS APPLIED ACROSS THE ENTIRE GRID CIRCUIT OF THIS STAGE.

HAVING DETERMINED THE DESIRED OUTPUT POWER FOR THE AMPLIFIER, WE MUST NEXT CONSIDER THE INPUT VOLTAGE AVAILABLE SO THAT THE "OVERALL-GAIN" OF THE AMPLIFIER CAN BE CALCULATED. AS A GENERAL RULE, YOU CAN CONSIDER A

SIGNAL VOLTAGE OF 0.1 TO 0.5 VOLTS AS BEING AVAILABLE AT THE OUTPUT OF A DETECTOR; 0.01 TO 0.05 VOLTS FROM A DOUBLE BUTTON CARBON MICROPHONE AND 0.5 TO 1.0 VOLT FROM A PHONOGRAPH PICK-UP. THESE ARE OF COURSE ONLY AVERAGE VALUES AND WILL DIFFER AMONG UNITS OF DIFFERENT DESIGN.

LET US ASSUME THAT CONDITIONS ARE SUCH THAT A SIGNAL VOLTAGE OF .37 VOLTS A.C. PEAK VALUE IS AVAILABLE AT THE INPUT OF THE PARTICULAR AMPLIFIER FOR WHICH WE ARE WORKING OUT THE DESIGN.

GAIN PER STAGE

OUR NEXT STEP WILL BE TO DETERMINE THE AMOUNT OF GAIN REQUIRED AND WHICH IS ALSO AVAILABLE FROM THE VARIOUS STAGES PRECEDING THE POWER STAGE. SINCE THE POWER STAGE IS TO BE OF THE PUSH-PULL TYPE, WE WILL HAVE A PUSH PULL TRANSFORMER FEEDING THIS CIRCUIT AND THE PARTICULAR TRANSFORMER AVAILABLE, WE WILL ASSUME, HAS A STEP-UP RATIO OF 4.5 TO 1.

BY USING SUCH A TRANSFORMER, THE SIGNAL VOLTAGE DEVELOPED ACROSS ITS SECONDARY WILL BE 4.5 TIMES AS GREAT AS THAT IMPRESSED ACROSS ITS PRIMARY WINDING, DUE TO THE FACT THAT THE SECONDARY CONSISTS OF APPROXIMATELY $4\frac{1}{2}$ TIMES AS MANY TURNS OF WIRE AS THE PRIMARY.

THE TURNS RATIO OF THIS TRANSFORMER BEING 4.5 TO 1, IT IS CLEAR THAT IN ORDER FOR THE SECONDARY PEAK VOLTAGE TO BE 100 VOLTS, THE SIGNAL VOLTAGE BEING DEVELOPED ACROSS THE PRIMARY WINDING MUST BE $\frac{100}{4.5}$ OR 22.2 PEAK VOLTS.

BY USING A TYPE -27 TUBE PRECEDING THE INPUT PUSH-PULL TRANSFORMER, THIS TUBE WILL GIVE US A GAIN OF ABOUT 8, WHICH MEANS THAT THE SIGNAL VOLTAGE APPLIED ACROSS ITS GRID CIRCUIT MUST BE $\frac{22.2}{8} = 2.7$ PEAK VOLTS.

NOW THEN, BY FIGURING AHEAD A LITTLE, WE CAN FORESEE THAT IN ORDER TO INCREASE THE SIGNAL INPUT OF .36 VOLTS TO 2.7 WE STILL REQUIRE A VOLTAGE AMPLIFICATION OF $\frac{2.7}{.37}$ OR 7.3. AN ADDITIONAL RESISTANCE — CAPACITY COUPLED STAGE EMPLOYING A TYPE -27 TUBE WILL TAKE CARE OF THIS REQUIRED GAIN OF 7.3 QUITE NICELY.

FOR EXAMPLE, IF THE LOAD RESISTOR FOR THIS ADDITIONAL RESISTANCE-CAPACITY COUPLED STAGE IS TO BE 100,000 OHMS, THEN BY USING OUR FORMULA:

$$\text{VOLTAGE AMPLIFICATION} = \frac{\text{LOAD RESISTANCE X EFFECTIVE AMPLIFICATION FACTOR OF THE TUBE.}}{\text{LOAD RESISTANCE + PLATE IMPEDANCE OF THE TUBE}}$$

WE HAVE VOLTAGE AMPLIFICATION $= \frac{100,000 \text{ X } 8}{100,000+9000} = \frac{800,000}{109000} = 7.3$

OUR BASIC CIRCUIT FOR THE AMPLIFIER THUS TAKES THE FORM AS ILLUSTRATED IN FIG. 10. THE GAIN FOR THE CIRCUIT NOW BECOMES APPROXIMATELY 270, SO THAT WE ARE ABLE TO AMPLIFY THE .37 VOLT SIGNAL INPUT TO VERY NEARLY 100 VOLTS.

SIGNAL VOLTAGE GAIN

FIG. 10 ALSO SHOWS YOU HOW THE SIGNAL VOLTAGE IS GRADUALLY INCREASED AS IT IS SUCCESSIVELY PASSED ON THROUGH THE AMPLIFYING SYSTEM. FOR EX-

AMPLE, THE FIRST STAGE AMPLIFIES THE SIGNAL ABOUT 7.3 TIMES, SO THAT APPROXIMATELY .37 TIMES 7.3 OR 2.7 A.C. PEAK VOLTS ARE AVAILABLE AS A SIGNAL ACROSS THIS SAME TUBE'S PLATE RESISTOR.

NO GAIN IS REALIZED BY THE RESISTANCE-CAPACITY COUPLING, SO THAT VERY NEARLY THIS SAME VOLTAGE IS AVAILABLE ACROSS THE GRID CIRCUIT OF THE SECOND -27 TUBE. THIS TUBE, HAVING AN EFFECTIVE AMPLIFICATION FACTOR OF 8, BOOSTS THE SIGNAL UP 8 TIMES MORE, THEREBY DELIVERING 8 TIMES 2.7 OR A SIGNAL OF PRACTICALLY 22 VOLTS A.C. PEAK VALUE ACROSS THE PRIMARY WINDING OF THE INPUT PUSH-PULL TRANSFORMER. THIS TRANSFORMER, DUE TO ITS 4.5 TO 1 RATIO, INCREASES THE SIGNAL VOLTAGE $4\frac{1}{2}$ TIMES AND THEREFORE DELIVERS 4.5 TIMES 22 = 99 OR VERY NEARLY 100 A.C. PEAK VOLTS TO THE GRID CIRCUIT OF THE POWER STAGE.

TUBE VOLTAGE

REFERRING TO A TABLE OF A.C. TYPE TUBE CHARACTERISTICS, WE FIND THAT IN ORDER TO REALIZE THE FULL AMPLIFICATION OF THE -27 TUBE, WE CAN USE A PLATE VOLTAGE OF 135 VOLTS, IN CONJUNCTION WITH A GRID BIAS OF -9 VOLTS. THIS BIAS VOLTAGE, YOU WILL NOTE, IS SUFFICIENTLY GREAT SO AS TO OFFER AN AMPLE MARGIN OF SAFETY IN PREVENTING THE SIGNAL VOLTAGES IN THE GRID CIRCUIT OF EITHER OF THE -27 TUBES OF OUR AMPLIFIER EVER EXCEEDING THE BIAS VOLTAGE EVEN AT MAXIMUM VOLUME. THE TYPE -45 POWER TUBES OF COURSE, ARE TO BE OPERATED WITH 250 VOLTS PLATE POTENTIAL AND A GRID BIAS OF -50 VOLTS.

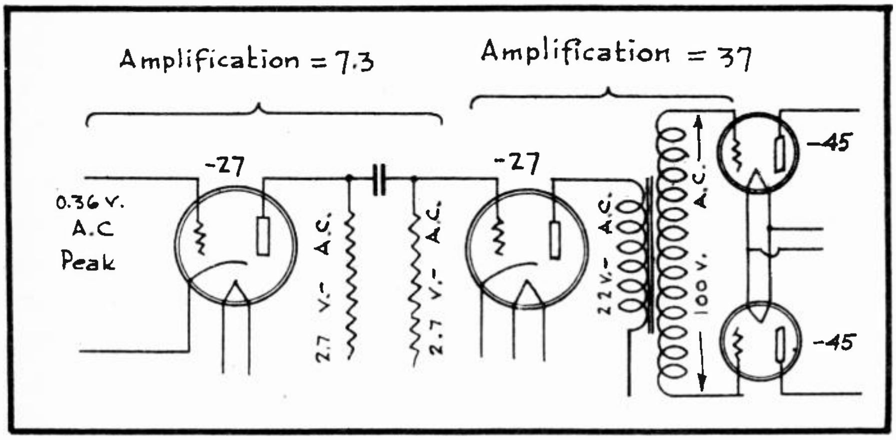

FIG. 10

"Lay-out" for the Complete Amplifier.

IN PREVIOUS LESSONS, YOU HAVE ALREADY LEARNED THE EXACT METHOD OF CALCULATING THE VALUE FOR BIAS RESISTORS AND CONDENSERS FOR ALL TYPES OF CIRCUITS, THEREFORE THERE IS NO NEED TO DISCUSS THIS MATTER ANY FURTHER AT THIS TIME.

THE NEXT STEP WILL BE TO CHOOSE A VALUE FOR THE COUPLING CONDENSER AND GRID LEAK OF THE RESISTANCE-CAPACITY COUPLING IN ORDER TO OBTAIN THE DESIRED FREQUENCY CHARACTERISTIC FOR THIS STAGE. TO DO THIS, SIMPLY APPLY THE INFORMATION REGARDING THIS PROBLEM WHICH WAS ALREADY GIVEN YOU EARLIER IN THIS LESSON.

SO ALTOGETHER, WE HAVE ALREADY WORKED OUT THE BASIC DESIGN FOR AN A.F. AMPLIFIER WHICH WILL UTILIZE A SIGNAL INPUT OF .37 A.C. PEAK VALUE AND DELIVER A POWER OF 3 WATTS TO THE LOUD SPEAKER. THE BALANCE OF THE DESIGN CONSISTS SOLELY OF CONNECTING THESE FUNDAMENTAL CIRCUITS TOGETHER CORRECTLY, WORKING OUT A POWER PACK AND VOLTAGE DISTRIBUTION ETC.

PERMISSIBLE OVERLOAD

SOMETIMES ENGINEERS CONSIDER THE TUBES IN A PUSH-PULL AMPLIFIER CIRCUIT AS CAPABLE OF SATISFACTORILY HANDLING 2.5 TIMES THE POWER OUTPUT RATING OF A SINGLE TUBE RATHER THAN JUST TWICE AS MUCH AS WE HAVE CONSIDERED IT IN WORKING OUT OUR AMPLIFIER DESIGN. IF THIS ASSUMPTION IS MADE, THEN THE TOTAL OUTPUT DERIVED FROM TWO TYPE -45 TUBES IN PUSH-PULL WILL BE 1.6 X 2.5 OR 4 WATTS BUT UNDER THIS CONDITION, THE SIGNAL VOLTAGE REQUIRED ACROSS THE GRID CIRCUIT OF THE POWER STAGE WOULD HAVE TO BE PROPORTIONATELY GREATER OR ABOUT 125 A.C. PEAK VOLTS. ALTHOUGH THIS SIGNAL VOLTAGE VALUE IS GREATER THAN ORDINARILY ALLOWED BY THE GRID BIAS OF THE POWER STAGE, YET THE PUSH-PULL THEORY AUTOMATICALLY KEEPS DISTORTION DOWN TO A MINIMUM IN SPITE OF A SLIGHT OVER-LOAD. AS A GENERAL RULE, HOWEVER, IT IS BETTER TO FIGURE CONSERVATIVELY AS WE HAVE IN WORKING OUT OUR SAMPLE PROBLEM AND IN THIS WAY AVOID ALL POSSIBILITY OF DISTORTION.

ALSO BEAR IN MIND THAT ALTHOUGH IN THIS PARTICULAR PROBLEM, WE CONSIDERED THE INPUT PUSH-PULL TRANSFORMER AS HAVING A 4.5 TO 1 STEP-UP RATIO, YET THIS DOES NOT APPLY TO ALL CASES. IT IS COMMON TO USE INPUT PUSH-PULL TRANSFORMERS IN RECEIVERS HAVING A 1 TO 1 RATIO OR EVEN A SLIGHT STEP-DOWN RATIO. THE PROBLEM, HOWEVER, WOULD STILL BE HANDLED ACCORDING TO THE SAME METHOD AS OUTLINED IN THIS LESSON, USING THE VALUES AS REQUIRED.

THEN TOO, REMEMBER THAT THE OVERALL GAIN OF THE A.F. AMPLIFIER IS ALSO GREATLY AFFECTED BY THE INPUT SIGNAL VOLTAGES WHICH ARE DELIVERED TO IT BY THE DETECTOR OR OTHER SOURCE, AS WELL AS THE OUTPUT REQUIREMENTS OF THE A.F. AMPLIFIER.

YOU WILL NO DOUBT AGREE THAT IN THIS LESSON, YOU HAVE LEARNED MANY NEW THINGS ABOUT A.F. AMPLIFIERS AND YOU MAY REST ASSURED THAT YOU WILL FIND ALL OF THIS ADVANCED STUDY OF GREAT VALUE, ESPECIALLY SO IF YOU INTEND TO GO INTO THE CONSTRUCTION WORK OF THIS EQUIPMENT IN ADDITION TO SERVICING IT.

AFTER YOU ARE SATISFIED THAT YOU UNDERSTAND EVERYTHING WHICH HAS BEEN OFFERED YOU IN THIS LESSON, ANSWER THE EXAMINATION QUESTIONS AND THEN CONTINUE YOUR STUDIES WITH THE NEXT LESSON, WHERE YOU WILL FIND ADDITIONAL VALUABLE INFORMATION REGARDING A.F. AMPLIFIERS, SUCH AS "PUSH-PUSH AMPLIFICATION", THE LATEST TYPE AUDIO AMPLIFIER CIRCUITS ETC.

Examination Questions

LESSON NO. 45

"No life is ever measured in terms of years. He is young who welcomes a new thought, a new purpose, a new ambition. He is old and ready for the grave whose mind is locked against the impact of new dreams."

1. - WHAT IS THE DIFFERENCE BETWEEN A VACUUM TUBE'S "PLATE RESISTANCE" AND ITS "PLATE IMPEDANCE"?

2. - WHAT IS MEANT BY A TUBE'S "MUTUAL CONDUCTANCE"?

3. - DESCRIBE A METHOD WHEREBY YOU CAN DETERMINE THE PLATE IMPEDANCE OF A TUBE.

4. - SHOULD AN AMPLIFIER TUBE OPERATE ON THE STRAIGHT OR CURVED PORTION OF ITS "GRID POTENTIAL — PLATE CURRENT" CHARACTERISTIC CURVE?

5. - IF A TUBE IS BEING USED BY ITSELF IN AN AMPLIFIER STAGE AND IS PROVIDED WITH A GRID BIAS OF -6 VOLTS, THEN WHAT IS THE MAXIMUM SIGNAL VOLTAGE EXPRESSED IN A.C. PEAK VOLTS, WHICH CAN BE APPLIED ACROSS THIS TUBE'S GRID CIRCUIT SO AS TO AVOID DISTORTION?

6. - HOW CAN YOU DETERMINE THE VOLTAGE AMPLIFICATION OR "GAIN" OFFERED BY AN AMPLIFIER STAGE WITH RESISTANCE-CAPACITY COUPLING?

7. - WHAT "TIME CONSTANT" IS DESIRABLE FOR RESISTANCE-CAPACITY COUPLING SO THAT THIS TYPE OF COUPLING WILL SATISFACTORILY HANDLE AUDIO FREQUENCIES AS LOW AS 50 CYCLES PER SECOND?

8. - WHAT DETERMINES THE CHOICE OF THE POWER TUBES USED IN AN A.F. AMPLIFIER?

9. - IF A CERTAIN TUBE HAS AN EFFECTIVE AMPLIFICATION FACTOR OF 8 AND A TRANSFORMER HAVING A 3 TO 1 RATIO IS CONNECTED IN ITS PLATE CIRCUIT, THEN WHAT WILL BE THE "GAIN" OBTAINED FROM THIS AMPLIFIER STAGE? 24

10. - HOW DO YOU DETERMINE THE "OVERALL GAIN" WHICH IS REQUIRED FROM A GIVEN A.F. AMPLIFIER?

LESSON NO. 46

CLASS 'B' AMPLIFICATION
SPEAKER MATCHING

NOW LET US CONTINUE OUR ADVANCED STUDY OF A.F. AMPLIFIERS BY CONSIDERING FIRST, THE TYPE-46 POWER TUBE AND ITS APPLICATION TO MODERN CIRCUITS. THIS TUBE IS OF QUITE RECENT DESIGN BUT IN A VERY SHORT TIME HAS FOUND EXTENSIVE USE IN THE RADIO INDUSTRY, BOTH IN COMMERCIAL BROADCAST RECEIVERS AS WELL AS IN PUBLIC ADDRESS AMPLIFIERS.

A PHOTOGRAPH OF THE -46 TUBE APPEARS IN FIG. 2 AND AS YOU WILL NO DOUBT IMMEDIATELY NOTICE, IT IS EQUIPPED WITH FIVE BASE PRONGS, THE SAME AS THE TYPE-47 PENTODE. THE ARRANGEMENT OF THE ELEMENTS WITHIN THE GLASS BULB OF THE -46, HOWEVER, IS QUITE DIFFERENT AS CAN READILY BE SEEN BY STUDYING THE SYMBOL FOR THIS TUBE, WHICH IS ILLUSTRATED FOR YOU IN THE UPPER SECTION OF FIG. 3.

NOTICE ESPECIALLY IN FIG. 3 THAT THE ELEMENTS OF THE -46 CONSIST OF A FILAMENT, TWO GRIDS AND A PLATE. EACH OF THE TWO GRIDS HAS ITS INDIVIDUAL BASE PRONG, THE PLATE IS CONNECTED TO THE THIRD PRONG AND THE FILAMENT ENDS TO THE FOURTH AND FIFTH PRONGS. THE ILLUSTRATION IN THE LOWER SECTION OF FIG. 3 SHOWS YOU HOW THE SOCKET CONNECTIONS ARE ARRANGED FOR THIS SAME TUBE. IN THIS CASE, YOU ARE LOOKING DOWN UPON THE SOCKET FROM ABOVE.

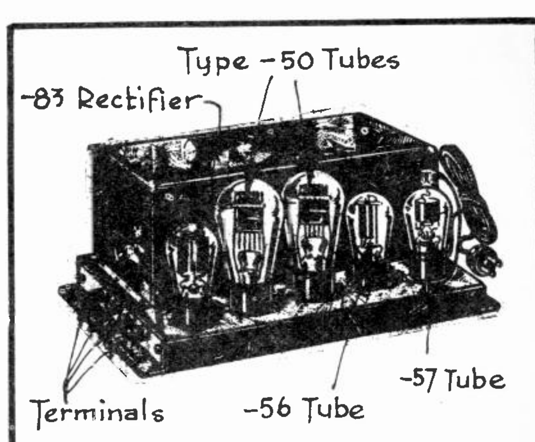

FIG. 1

A Modern 14 Watt P.A. Amplifier.

THIS TUBE CAN BE EMPLOYED IN TWO DIFFERENT WAYS, NAMELY FOR CLASS "A" AMPLIFICATION AND FOR CLASS "B" AMPLIFICATION. FOR CLASS "A" AMPLIFICATION, THE SCREEN GRID (THE ONE NEAREST THE PLATE) IS CONNECTED DIRECTLY TO THE PLATE AND THE TUBE IS THUS USED IN A CIRCUIT IN THE MANNER ILLUSTRATED IN FIG. 4. UNDER SUCH CONDITIONS, THE TUBE'S AMPLIFICATION FACTOR IS LOWERED.

CLASS "A" AMPLIFICATION

BY DEFINITION, CLASS "A" AUDIO

AMPLIFICATION IS CONSIDERED AS A CONDITION WHERE THE FIXED NEGATIVE GRID BIAS OF THE TUBE IS SO SET THAT THE SIGNAL VOLTAGES VARY THE GRID POSITIVE AND NEGATIVE BETWEEN THE LIMITS SET BY THE STRAIGHT PORTION OF THE TUBE'S GRID VOLTAGE--PLATE CURRENT CHARACTERISTIC CURVE. IN OTHER WORDS, CLASS "A" AMPLIFICATION IS THE TYPE WE GENERALLY EMPLOY IN THE INTERMEDIATE STAGES OF AN A.F. AMPLIFIER.

FIG. 2
The Type-46 Amplifier Tube.

ALTHOUGH A PUSH-PULL POWER STAGE IS CONSIDERED BY SOME AS BEING OF THE CLASS "A" TYPE, YET STRICTLY SPEAKING, THIS IS NOT GENERALLY THE CASE BECAUSE AS A RULE, THE PUSH-PULL STAGES UP TO THE PRESENT TIME HAVE THEIR FIXED GRID BIAS SET AT A POINT SUBSTANTUALLY MIDWAY BETWEEN ZERO BIAS AND THE BEND AT THE NEGATIVE END OF THE GRID VOLTAGE-PLATE CURRENT CURVE.

AS A CLASS "A" AMPLIFIER, THE CHARACTERISTICS FOR THE -46 TUBE ARE AS FOLLOWS:

FILAMENT VOLTAGE------2.5 VOLTS
" CURRENT-----1.75 AMPS.
PLATE VOLTAGE---------250-300 VOLTS
" CURRENT---------22 MA.
GRID BIAS VOLTAGE----33 VOLTS NEGATIVE
AMPLIFICATION FACTOR--5.6
MUTUAL CONDUCTANCE----2350 MICHROMHOS
PLATE RESISTANCE------2380 OHMS
UNDISTORTED OUTPUT----1.25 WATTS.

FIG. 5 SHOWS YOU HOW TO CONNECT TWO-46 TUBES IN A PUSH-PULL CIRCUIT. IN THIS CASE, OBSERVE THAT THE SCREEN GRID IS ALSO CONNECTED TO THE PLATE. OTHER THAN THIS, THE CIRCUIT REMAINS CONVENTIONAL.

A DOUBLE PUSH-PULL CIRCUIT

HAVING SO FAR SEEN HOW THE TYPE-46 TUBE CAN BE USED AS A STRAIGHT AMPLIFIER OR PUSH-PULL AMPLIFIER, LET US NEXT STUDY A STILL DIFFERENT ARRANGEMENT OF THESE TUBES, CONSISTING OF A DOUBLE OR PARALLEL PUSH-PULL CIRCUIT. THIS CIRCUIT IS LAID OUT FOR YOU IN FIG. 6.

OBSERVE CLOSELY IN FIG. 6 THAT THE SCREEN GRIDS ARE ALL CONNECTED TO THE PLATES OF THEIR RESPECTIVE TUBES AND THAT THE CONTROL GRIDS AND PLATES OF EACH PAIR OF TUBES ARE CONNECTED IN PARALLEL. THIS ARRANGEMENT WILL PROVIDE AN OUTPUT OF ABOUT 5.5 WATTS.

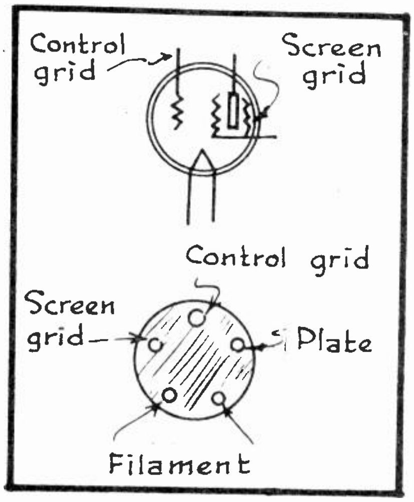

FIG. 3
Symbol and Socket Connections for the -46 Tube.

CLASS "B" AMPLIFICATION

THE TYPE-46 TUBE IS BEST ADAPTED TO CLASS "B" AMPLIFICATION AND AT PRESENT IS FINDING ITSELF MOST USED IN CIRCUITS OF THIS CLASSIFICATION. CLASS "B" AUDIO FREQUENCY AMPLIFIERS ARE ALSO SOMETIMES SPOKEN OF AS "PUSH-PUSH" AMPLIFIERS. IN THIS CASE, THE TUBE IS OPERATED UNDER SUCH CONDITIONS SO THAT WITH NO INPUT SIGNAL, THE PLATE CURRENT IS REDUCED TO ZERO.

UPON FIRST GLANCE, A PUSH-PUSH OR CLASS "B" POWER AMPLIFIER STAGE APPEARS QUITE SIMILAR TO THE CONVENTIONAL PUSH-PULL AMPLIFIER STAGE BUT UPON CLOSER INSPECTION, YOU WILL NOTE A DISTINCT DIFFERENCE BETWEEN THEM. FOR EXAMPLE, A CIRCUIT WITH TWO TYPE-46 TUBES IN PUSH-PUSH IS ILLUSTRATED FOR YOU FIG. 7. FIRST YOU WILL NOTICE IN THIS CIRCUIT THAT THE SCREEN GRIDS OF THE TWO TUBES ARE CONNECTED TO THE CONTROL GRID OF THE SAME TUBE, WHILE THE GRID RETURN OF THE CIRCUIT (CENTER TAP OF INPUT TRANSFORMER) IS CONNECTED TO THE "ELECTRICAL CENTER" OF THE FILAMENT TRANSFORMER --NO BIAS RESISTOR BEING EMPLOYED. IN ADDITION, THE PLATE VOLTAGE IS BOOSTED UP TO A VALUE BETWEEN 300 AND 400 VOLTS.

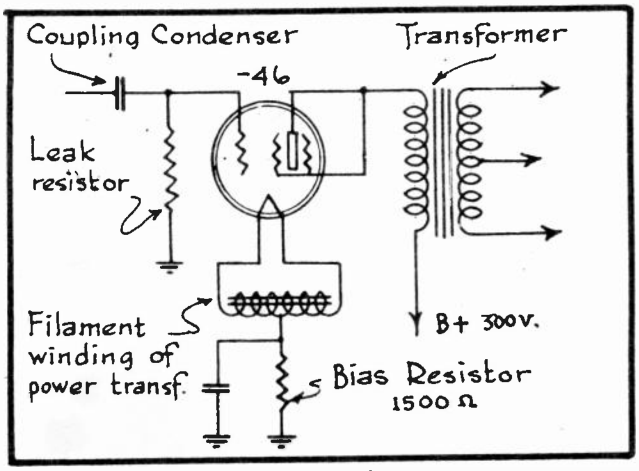

FIG. 4

The -46 Tube Used as a Class "A" Amplifier.

WITH THESE MINOR CIRCUIT CHANGES MADE, THE AMPLIFICATION FACTOR OF THE TUBES IS INCREASED MATERIALLY AND THE MAXIMUM OUTPUT APPROACHES A VALUE OF APPROXIMATELY 20 WATTS. BESIDES THIS, THE OPERATING PRINCIPLES OF THIS CLASS "B" OR PUSH-PUSH CIRCUIT BECOMES RADICALLY DIFFERENT FROM THAT ENCOUNTERED IN PUSH-PULL ARRANGEMENTS. THIS DIFFERENCE CAN BEST BE POINTED OUT BY FIRST GIVING YOU A BRIEF DESCRIPTION OF PUSH-PULL THEORY SO THAT YOU YOURSELF CAN COMPARE THE TWO SYSTEMS.

OPERATING PRINCIPLES OF "PUSH-PULL" AMPLIFICATION

NOW THEN, IN THE CASE OF A PUSH-PULL AMPLIFIER CIRCUIT, BOTH OF THE TUBES ARE IN OPERATION AT ALL TIMES BUT WITH THEIR GRID EXITATION IN "PHASE OPPOSITION". TO ILLUSTRATE THIS POINT, LET US REFER TO FIG. 8, WHERE WE HAVE TWO TUBES, OPERATING AS A PUSH-PULL AMPLIFIER. AT THE TIME NO SIGNAL VOLTAGE IS IMPRESSED UPON THE GRID OF EITHER OF THE TUBES, THE PLATE CURRENT, AS FURNISHED BY THE "B" SUPPLY, WILL DIVIDE EQUALLY BETWEEN THEM----HALF OF THE TOTAL FLOWING THROUGH EACH TUBE. IN DOING SO, NOTICE CAREFULLY IN FIG. 8 THAT FROM THE CENTER TAP OF THE OUTPUT TRANSFORMER'S PRIMARY WINDING, THE PLATE CURRENT FOR THE TWO TUBES IS FLOWING OUTWARD OR TOWARD THE TWO EXTREMETIES OF THIS WINDING AS INDICATED BY THE ARROWS.

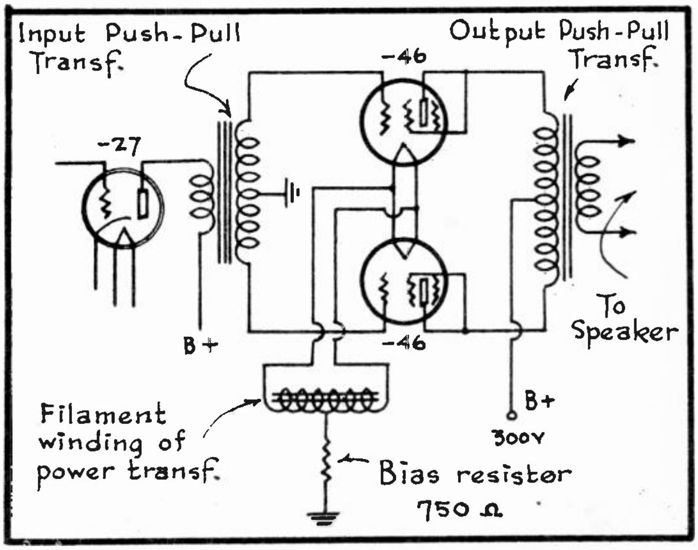

FIG. 5

Type -46 Tubes in a Push-Pull Circuit.

IN OTHER WORDS, WITH THE CENTER TAP OF THIS WINDING AS A STARTING POINT, THE PLATE CURRENT IS FLOWING IN OPPOSITE DIRECTIONS THROUGH THE WINDING. THEN SINCE BOTH HALVES OF THIS WINDING CONSIST OF AN EQUAL NUMBER OF TURNS AND THE CURRENT THROUGH EACH HALF IS ALSO THE SAME, IT BECOMES QUITE OBVIOUS THAT THE MAGNETIC FIELDS CREATED ABOUT THE TWO HALVES OF THE WINDING WILL BE OF OPPOSITE POLARITY AND THEREBY NEUTRALIZE ONE-ANOTHER. THE EFFECT OF THIS OPPOSING REACTION IS SUCH THAT NO EFFECTIVE MAGNETIC FIELD IS PRESENT AT THIS TIME.

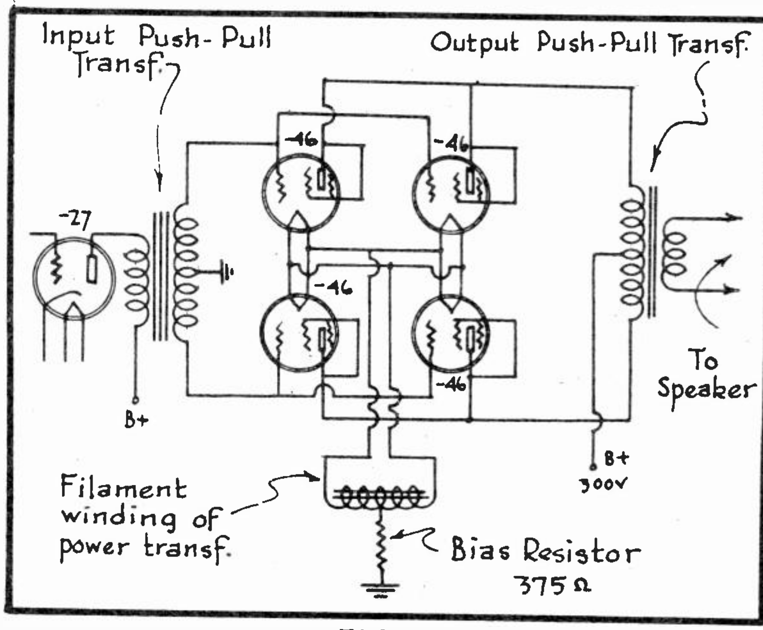

FIG. 6
A Double Push-Pull Power Stage.

NOW LET US SUPPOSE THAT A SIGNAL VOLTAGE IS INDUCED INTO THE SECONDARY WINDING OF THE INPUT TRANSFORMER OF FIG. 9, CAUSING THE UPPER END OF THIS WINDING TO ASSUME A POSITIVE POTENTIAL AND THE LOWER END A NEGATIVE POTENTIAL. THE RESULT OF THIS WILL BE TO MAKE THE GRID OF TUBE #1 OF THIS ILLUSTRATION LESS NEGATIVE AND THE GRID OF TUBE #2 MORE NEGATIVE AND THIS IN TURN CAUSES AN INCREASE IN THE PLATE CURRENT FLOW THROUGH TUBE #1 AND A CORRESPONDING DECREASE IN THE PLATE CURRENT FLOW THROUGH TUBE #2.

THIS CHANGE OF PLATE CURRENT THROUGH THESE TWO TUBES AND THEIR CORRESPONDING HALVES OF THE OUTPUT TRANSFORMER'S PRIMARY WINDING, ACTS THE SAME AS THOUGH THE CURRENT WERE FLOWING TOWARDS THE PLATE OF TUBE #1 AND AWAY FROM TUBE #2. THE TWO RESULTING CURRENTS IN THIS WAY ADDING THEIR EFFECTS TOGETHER AND THEREBY HELPING TO INCREASE THE VOLTAGE CHANGES INDUCED OVER INTO THE SECONDARY WINDING OF THE OUTPUT TRANSFORMER. IT IS ON ACCOUNT OF THIS LAST MENTIONED FACT CONCERNING THE BEHAVIOR OF THE CURRENT IN THE PRIMARY WINDING OF THE OUTPUT TRANSFORMER THAT THE SUITABLE TERM "PUSH-PULL" HAS BECOME ASSOCIATED WITH THIS SYSTEM OF AMPLIFICATION.

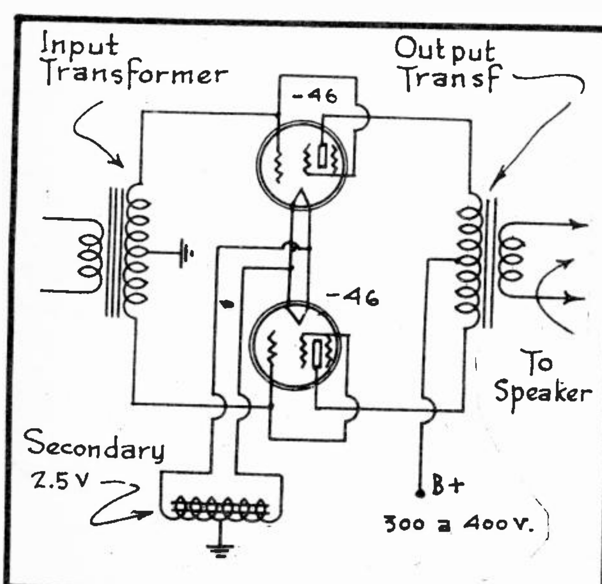

FIG. 7
Two -46 Tubes Connected in Push-Push.

NOTICE ESPECIALLY THAT WHEN EMPLOYING PUSH-PULL AMPLIFICATION, AT NO TIME WILL THERE BE A STEADY SATURATION OF THE OUTPUT TRANS-

FORMER'S CORE, DUE TO THE NEUTRALIZING EFFECT PRODUCED BY THE STEADY FLOW OF PLATE CURRENT WHEN NO SIGNALS ARE APPLIED TO THE GRID OF THE TUBES.-- ONLY THE SIGNALS ARE CAPABLE OF PRODUCING AN EFFECTIVE MAGNETIC FIELD IN THIS TRANSFORMER.

OPERATING PRINCIPLES OF "PUSH-PUSH" AMPLIFICATION

WITH THIS PRINCIPLE OF PUSH-PULL OPERATION FRESH IN MIND, LET US NEXT INVESTIGATE THE "PUSH-PUSH" SYSTEM MORE THOROUGHLY. IN FIG. 10 YOU ARE SHOWN THE FUNDAMENTAL CIRCUIT FOR PUSH-PUSH AMPLIFICATION EMPLOYING A PAIR OF TRIODES.

NOW THEN, REMEMBER THAT THE "B" (PLATE) AND "C" (GRID BIAS) VOLTAGES ARE SO ADJUSTED THAT NO CURRENT FLOWS THROUGH EITHER OF THE TWO TUBES AT THE TIME THAT NO SIGNAL VOLTAGE IS APPLIED TO THEIR GRIDS. LET US NEXT SUPPOSE THAT A SIGNAL VOLTAGE IS INDUCED INTO THE INPUT TRANSFORMER'S SECONDARY WINDING SO THAT THE UPPER END OF THIS WINDING BECOMES POSITIVE WHILE ITS LOWER EXTREMITY TAKES ON A NEGATIVE POTENTIAL.

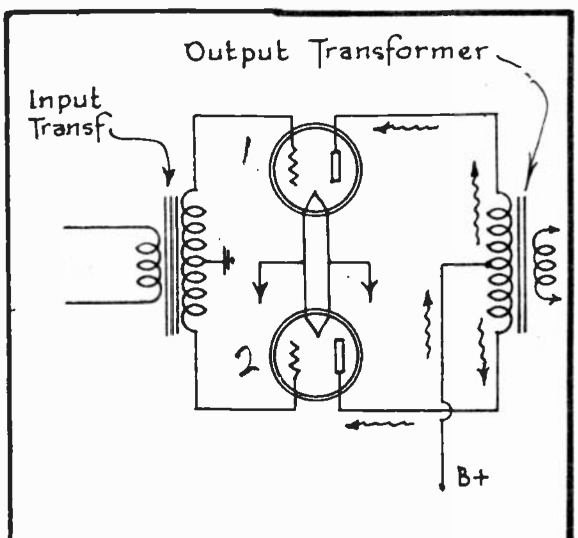

FIG. 8
Push-Pull Operation.

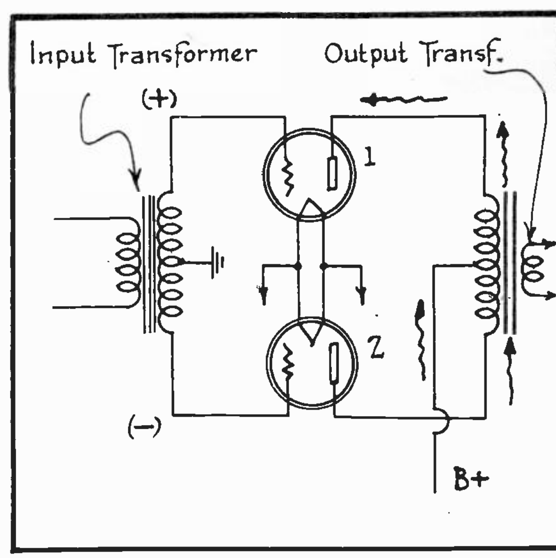

FIG. 9
Plate Current Variation.

THIS CAUSES THE GRID OF TUBE #1 TO BECOME POSITIVELY CHARGED, THEREBY PERMITTING A SURGE OF PLATE CURRENT TO PASS THROUGH THIS TUBE AS INDICATED BY THE ARROWS. THE GRID OF TUBE #2, HOWEVER, IS AT THIS TIME BEING CHARGED STILL MORE NEGATIVELY, SO THAT IT PREVENTS A PASSAGE OF PLATE CURRENT THROUGH THE LOWER TUBE STILL MORE SO THAN WITH THE BIAS VOLTAGE ALONE APPLIED TO THIS TUBE'S GRID.

THUS YOU WILL READILY SEE THAT DURING THIS INSTANT, ONLY TUBE #1 OF FIG. 10 IS OPERATING WHILE TUBE #2 IS COMPLETELY INOPERATIVE.

AS THE INPUT SIGNAL VOLTAGE REVERSES ITS POLARITY, SO THAT THE LOWER END OF THE INPUT TRANSFORMER'S SECONDARY BECOMES POSITIVE AND ITS UPPER EXTREMETY NEGATIVE, A SURGE OF PLATE CURRENT WILL PASS THROUGH TUBE #2 WHILE TUBE #1 REMAINS INOPERATIVE. NOTICE THAT THE TWO TUBES TAKE TURNS ABOUT IN "PASSING-ON" THE SIGNAL-EACH ONE WAITING ITS TURN TO "PUSH THE SIGNAL THROUGH", SO TO SPEAK AND THEREBY DERIVING THE FITTING NAME OF A "PUSH-PUSH AMPLIFIER."

THE CHIEF ADVANTAGE GAINED FROM EMPLOYING PUSH-PUSH OR CLASS "B" AMPLIFICATION IS THAT A PAIR OF TUBES, WHEN OPERATED IN THIS MANNER, WILL DELIVER AN UNDISTORTED OUTPUT OF FROM FIVE TO TEN TIMES THAT OBTAINABLE WITH THE SAME PAIR OF TUBES IN CLASS "A" OPERATION WITH THE SAME PLATE VOLTAGE.

EVEN THOUGH THE GRIDS OF THE TUBES OPERATING IN PUSH-PUSH ACTUALLY DO SWING TO A POSITIVE POTENTIAL AND THEREFORE DRAW A CERTAIN AMOUNT OF GRID CURRENT, YET THE SLIGHT AMOUNT OF DISTORTION CAUSED BY THIS OTHERWISE UNFAVORABLE CONDITION DOES NOT EXCEED THE 5% LIMIT WHICH IS CONSIDERED AS BEING PERMISSABLE WITHOUT BEING NOTICEABLE TO THE LISTENER.

THE ONLY RADICAL CIRCUIT CHANGES NECESSARY FOR PUSH-PUSH AMPLIFICATION OVER PUSH-PULL AMPLIFICATION ARE: (1) THE INPUT TRANSFORMER MUST BE OF LOW RATIO, SINCE THE GRID (SECONDARY) WINDING MUST BE OF LOW EFFECTIVE IMPEDANCE DURING THE TIME THAT THE INDIVIDUAL TUBE IS DRIVEN POSITIVE IN ORDER THAT THE GRID CURRENT FLOWING WILL NOT DISTURB THE CONSTANTS OF THE CIRCUIT; (2) THE INPUT SIGNAL VOLTAGE OR "GRID SWING" MUST BE SEVERAL TIMES THE AMPLITUDE OF THAT REQUIRED FOR NORMAL OPERATION. (3) THE OUTPUT TRANSFORMER MUST BE CAPABLE OF HANDLING THE HEAVY D.C. PULSATIONS RESULTING FROM THIS FORM OF OPERATION (4) THE POWER SUPPLY MUST BE CAPABLE OF OFFERING A HIGH DEGREE OF REGULATION OR CONSTANCY OF VOLTAGE UNDER VARYING LOADS AND (5) THE GRID BIAS MUST BE OBTAINED IN SUCH A MANNER THAT IT WILL NOT BE DEPENDENT FOR ITS VALUE UPON THE PLATE CURRENT FLOWING THROUGH THE TUBES.

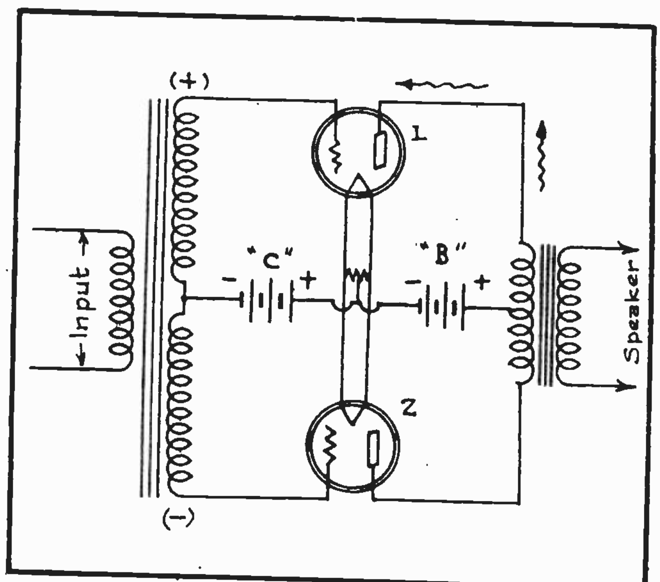

FIG. 10

The Push-Push Principle.

CHARACTERISTICS OF THE -46 TUBE OPERATED AS A "CLASS B" AMPLIFIER

NOW TO RETURN TO THE -46 TUBE, CONSIDERING ITS USE AS A CLASS "B" AMPLIFIER. OPERATING UNDER THESE CONDITIONS, THE CHARACTERISTICS OF THIS TUBE ARE AS FOLLOWS:

PLATE VOLTAGE-------------------300 TO 400 VOLTS
" CURRENT-------------------150 TO 200 MA. (PEAK VALUES)
GRID BIAS VOLTAGE---------------0. (GRIDS TIED TOGETHER)
MAXIMUM SIGNAL VOLTAGE HANDLED--40 TO 41 VOLTS
MAXIMUM ~~CONTINUOUS~~ POWER OUTPUT-16 TO 20 WATTS.
(TWO TUBES)
LOAD RESISTANCE PER TUBE--------1300 TO 1450 OHMS.

THE FILAMENT VOLTAGE AND CURRENT, OF COURSE, REMAIN THE SAME AS ALREADY SPECIFIED, IRRESPECTIVE OF USE.

IN FIG. 11, YOU ARE GIVEN A DIAGRAM OF AN A.F. AMPLIFIER EMPLOYing two type -46 tubes in the final stage, arranged for push-push operation and thereby affording class "B" amplification. Notice that this power stage is being driven by a single type-46 tube used as a Class "A" amplifier, while a type "24A" tube is employed in the input circuits. (The-24A tube is an improved type-24 tube and the two tubes can be interchanged in any circuit designed for the use of either of the two).

This particular amplifier has an output rating of 13-Watts and specifications for the circuit's construction are as follows:

R1 --------------------750 Ohms (1 Watt)
R2 ------------------10,000 " (2 ")
R3------------------20,000 " (2 ")
R4------------------25,000 " (1 ")
R5-----------------0.25 megohm (1 ")
R6--------------------1500 Ohms (1 ")
R7---------0 to 0.5 megohm potentiometer
C1---------10 mfd. (25 D.C. Volt rating)
C2-------- 1 mfd. (200 D.C. " ")
C3---------.02mfd. (300 D.C. " ")
C4-C5-C6-- 8 Mfd. (500 D.C. " ")
C7---------10 Mfd. (50 D.C. " ")
T1 --100 Henry A.F. Choke Coil (4 ma. rating)
T2 --Special Push-push input transformer.
T3 -- " " " output "
P.T.--Power Transformer (High Voltage Secondary capable of carrying 200 ma. & for type-82 mercury rectitube.
CH1-CH2--15 Henry Filter Choke (120 M.A. rating)
CH3-CH4--30 " " " (65 M.A. ")

The secondary winding of the output transformer for this amplifier is tapped, offering connections for speaker systems of various impedance ratings.

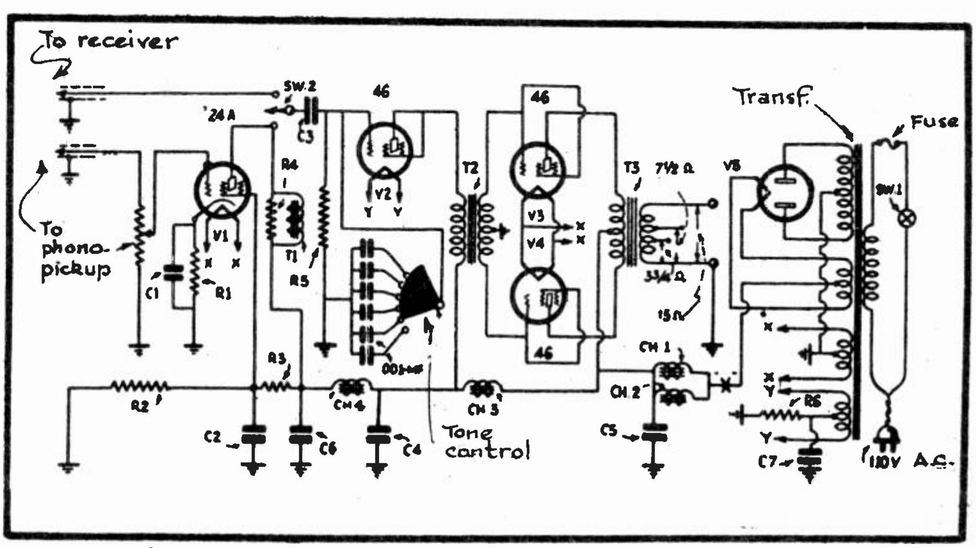

FIG. 11

An A.F. Amplifier Employing Class "B" Amplification With -46 Tubes.

CONSTRUCTION OF CLASS "B" INPUT TRANSFORMER

While we are on the subject of "Class B" amplifiers, let us consider the construction of transformers suitable for this purpose, beginning with the input transformer.

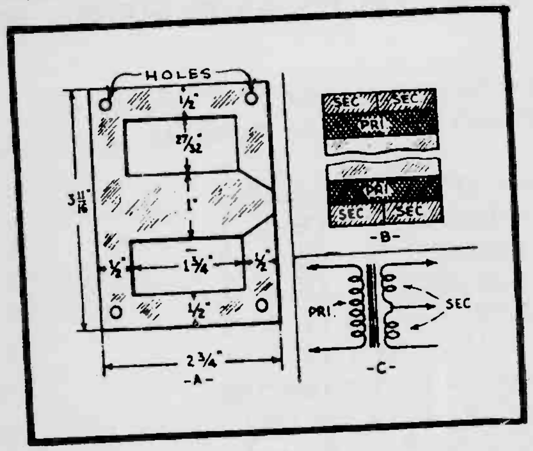

FIG. 12
Construction Details for Class "B" Input Transformer.

In Fig. 12, you are shown the constructional details for the input push-push transformer. The core construction is shown in section "A" of this illustration while the arrangements of the windings for this same transformer are shown in sections "B" and "C" of Fig. 12.

Since a great deal depends upon this transformer as regards the quality of the sounds reproduced by the speaker, the necessity for constructing this unit with utmost care cannot be over emphasized.

The core material consists of #29 gauge lamination iron of the type specially adaptable for use in A.F. transformer construction. From this material sufficient laminations are cut so that they can be interleaved and stacked up to a pile which is 1" high and so that the various sections of the core will have the dimensions specified in "A" of Fig. 12. Note in "A" of Fig. 12 that the center leg of the core is 1" wide, while all of the end material is of but $\frac{1}{2}$" width.

The primary winding consists of 5,200 turns of #29 B&S enameled wire, the latter being wound directly over the core as shown at "B" of Fig. 12. The secondary winding is wound in two sections of 2100 turns each, thus affording the center-tap.

Each layer of wire in all windings is insulated from the adjacent layer by glassine paper, while "Empire Cloth" is inserted between the various windings.

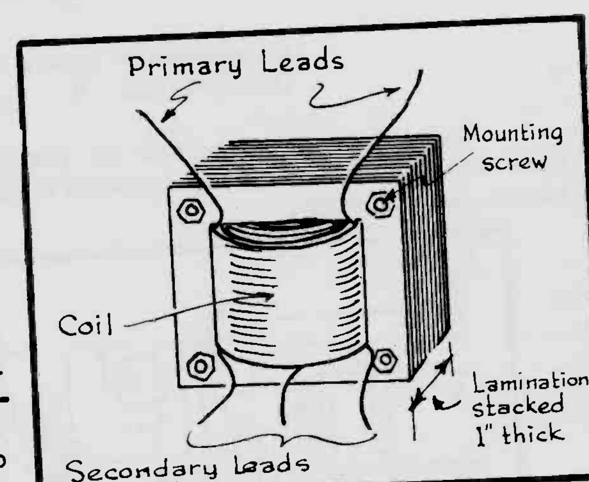

FIG. 13
The Input Push-Push Transformer.

As you will note from these specifications, this transformer is of the step-down type, due to the fact that the secondary winding consists of a less number of turns than the primary. This is necessary so that the load of the tube will be accurately matched to the "Class "B" grid circuit.

It is generally the practice to wind the transformer coils on a wooden form, whose demensions correspond with that of the core material's center-leg, so that upon removing the finished coils as a unit from the form, the core laminations can be stacked up about it, with the center leg of the core section passing through the hole provided at the center of the windings and the balance of the metal forming an enclosure all around the coil. The finished transformer will then appear somewhat as illustrated in Fig. 13. (You will receive more details regarding the "mechanical process" of constructing transformers in a later lesson.)

CONSTRUCTION OF CLASS "B" OUTPUT TRANSFORMER

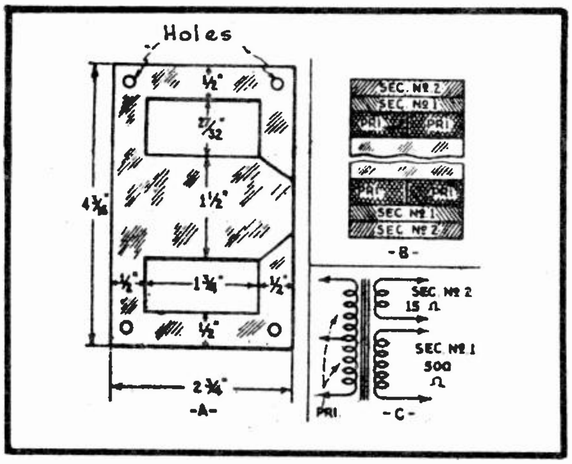

FIG. 14

Construction Detail for A Class "B" Output Transformer.

In Fig. 14 you will see the the constructional details illustrated for the output push-push transformer. By inspecting the core arrangement in illustration "A" of Fig. 14, you will observe that it is similar to that of the input transformer with the exception of the dimensions. The output transformer is of larger overall dimensions, but #29 gauge lamination iron is also used for its construction. These laminations or sheets are to be stacked-up in this case so as to form a pile $1\frac{1}{2}$" thick.

As regards the windings for this output transformer, the primary is wound first and it consists of two sections of 2,250 turns each wound with #29 B&S enameled wire.

Secondary winding #1 consists of 1400 turns of #26 B & S enamelled wire and offers an output impedance of 500 ohms. Secondary winding #2 is wound on top of secondary #1, and consists of 240 turns of #18 B&S enamelled wire. This secondary winding offers an impedance of approximately 15 ohms.

For general amplifier purposes, these two output impedance ratings serve a varied number of uses as regards coupling the system to miscellaneous speaker circuit combination in multiple speaker installations.

In the construction of this output transformer, it is also necessary to place glassine paper between adjacent layers of

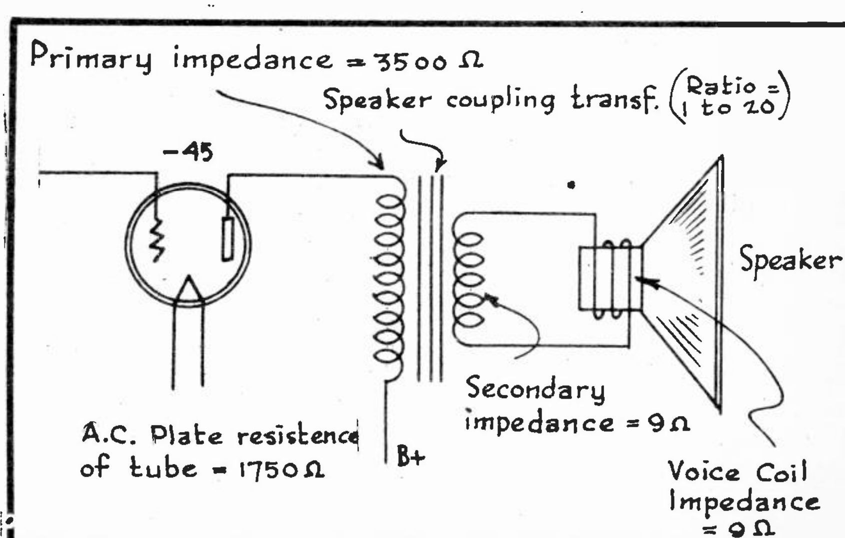

FIG. 15

Speaker Impedance Matching With Single Power Tube.

ALL WINDINGS AND "EMPIRE CLOTH" BETWEEN ADJACENT COILS

REQUIRED TURNS-RATIO OF OUTPUT TRANSFORMERS

NOW LET US INVESTIGATE THE MATTER OF SPEAKER IMPEDANCE MATCHING A LITTLE MORE THOROUGHLY. THAT IS, THE RELATION EXISTING BETWEEN THE PRIMARY AND SECONDARY TURNS OF AN IMPEDANCE MATCHING TRANSFORMER. AS AN EXAMPLE, LET US SUPPOSE THAT AN ELECTRODYNANIC SPEAKER, WHOSE VOICE COIL HAS A RATED IMPEDANCE OF 9 OHMS, IS TO BE CONNECTED TO THE OUTPUT AS FURNISHED BY A TYPE-45 POWER TUBE. THE PROBLEM IS TO DETERMINE THE WINDING RATIO OF THIS TRANSFORMER.

THE FORMULA FOR A PROBLEM OF THIS TYPE IS:

$$\text{TURNS RATIO OF SPEAKER COUPLING TRANSFORMER} = \sqrt{\frac{\text{IMPEDANCE OF SECONDARY WINDING}}{\text{IMPEDANCE OF PRIMARY WINDING}}}$$

BY REFERING TO A TABLE OF VACUUM TUBE CHARACTERISTICS, WE FIND THE PLATE RESISTANCE OF THE TYPE-45 TUBE SPECIFIED AS 1750 OHMS. IN ORDER THAT THE MAXIMUM UNDISTORTED POWER OUTPUT OF THE -45 TUBE MAY BE OBTAINED FOR ANY GIVEN SIGNAL VOLTAGE, THE LOAD IMPEDANCE FOR THIS TUBE SHOULD BE EQUAL TO APPROXIMATELY TWICE THE TUBE'S A.C. PLATE RESISTANCE. THAT IS, FOR THE PARTICULAR PROBLEM UNDER OUR IMMEDIATE ATTENTION, THE IMPEDANCE OF THIS COUPLING TRANSFORMER'S PRIMARY WINDING SHOULD BE ABOUT 2X1750 OR 3500 OHMS.

IN ORDER THAT THE MAXIMUM AMOUNT OF POWER BE TRANSFERRED FROM THE SECONDARY WINDING OF THE SPEAKER COUPLING TRANSFORMER TO THE SPEAKER'S VOICE COIL, THE IMPEDANCE OF THE SECONDARY WINDING SHOULD BE EQUAL TO THE IMPEDANCE OF THE SPEAKER VOICE COIL. IN OTHER WORDS, THE IMPEDANCE OF THE SECONDARY WINDING FOR OUR PARTICULAR TRANSFORMER IS TO BE 9 OHMS.

HAVING SO FAR DETERMINED THE PRIMARY IMPEDANCE OF OUR TRANSFORMER AS BEING 3500 OHMS AND ITS SECONDARY IMPEDANCE AS 9 OHMS, WE CAN SUBSTITUTE THESE VALUES IN OUR FORMULA--OUR PROBLEM THUS TAKING THE FOLLOWING FORM:

$$\text{TURNS RATIO OF TRANSFORMER} = \sqrt{\frac{9}{3500}} = \frac{3}{59.1} = \frac{1}{19.1}$$

THE RATIO THUS FIGURES OUT AS 1 TO 19.1. RESULTS WILL BE SUFFICIENTLY ACCURATE FOR PRACTICAL PURPOSES BY CONSIDERING THIS RATIO IN "ROUND NUMBERS" AS SIMPLY 1 TO 20. THIS WILL THEN MEAN THAT FOR EACH 20 TURNS OF PRIMARY WINDING THERE WILL BE 1 TURN OF SECONDARY WINDING OR THAT ALTOGETHER, THERE WILL BE 20 TIMES AS MANY TURNS OF PRIMARY WINDING ON THIS TRANSFORMER AS THERE ARE SECONDARY TURNS.

THE EXACT NUMBER OF PRIMARY TURNS WILL DEPEND UPON THE RELATION EXISTING BETWEEN THE RESISTANCE AND INDUCTANCE OF THE PRIMARY WINDING, SO THAT ITS IMPEDANCE WILL BECOME 3500 OHMS. THE EXACT NUMBER OF SECONDARY TURNS WILL THEN BE PROPORTIONAL TO THE PRIMARY TURNS, IN ACCORD WITH THE 1 TO 20 RATIO WHICH WE HAVE ALREADY DETERMINED. THE SPECIFICATIONS WILL THEN BE AS ILLUSTRATED IN FIG. 15.

WHEN MATCHING A PAIR OF PUSH-PULL CONNECTED POWER TUBES TO THE VOICE COIL OF A DYNAMIC SPEAKER, THE NATURE OF THE PROBLEM BECOMES DIFFERENT. IN THIS CASE, EACH HALF OF THE PUSH-PULL PRIMARY WINDING MUST MATCH THE PLATE IM-

PEDANCE RATING OF ONE OF THE POWER TUBES.

IN OTHER WORDS, THE PLATE IMPEDANCE OF EACH -45 TUBE IS 1750 OHMS. THEREFORE, IN ORDER THAT THE IMPEDANCE OF THE PRIMARY WINDING OF THE OUTPUT PUSH-PULL TRANSFORMER WILL AFFORD MAXIMUM UNDISTORTED POWER OUTPUT WITH A GIVEN SIGNAL VOLTAGE, EACH HALF OF THE PRIMARY WINDING SHOULD PROVIDE AN IMPEDANCE OF 2 X 1750 OR 3500 OHMS. THE TOTAL IMPEDANCE OF BOTH HALVES OF THIS WINDING WILL OF COURSE BE 2 X 3500 OR 7000 OHMS.

ACCORDING TO OUR IMPEDANCE MATCHING TRANSFORMER FORMULA, THE TURNS RATIO WILL THEN FIGURE OUT AS FOLLOWS:

SECONDARY WINDING IMPEDANCE = 9 OHMS
PRIMARY WINDING IMPEDANCE = 7000 OHMS

TURNS RATIO $\sqrt{\frac{9}{7000}} = \frac{3}{83.6} = \frac{1}{27.86}$ OR APPROXIMATELY 1 TO 28. IT IS OF COURSE UNDERSTOOD THAT DURING THE WINDING PROCESS, THE PRIMARY WINDING IS TO BE CENTER TAPPED.

DUAL SPEAKERS FOR BETTER TONE QUALITY

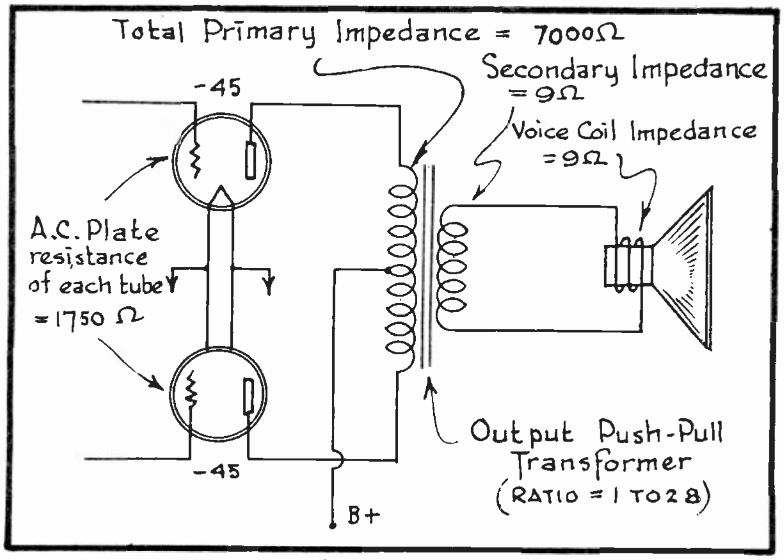

FIG. 16
Speaker Impedance Matching With Push-Pull Power Tubes.

IN ORDER TO IMPROVE TONE QUALITY, A NUMBER OF RECEIVER MANUFACTURERS ARE USING TWO ELECTRODYNAMIC SPEAKERS WITHIN A SINGLE CABINET. EACH OF THESE SPEAKERS HAS ITS INDIVIDUAL REPRODUCING CHARACTERISTICS-- ONE BEING PITCHED LOW AND THE OTHER HIGH. THIS FEATURE IS ACCOMPLISHED IN THE ORIGINAL DESIGN OF THE TWO MATCHED SPEAKERS.

IN THIS WAY, ONE OF THE SPEAKERS IS MOST EFFICIENT IN REPRODUCING THE LOWER AUDIO FREQUENCIES, WHILE THE OTHER SPEAKER IS MOST EFFICIENT IN REPRODUCING THE HIGHER AUDIO FREQUENCIES. THE FREQUENCY CHARACTERISTICS OF THESE TWO SPEAKERS ARE SO BALANCED IN RELATION TO EACHOTHER THAT THEY WILL TOGETHER PRODUCE TONES COVERING THE GREATER PORTION OF THE ENTIRE AUDIO FREQUENCY RANGE, THEREBY OFFERING RICH AND NATURAL TONE QUALITY.

IN FIG. 17 A POPULAR METHOD OF CONNECTING THE VOICE COILS AND FIELDS OF THE TWO SPEAKERS IN THE STANDARD TYPE RECEIVER CIRCUIT IS ILLUSTRATED. AS YOU WILL OBSERVE FROM THIS DIAGRAM, THE VOICE COILS OF THE TWO SPEAKERS ARE CONNECTED IN PARALLEL ACROSS THE SECONDARY WINDING OF THE OUTPUT TRANSFORMER, WHEREAS THE FIELDS OF THE TWO SPEAKERS ARE CONNECTED IN SERIES.

ALTHOUGH SOME MANUFACTURES VARY THESE SPEAKERS CIRCUITS SOMEWHAT AS REGARDS THE DISTRIBUTION OF THE D.C. CURRENT THROUGH THE FIELD COILS, YET

THEY ARE FUNDAMENTALLY ALL THE SAME AND ARE SIMPLE ENOUGH TO UNDERSTAND UPON OBSERVATION OF THE CIRCUIT ITSELF.

CONSTRUCTION DATA OF SOME GOOD A.F. AMPLIFIERS

CONSTANT DEVELOPMENT IS BEING MADE IN THE DESIGN AND CONSTRUCTION OF AUDIO AMPLIFIERS AS TIME GOES ON AND SO IN THE PAGES IMMEDIATELY TO FOLLOW, MANY OF THESE LATER CIRCUITS ARE GOING TO BE DESCRIBED TO YOU.

THE CIRCUIT WHICH IS SHOWN YOU IN FIG. 18 IS THAT OF A GOOD AMPLIFIER FOR GENERAL PUBLIC ADDRESS WORK AND WHICH CAN BE CONSTRUCTED AT A MODERATE COST. AS YOU WILL OBSERVE, IT EXPLOYS A TYPE-24 TUBE IN THE FIRST STAGE, A TYPE-45 IN THE FOLLOWING STAGE A PAIR OF TYPE-50TUBES IN THE POWER STAGE AND TWO PARALLEL CONNECTED TYPE-81 TUBES IN THE RECTIFYING SYSTEM.

THE INPUT CIRCUIT IS ESPECIALLY ADAPTABLE FOR A PHONOGRAPH PICK-UP, A SINGLE-BUTTON CARBON MICHROPHONE OR A DOUBLE-BUTTON CARBON MICROPHONE. THE VOLUME FOR THE MICROPHONE INPUT IS CONTROLLED BY A 400 OHM POTENTIOMETER WHILE THE VOLUME CONTROL FOR THE PHONGRAPH PICKUP IS MOUNTED DIRECTLY UPON THIS LATTER UNIT AND IS THEREFORE NOT SHOWN IN THIS CIRCUIT DIAGRAM.

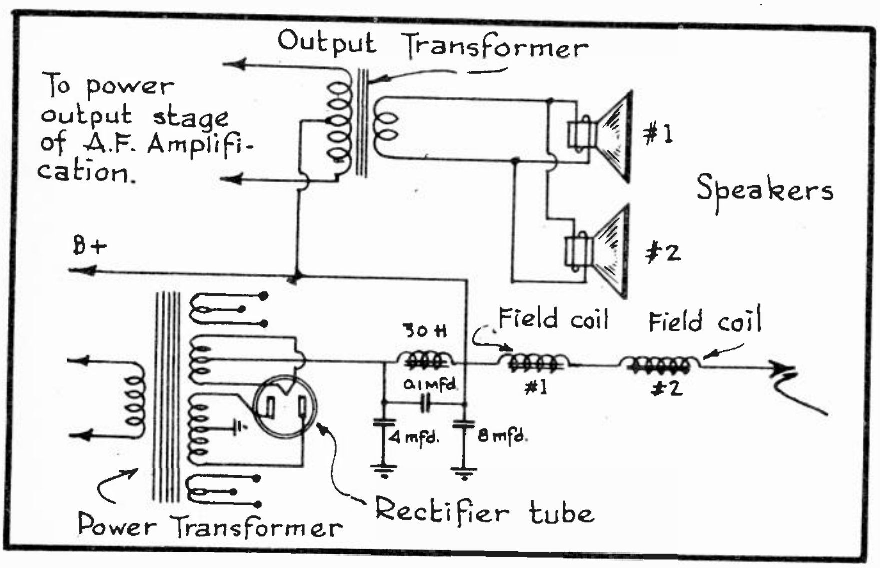

FIG. 17

Dual Speaker Connection for Receivers.

THE ENTIRE INPUT CIRCUIT IS CONNECTED TO OR REMOVED FROM THE AMPLIFIER PROPER BY MEANS OF THE PLUG AND SOCKET WHICH IS SHOWN IN THIS DIAGRAM. THE 2 MFD. CONDENSER BETWEEN THE PRIMARY WINDING OF THE POWER TRANSFORMER AND GROUND SERVES TO BY-PASS TO GROUND ALL LINE NOISES REACHING THE POWER TRANSFORMER SO THAT THEY WON'T HAVE A CHANCE TO BE INDUCED INTO THE AMPLIFIER CIRCUITS.

DUE TO THE HIGH "B" VOLTAGE OFFERED BY THE -81 TUBES, THE FILTER CONDENSERS MUST BE CAPABLE OF WITHSTANDING THIS VOLTAGE. SINCE FILTER CONDENSERS OF SUCH HIGH VOLTAGE ARE RATHER COSTLY, YOU WILL OBSERVE THAT IN THE FILTER CIRCUIT FOR THIS PARTICULAR AMPLIFIER, THREE GROUPS, EACH CONSISTING OF TWO SERIES CONNECTED 8 MFD. ELECTROLYTIC CONDENSERS ARE USED. THIS ARRANGEMENT DOUBLES THE D.C. WORKING VOLTAGE RATING FOR EACH CONDENSER GROUP AND AT THE SAME TIME REDUCES THE EFFECTIVE CAPACITY OF EACH GROUP TO 4 MFD. (ONE-HALF OF THE CAPACITIVE VALUE OF EACH CONDENSER).

THE PLATE CIRCUIT OF THE -45 TUBE CONSISTS OF A COMBINATION RESISTANCE--CAPACITY--INDUCTANCE ARRANGEMENT. THIS SYSTEM OFFERS A GOOD LOAD FOR THE -45 TUBE, THEREBY AIDING IN OBTAINING HIGH AMPLIFICATION, WHILE STILL AT THE SAME TIME OFFERING GOOD TONAL QUALITY.

THE OUTPUT TRANSFORMER IS OF THE "UNIVERSAL TYPE" HAVING A MULTI-TAPPED SECONDARY WINDING, THEREBY PROVIDING A GREAT VARIETY OF SECONDARY IMPEDANCES TO MATCH A VARIED NUMBER OF SPEAKER ARRANGEMENTS.

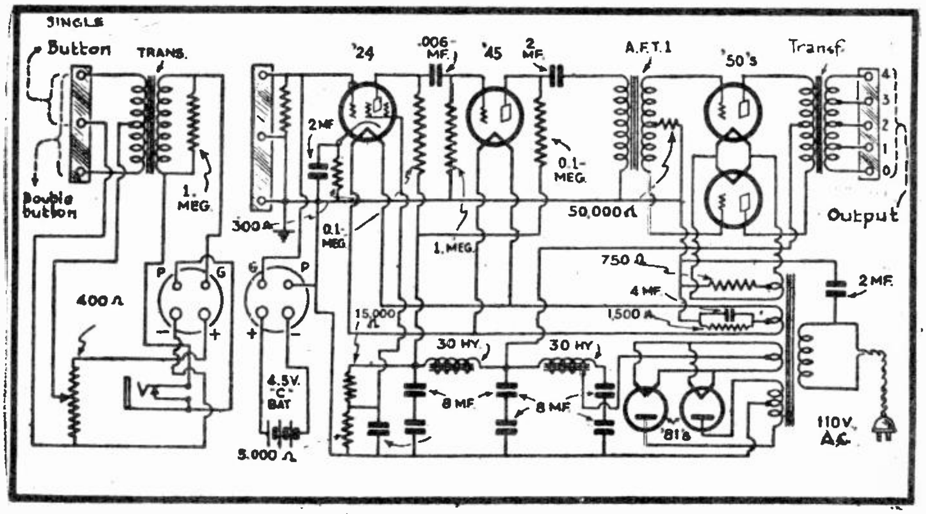

FIG. 18

A Good Amplifier for Public Address Work.

UNIVERSAL AMPLIFIER

NOW IN FIG. 19 YOU WILL SEE A DIAGRAM FOR A UNIVERSAL TYPE A.F. AMPLIFIER FOR GENERAL PUBLIC ADDRESS WORK. THIS UNIT CAN BE OPERATED FROM EITHER THE 110 VOLT A.C. LIGHTING CIRCUIT OR FROM A 6 VOLT STORAGE BATTERY (NO "B" BATTERIES REQUIRED). IT IS THUS ADAPTABLE FOR A GREAT VARIETY OF USES, SUCH AS FOR A PUBLIC ADDRESS AMPLIFIER WHERE A 110 VOLT A.C. SUPPLY AVAILABLE, FOR INSTALLATION IN A SOUND TRUCK OR BOAT, IN LOCALITIES WHERE NO A.C. SUPPLY IS AVAILABLE ETC. THIS AMPLIFIER HAS A RATED OUTPUT OF 15 WATTS AND CAN THUS FURNISH SOUND FOR AN AUDITORIUM HAVING A SEATING CAPACITY OF ABOUT 2,500 PERSONS. OBVIOUSLY WITH REDUCED VOLUME, IT CAN BE USED IN SMALL DANCE HALLS, CHURCHES ETC.

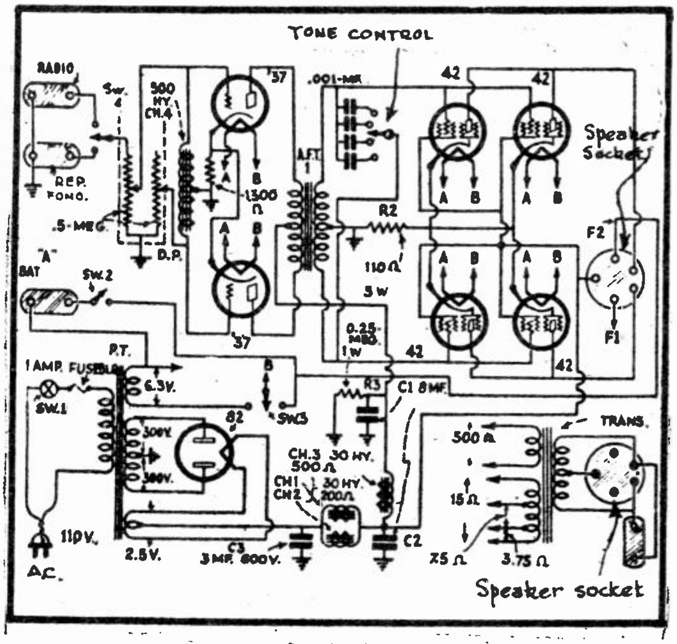

FIG. 19

A Universal Public Address Amplifier.

AS YOU WILL OBSERVE IN FIG. 19, THE INPUT STAGE CONSISTS OF TWO TYPE-37 TUBES IN PUSH-PULL WHICH IN TURN OPERATE INTO A PARALLEL PUSH-PULL CIRCUIT EMPLOYING FOUR TYPE--- 42 TUBES. THE TYPE-37 TUBE IS A NEW AUTOMOTIVE TUBE DESIGNED FOR DETECTOR AND AMPLIFYING PURPOSES IN AUTOMOTIVE RECEIVERS. ITS OPERATING CHARACTERISTICS ARE AS FOLLOWS: HEATER VOLTAGE 6.3V; HEATER CURRENT .3 AMP. AND ITS FILAMENT SUPPLY MAY BE EITHER A.C. OR D.C.; IT CAN BE OPERATED WITH A PLATE VOLTAGE OF 90 VOLTS AND GRID

BIAS OF -6.0 VOLTS OR A PLATE VOLTAGE OF 135 VOLTS WITH A GRID BIAS OF -9.0 VOLTS. WITH 90 VOLTS APPLIED TO ITS PLATE, IT DRAWS 2.6 MA; WHERE AS WITH 135 VOLTS APPLIED TO ITS PLATE, IT DRAWS 4.3 MA; ITS A.C. PLATE RESISTANCE IS 10,000 OHMS; MUTUAL CONDUCTANCE 900-- MICROMHOS; AMPLIFICATION FACTOR 9.; OUTPUT POWER 80 MILLIWATTS.

THE CHARACTERISTICS OF THE -42 PENTODE AMPLIFIER TUBE ARE; HEATER VOLTAGE 6.3 VOLTS A.C. OR D.C.; HEATER CURRENT .65 AMP.; PLATE VOLTAGE 250: SCREEN-GRID VOLTAGE 250; GRID BIAS -16.5 VOLTS; PLATE CURRENT 34 MA.; A.C. PLATE RESISTANCE 100,000 OHMS. MUTUAL CONDUCTANCE 2200 MICROMHOS; AMPLIFICATION FACTOR 220; POWER OUTPUT 3 WATTS.

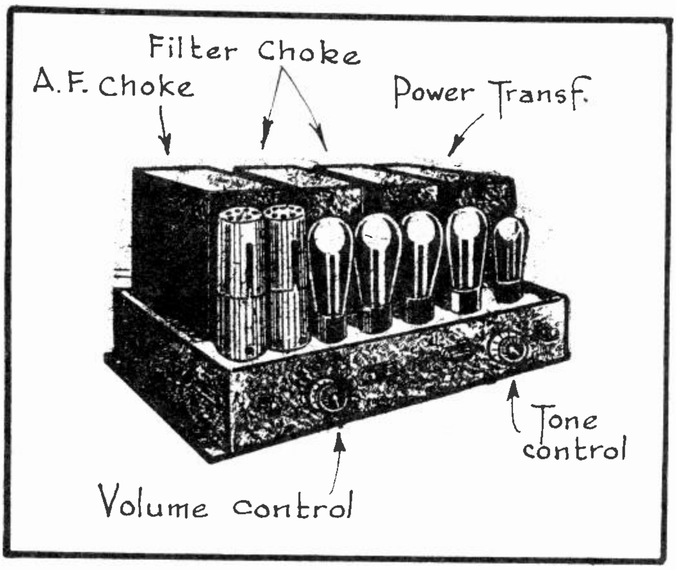

FIG. 20
A Complete Universal Amplifier.

THE VALUES FOR ALL PARTS OF THE CIRCUIT ARE CLEARLY MARKED IN FIG. 19. THE VOLUME CONTROL CONSISTS OF A DOUBLE-SECTION .5 MEG. POTENTIOMETER SINGLE CONTROL OPERATED UNIT. THE COMPLETED AMPLIFIER IS SHOWN YOU IN FIG. 20.

TO OPERATE THIS AMPLIFIER FROM THE 110 VOLT A.C. CIRCUIT, INSERT THE LINE PLUG INTO A 110 VOLT A.C. LIGHTING CIRCUIT OUTLET, CLOSE SWITCH #1, OPEN SWITCH #2, CLOSE SWITCH #3 TO THE RIGHT AND CLOSE SWITCH #4 TO THE POSITION REQUIRED FOR THE TYPE OF INPUT BEING USED. THE SPEAKER PLUG IS OF COURSE INSERTED IN ITS SOCKET AND THE SECONDARY TERMINALS ARE CHOSEN ACCORDING TO THE IMPEDANCE VALUE DESIRED.

TO OPERATE THE AMPLIFIER FROM A 6 VOLT STORAGE BATTERY, THE POWER TRANSFORMER'S LINE PLUG IS COUPLED TO THE SPECIAL POWER SUPPLY UNIT FOR AUTO OPERATION WHICH IS SHOWN YOU IN FIG. 21. CLOSE SWITCH #1 AND SWITCH #2 AND CLOSE SWITCH #3 TO THE LEFT. THE FILAMENT SUPPLY FOR THE TUBES WILL THEN BE TAKEN DIRECTLY FROM THE 6 VOLT "A" STORAGE BATTERY OR THE CAR BATTERY IF INSTALLED IN AN AUTO.

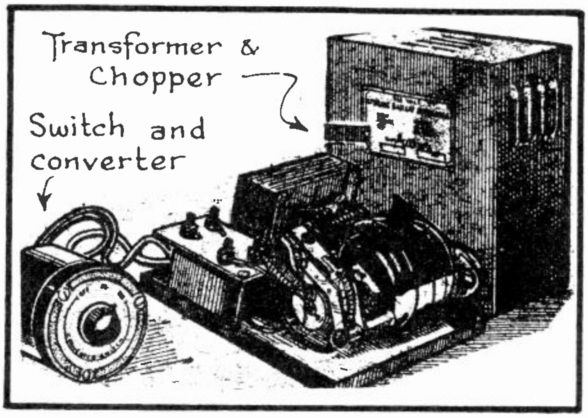

FIG. 21
Power Supply for Auto Operation.

THE DETAILS FOR THE AUTO POWER SUPPLY ARE ILLUSTRATED FOR YOU IN FIG. 22. THIS UNIT CONSISTS OF A SPECIAL ROTATING ARMATURE EQUIPPED WITH A COMMUTATOR AND COLLECTOR RINGS, IN ADDITION TO THREE BRUSHES. THIS SPECIAL ARMATURE SERVES AS A CHOPPER, ALTERNATELY COMPLETING AND INTERRUPT--

ING THE FLOW OF BATTERY CURRENT THROUGH THE PRIMARY WINDING OF A SPECIAL TRANSFORMER, WHICH IS ALSO CONTAINED WITHIN THIS POWER UNIT. IN THIS WAY, A 110 VOLT A.C. SUPPLY IS INDUCED INTO THE SECONDARY WINDING OF THIS TRANSFORMER AND IS IN TURN DELIVERED TO THE PRIMARY WINDING OF THE AMPLIFIER'S POWER TRANSFORMER, THEREBY FURNISHING THE "B" SUPPLY IN THE CUSTOMARY MANNER.

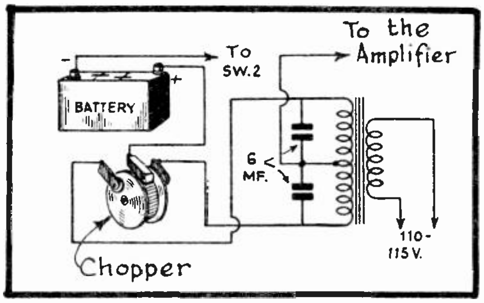

FIG. 22
Circuit of the Power Supply Unit.

YOU SHOULD NOW HAVE A GOOD PRACTICAL KNOWLEDGE OF A.F. AMPLIFIERS, WHICH YOU CAN USE TO YOUR ADVANTAGE. YOU SHOULD ALSO NOW FEEL CONFIDENT OF YOUR ABILITY TO CORRECTLY PLAN AND CONSTRUCT EQUIPMENT OF THIS TYPE WHICH IS ADAPTABLE TO A LARGE VARIETY OF USES. WORK OF THIS NATURE IS INTERESTING AS WELL AS EXCEPTIONALLY PROFITABLE--IN ADDITION, THERE IS A GREAT DEMAND FOR IT. TAKE ADVANTAGE OF THESE OPPORTUNITIES AND "CASH-IN" ON YOUR SHARE OF THE PROFITS.

IN THE NEXT LESSON, WE ARE GOING TO STUDY AN ENTIRELY DIFFERENT SUBJECT, NAMELY SHORT-WAVE ADAPTERS AN CONVERTERS. THESE UNITS MAKE IT POSSIBLE TO OBTAIN SHORT-WAVE RECEPTION THROUGH STRAIGHT BROADCAST RECEIVERS AND WITHOUT A DOUBT, YOU ARE GOING TO FIND THIS STUDY ESPECIALLY INTERESTING.

"Work—good, hard, honest work, will achieve almost any material thing in this world, and work may be delightful, noble, exhilarating, fascinating.

"Work may be full of excitement, of satisfaction, of joy and happiness."

Examination Questions

LESSON NO. 46

"It's good to have money and the things that money can buy, but it's good, too, to check up once in a while and make sure you haven't lost the things that money can't buy.

1. - DESCRIBE HOW THE ELEMENTS OF A TYPE -46 TUBE SHOULD BE CONNECTED TOGETHER FOR "CLASS A" AMPLIFICATION.

2. - DESCRIBE HOW THE ELEMENTS OF A TYPE -46 TUBE SHOULD BE CONNECTED TOGETHER FOR "CLASS B" AMPLIFICATION.

3. - DESCRIBE BRIEFLY, THE OPERATING PRINCIPLES OF A "PUSH-PULL" AMPLIFIER CIRCUIT.

4. - DESCRIBE BRIEFLY, THE OPERATING PRINCIPLES OF A "PUSH-PUSH" AMPLIFIER CIRCUIT.

5. - WHAT IS THE CHIEF ADVANTAGE OF USING "PUSH-PUSH" OR "CLASS "B" AMPLIFICATION?

6. - IF IN A CERTAIN OUTPUT OR SPEAKER COUPLING TRANSFORMER, THE PRIMARY WINDING OF THE TRANSFORMER HAS A RATED IMPEDANCE OF 3600 OHMS AND THE SECONDARY WINDING OF THIS SAME TRANSFORMER IS TO MATCH A SPEAKER VOICE COIL WHOSE IMPEDANCE IS RATED AT 9 OHMS, THEN WHAT SHOULD BE THE CORRECT TURNS RATIO FOR THE WINDINGS OF THIS TRANSFORMER?

7. - WHAT IS THE CHIEF ADVANTAGE OBTAINED THROUGH THE USE OF DUAL SPEAKERS IN MODERN RECEIVER DESIGNS?

8. - WHAT IS MEANT BY THE EXPRESSION "A UNIVERSAL TYPE AMPLIFIER"?

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LESSON NO. 47

SHORT-WAVE ADAPTERS AND CONVERTERS
SPECIAL SHORT-WAVE CIRCUITS.

ALL OF THE SHORT-WAVE RECEIVER CIRCUITS, WHICH WE DISCUSSED SO FAR, REQUIRED THE USE OF A SPECIAL RECEIVER, WHICH IS NOT ADAPTED FOR USE AT BROADCAST FREQUENCIES. RADIO LISTENERS IN GENERAL DON'T ALWAYS CARE TO HAVE ONE SEPARATE RECEIVER FOR SHORT-WAVE WORK AND ANOTHER FOR BROADCAST LISTENING. THEY WOULD MUCH RATHER BE ABLE TO USE A SINGLE RECEIVER FOR EITHER SHORT-WAVE OR BROADCAST RECEPTION AND THIS DESIRE PUT THE ENGINEERS TO EARNEST WORK AND FINALLY THEY DEVELOPED THE SHORT-WAVE ADAPTER.

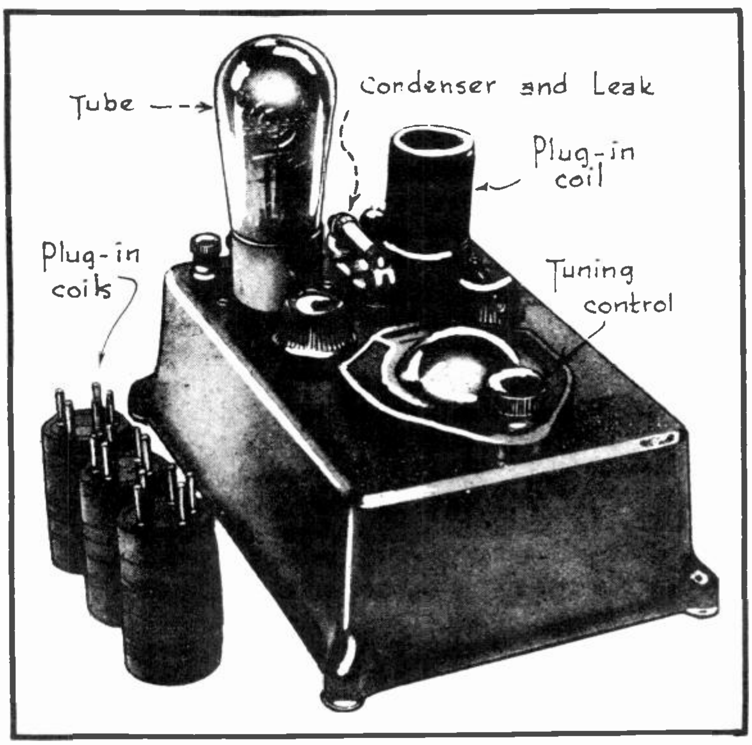


FIG. 1
A Typical Short-wave Adapter.

THE SHORT-WAVE ADAPTER IS A SHORT-WAVE TUNER AND DETECTOR, CONTAINED WITHIN A SEPARATE CABINET AND ITS CIRCUITS CAN BE QUICKLY PLUGGED INTO THE CIRCUITS OF THE REGULAR BROADCAST RECEIVER, SO THAT SHORT WAVE RECEPTION CAN COME THROUGH THE LOUD SPEAKER OF THE REGULAR BROADCAST RECEIVER.

IN FIG. 1, YOU WILL SEE A PHOTOGRAPH OF ONE SUCH FACTORY BUILT SHORT-WAVE ADAPTER. IN THIS CASE, THE PARTS, SUCH AS CONDENSERS ETC. ARE ALL HOUSED WITHIN A HOLLOW AL-

UMINUM CASTING, WHICH SERVES BOTH AS A SHIELD, AS WELL AS A NEAT LOOKING CABINET.

A TUBE SOCKET IS MOUNTED ON THE ADAPTER CABINET, IN WHICH THE TUBE FOR THE SHORT WAVE DETECTOR CAN BE INSERTED. FOUR PLUG-IN COILS ARE PROVIDED, SO THAT THE ENTIRE BAND FROM 15 TO 550 METERS CAN BE COVERED.

THE CIRCUIT DIAGRAM OF THE ADAPTER IS SHOWN IN FIG. 2 AND AS YOU WILL OBSERVE, IT IS NOTHING MORE THAN A REGULAR REGENERATIVE TYPE SHORT-WAVE DETECTOR. AN ADAPTER PLUG IS PROVIDED, WHICH IS CONNECTED TO BOTH SIDES OF THE FILAMENT OF THE ADAPTER TUBE, AS WELL AS TO ITS PLATE CIRCUIT. THIS ACCOUNTS FOR THREE PRONGS IN THE ADAPTER PLUG, LEAVING THE REMAINING GRID PRONG AS A "DUMMY".

TO CONNECT THIS ADAPTER TO THE BROADCAST RECEIVER, ALL THAT MUST BE DONE IS TO REMOVE THE DETECTOR TUBE FROM THE BROADCAST RECEIVER AND TO INSERT THE ADAPTER PLUG IN ITS PLACE. THE DETECTOR TUBE CAN THEN BE INSERTED IN THE SOCKET OF THE SHORT-WAVE ADAPTER, PROVIDED OF COURSE, THAT THE TUBE IS OF THE PROPER TYPE.

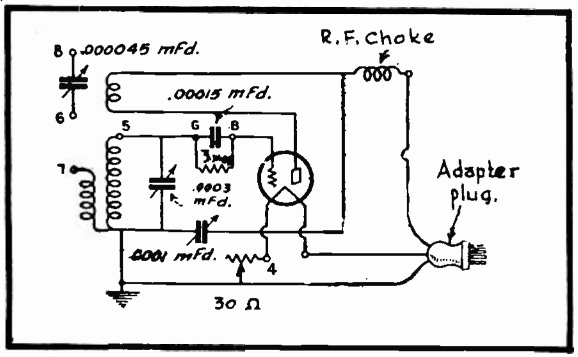


FIG. 2
A Short-Wave Adapter Circuit.

THE ANTENNA LEAD-IN WIRE IS THEN DISCONNECTED FROM THE ANTENNA TERMINAL OF THE BROADCAST RECEIVER AND IS CONNECTED TO EITHER TERMINALS 8, 5 OR 7 OF THE ADAPTER, WHICHEVER APPEARS TO GIVE THE BEST RESULTS. FOR EXAMPLE, BY CONNECTING THE ANTENNA LEAD-IN DIRECTLY TO TERMINAL #7, THE PRIMARY AND SECONDARY OF THE SHORT-WAVE COIL WILL BOTH BE USED BUT WITHOUT THE ANTENNA CONDENSER.

BESIDES THIS CONNECTION, IT IS ALSO POSSIBLE TO CONNECT TERMINAL #6 TO EITHER TERMINAL #5 OR #7 AND THEN CONNECTING THE ANTENNA LEAD-IN WIRE TO TERMINAL #8. IN THIS WAY, THE SECONDARY CAN BE USED EITHER ALONE OR WITH ITS PRIMARY, AT THE SAME TIME HAVING THE ANTENNA CONDENSER CONNECTED IN SERIES WITH THE ANTENNA AND THE RECEIVER'S TUNED CIRCUITS, SO THAT THE NATURAL OSCILLATING FREQUENCY OF THE ANTENNA CIRCUIT CAN BE STILL FURTHER CONTROLLED. EXPERIMENT WILL DETERMINE WHICH CONNECTIONS ARE MOST SUITABLE FOR "BRINGING-IN" A CERTAIN RANGE OF FREQUENCIES.

NOTICE ESPECIALLY FROM THIS EXPLANATION THAT WHEN USING THIS TYPE OF SHORT-WAVE ADAPTER, THE R.F. STAGES OF THE BROADCAST RECEIVER ARE NOT IN USE. WHAT THE SYSTEM REALLY AMOUNTS TO AT THIS TIME IS THAT WE HAVE A REGULAR REGENERATIVE SHORT-WAVE DETECTOR CIRCUIT WORKING INTO THE A.F. PORTION OF THE BROADCAST RECEIVER SO THAT THE SIGNALS MAY BE REPRODUCED BY THE SPEAKER OF THE BROADCAST RECEIVER.

ANOTHER SHORT-WAVE ADAPTER IS SHOWN YOU IN FIG. 3. IN THIS PARTICULAR CASE, A TYPE -27 TUBE IS USED IN THE REGENERATIVE DETECTOR STAGE. ASSUMING THAT THE DETECTOR TUBE OF THE BROADCAST RECEIVER IS OF THE -27 TYPE, IT IS ONLY NECESSARY TO REMOVE THIS TUBE FROM ITS SOCKET AND INSERT IT IN THE SOCKET OF THE ADAPTER. THE ADAPTER PLUG CAN THEN BE INSERTED IN

THE DETECTOR TUBE SOCKET OF THE BROADCAST RECEIVER AND THE ANTENNA AND GROUND WIRES CONNECTED TO THE CORRESPONDING TERMINALS OF THE ADAPTER.

PLUG-IN COILS CAN BE USED IN THE ADAPTER SO AS TO COVER THE ENTIRE SHORT-WAVE BAND. THE SAME WINDING DATA HOLDS GOOD FOR THESE COILS AS ALREADY GIVEN YOU IN LESSON #36 FOR SHORT-WAVE COILS IN GENERAL.

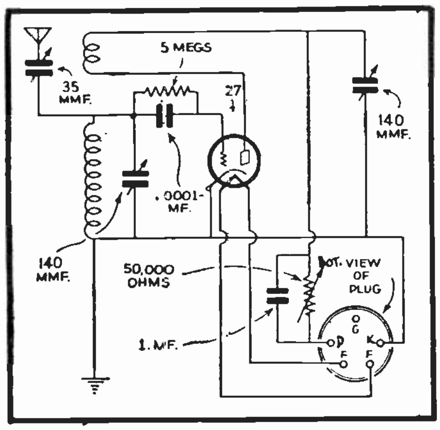


FIG. 3
Short-Wave Adapter With a -27 Tube.

SHORT-WAVE CONVERTERS

THE NEXT STEP WHICH WAS TAKEN IN THE DEVELOPMENT OF SHORT-WAVE ADAPTERS WAS TO CONSTRUCT THESE UNITS IN SUCH A MANNER SO THAT THE ENTIRE BROADCAST RECEIVER (R.F. STAGES AND ALL) COULD BE UTILIZED DURING THE RECEPTION OF SHORT-WAVE PROGRAMS. UNITS AS THIS ARE GENERALLY CLASSIFIED AS SHORT-WAVE CONVERTERS.

THIS PRINCIPLE IS ILLUSTRATED IN FIG. 4 WHERE YOU WILL SEE HOW THE SHORT WAVE CONVERTER IS CONNECTED TO THE BROADCAST RECEIVER. THIS SHORT-WAVE CONVERTER CONSISTS OF AN OSCILLATOR AND FIRST DETECTOR OR MIXER TUBE, THE SAME AS USED IN A SUPERHETERODYNE RECEIVER. THE ARRANGEMENT THEN WORKS AS FOLLOWS:

THE SHORT-WAVE SIGNALS AFTER BEING PICKED UP BY THE ANTENNA ARE IMPRESSED UPON THE GRID CIRCUIT OF THE CONVERTER'S FIRST DETECTOR OR MIXER TUBE WHICH IS TUNED TO THE FREQUENCY BEING RECEIVED. AT THE SAME TIME, THE CONVERTER'S OSCILLATOR IS GENERATING A DIFFERENT FREQUENCY WHICH IS COMBINED WITH THE SIGNAL FREQUENCY SO AS TO PRODUCE A THIRD, RESULTING OR BEAT FREQUENCY.

THIS BEAT OR INTERMEDIATE FREQUENCY IS THEN FED INTO THE FIRST R.F. STAGE OF THE BROADCAST RECEIVER, WHICH IS TUNED EXACTLY TO RESONATE WITH THIS BEAT FREQUENCY, SO THAT THE R.F. AMPLIFIER OF THE BROADCAST RECEIVER NOW BECOMES THE I.F. AMPLIFIER OF A SUPERHETERODYNE TYPE SHORT-WAVE RECEIVER. TO MAKE THIS POSSIBLE, IT IS OF COURSE NECESSARY THAT THIS INTERMEDIATE FREQUENCY FALL WITHIN THE TUNING RANGE OF THE BROADCAST RECEIVER'S R.F. AMPLIFIER.

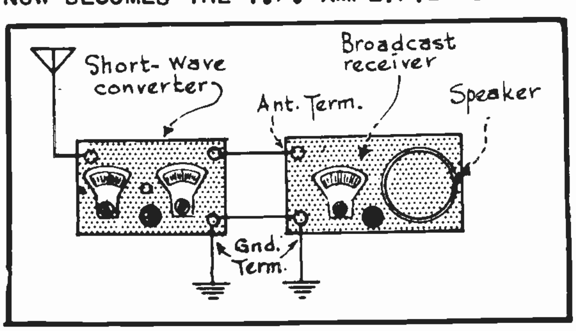


FIG. 4
The Short-Wave Converter.

AFTER BEING AMPLIFIED BY THE BROADCAST RECEIVER'S R.F. AMPLIFIER, THE BEAT FREQUENCY IS DETECTED OR DEMODULATED BY THE DETECTOR OF THE BROADCAST RECEIVER WHICH NOW BECOMES THE SECOND DETECTOR OF A SHORT-WAVE SUPERHETERODYNE RECEIVER. THE A.F. SIGNALS ARE THEN PASSED THROUGH THE A.F. AMPLIFIER AND SPEAKER OF THE BROADCAST RECEIVER IN THE USUAL WAY.

THE CIRCUIT DIAGRAM OF ONE SUCH CONVERTER IS SHOWN IN FIG. 5, TOGETHER WITH THE VALUES OF THE VARIOUS PARTS. A -32 TYPE TUBE IS USED FOR THE

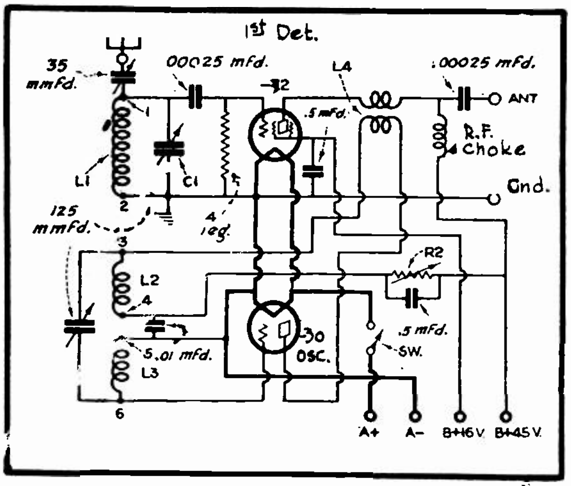


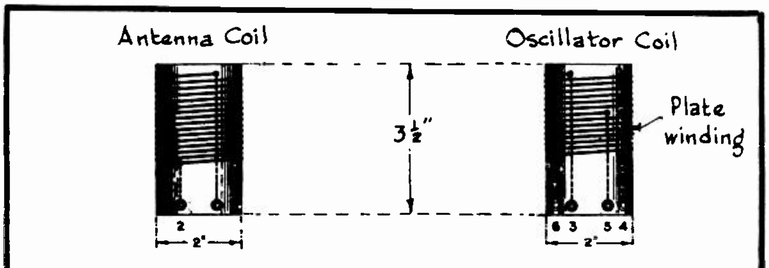
FIG. 5
Circuit Diagram of Superheterodyne Short-Wave Adapter.

THE 1ST. DETECTOR AND A -30 FOR THE OSCILLATOR IN THIS PARTICULAR CASE. THESE ARE DRY CELL TUBES AND THE NECESSARY BATTERIES FOR THE CONVERTER REQUIRE LITTLE SPACE SO THAT THEY CAN BE HOUSED IN THE CABINET CONVENIENTLY. BY HAVING THIS TYPE OF INDIVIDUAL POWER SUPPLY FOR THE CONVERTER, IT MAKES IT POSSIBLE TO USE THE CONVERTER WITH EITHER AN A.C. OR BATTERY OPERATED BROADCAST RECEIVER. ALSO NOTICE THAT THE OSCILLATOR TRANSFERS ITS OSCILLATIONS TO THE DETECTOR TUBE BY MEANS OF THE COUPLING COIL L4, WHICH IS INSTALLED IN THE PLATE CIRCUIT OF THE DETECTOR. THIS COUPLING COIL CONSISTS OF PRIMARY AND SECONDARY WINDING, EACH CONTAINING 3 TURNS OF WIRE WOUND ON A 3/4" TUBULAR FORM AND WITH THE TWO COILS WOUND SIDE BY SIDE, ALLOWING A 1/4" SEPARATION BETWEEN THEM.

FOUR OSCILLATOR AND FOUR ANTENNA COILS ARE REQUIRED TO COVER THE BAND FROM 15 TO 115 METERS AND FIG. 6 SHOWS YOU THE DETAILS OF CONSTRUCTION FOR BOTH THE ANTENNA AND OSCILLATOR COILS AS WELL AS GIVING YOU THE SPECIFICATIONS FOR THEIR WINDINGS. ALL OF THESE COILS ARE WOUND WITH #16 B&S ENAMEL COVERED WIRE.

TO USE THE CONVERTER, THE BROADCAST RECEIVER AND CONVERTER ARE CONNECTED TOGETHER AS SHOWN IN FIG. 4. THE VOLUME CONTROL OF THE BROADCAST RECEIVER IS THEN TURNED ALL THE WAY ON AND THEN THE TUNING CONTROL OF THE BROADCAST RECEIVER IS TURNED TO SOME SETTING WHERE NO BROADCAST SIGNALS ARE HEARD IN THE LOUD SPEAKER.

THIS WILL NOW BE THE INTERMEDIATE FREQUENCY SETTING AND WITH THIS DONE, DON'T DISTURB THIS SETTING. NOW TUNE YOUR SHORT WAVE CONVERTER BY SLOWLY TURNING THE DETECTOR AND OSCILLATOR TUNING CONTROLS SIMULTANEOUSLY UNTIL THE DESIRED SHORT WAVE SIGNAL COMES IN. EXPERIMENT WILL SHOW YOU WHICH INTERMEDIATE FREQUENCY SETTING OF THE BROADCAST TUNER IS MOST SATISFACTORY AND HAVING DETERMINED THIS, NOTE THE DIAL SETTING OF THE BROADCAST RECEIVER, SO THAT AT ANY LATER TIME, YOU



COIL No.	ANT. COIL	OSCILLATOR COIL TOP	OSCILLATOR COIL BOTTOM	BAND COVERED
#1	5 TURNS	3 TURNS	2 TURNS	15 TO 25 MET.
#2	7 TURNS	4 TURNS	3 TURNS	24 TO 40 MET.
#3	13 TURNS	7 TURNS	6 TURNS	37 TO 65 MET.
#4	25 TURNS	13 TURNS	12 TURNS	64 TO 115 MET.

FIG. 6
Coil Specifications.

can always set the intermediate frequency to the best operating position very quickly. The short-wave tuners are then set to the maximum volume position and the volume control of the broadcast receiver is adjusted so as to give the desired speaker volume.

A.C. SHORT-WAVE CONVERTER

In Fig. 7 you are shown the circuit diagram of an A.C. short-wave converter which has its own power pack.

This particular circuit consists of an untuned R.F. input stage followed by a first detector stage — type 24 tubes being used in both these stages. A type -27 tube is used in the oscillator circuit and an -80 rectifier in the power pack.

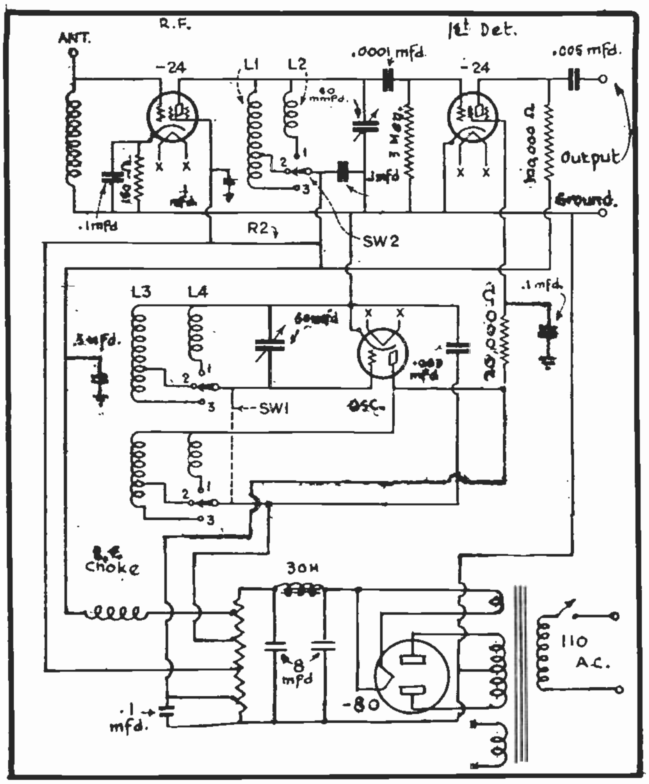


FIG. 7
Short-Wave Converter With Power Pack.

Instead of using plug-in coils to cover the various short-wave bands, special coils together with a switching arrangement are used to accomplish this feature. In this way, it is only necessary to set the three switches shown on this diagram to whichever of the three possible positions required in order to include the winding of the necessary number of turns in the tuned circuit so as to tune through the desired wave band.

The construction of the R.F. coils L_1 and L_2, as used in this converter, are illustrated in Fig. 8, together with all specifications relative to the windings. The data for the construction of the oscillator coils L_3 and L_4, as well as for the tickler or plate feed-back coils are all given you in Fig. 9.

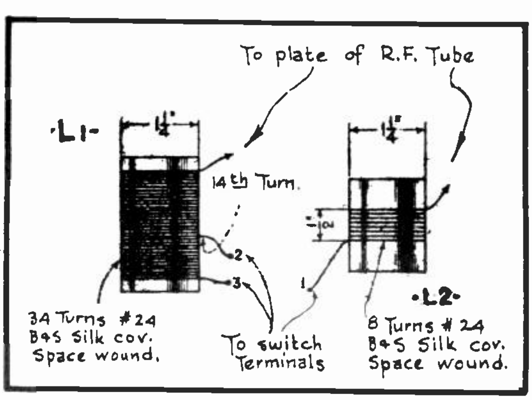


FIG. 8
Construction of the R.F. Coils.

The voltage distribution may be accomplished by connecting a 25,000 ohm adjustable voltage divider across the output of the power pack and adjusting the voltages to the different values required for the particular types of tubes used in the circuit diagram of Fig. 7.

The R.F. choke, which is connected in series with the antenna and ground in the input circuit, may be constructed by winding 120 turns of

#36 DOUBLE COTTON COVERED WIRE ON A ½" DIAMETER FORM. THESE TURNS SHOULD BE BUNCH-WOUND.

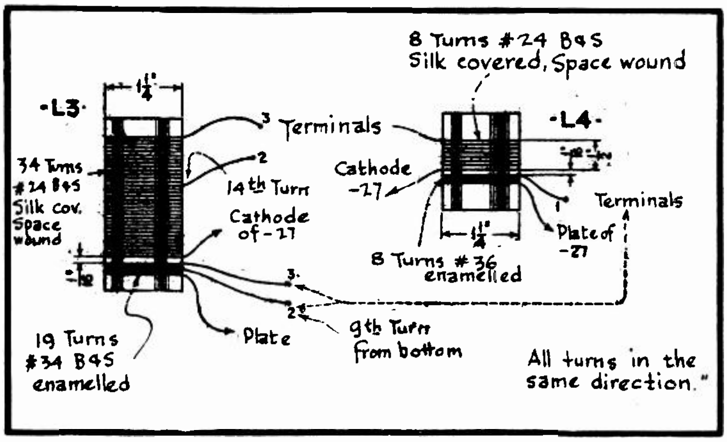


FIG. 9

Construction of the Oscillator Coils.

TO OPERATE THIS CONVERTER, ALL THAT NEED BE DONE IS TO CONNECT THE ANTENNA LEAD-IN WIRE TO THE TERMINAL MARKED "ANTENNA" AT THE INPUT OF THE CONVERTER. CONNECT THE GROUND TERMINAL OF THE CONVERTER TO THE GROUND TERMINAL OF THE BROADCAST RECEIVER AND THE ANTENNA OUTPUT TERMINAL OF THE CONVERTER TO THE ANTENNA TERMINAL OF THE BROADCAST RECEIVER.

ADJUST THE BROADCAST RECEIVER TO SOME SUITABLE BROADCAST FREQUENCY WHICH IS FREE FROM INTERFERENCE AND TUNE IN THE SHORT WAVE PROGRAMS WITH THE CONVERTER'S TUNING CONDENSER IN THE NORMAL MANNER.

WITH THIS SYSTEM, THE BROADCAST RECEIVER UTILIZER ITS OWN POWER SUPPLY AND THE CONVERTER HAS ITS INDIVIDUAL POWER SUPPLY.

A ONE-TUBE SHORT-WAVE CONVERTER

FIG. 10 SHOWS YOU THE CIRCUIT DIAGRAM OF A SHORT-WAVE CONVERTER IN WHICH A SINGLE -27 OR -56 TUBE SERVES BOTH AS AN OSCILLATOR AND 1ST. DETECTOR.

SINCE THIS PARTICULAR CONVERTER DOESN'T HAVE ITS OWN POWER PACK, IT WILL HAVE TO OBTAIN ITS VOLTAGE SOURCES FROM THE BROADCAST RECEIVER. IN OTHER WORDS, THE HEATER TERMINALS OF THE CONVERTER'S TUBE WILL HAVE TO BE WIRED TO THE HEATER CIRCUIT OF CORRESPONDING VOLTAGE IN THE BROADCAST RECEIVER; THE B+ TERMINAL OF THE CONVERTER CAN BE CONNECTED TO THE PLATE TERMINAL OF THE BROADCAST RECEIVER'S POWER TUBE AND THE B- TERMINAL OF THE CONVERTER TO THE GROUND TERMINAL OF THE BROADCAST RECEIVER. AN ADAPTER

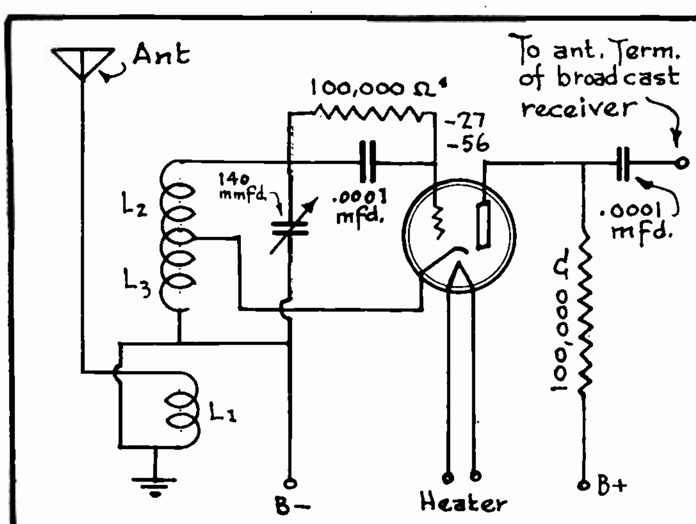


FIG. 10

The One Tube Converter.

PLUG COULD BE USED TO SIMPLIFY THESE CONNECTIONS BETWEEN THE SHORT-WAVE CONVERTER AND THE BROADCAST RECEIVER IF SO DESIRED.

THREE PLUG-IN COILS CAN BE USED WITH THIS CONVERTER TO COVER THE SHORT-WAVE BAND FROM 20 TO 200 METERS. NOTICE IN FIG. 10 THAT COILS L_2 AND L_3 ARE REALLY A CONTINUOUS WINDING WITH A TAP WHILE L_1 IS A SEPARATE PRIMARY WINDING WOUND ON THE SAME FORM.

WAVE BAND	NUMBER OF TURNS		
	L_1	L_2	L_3
80 - 200 METERS	8	27	8
40 - 80 METERS	5	10	5
20 - 40 METERS	3	7	3

FIG. 11
Coil Data For the One-Tube Converter

WHEN USING STANDARD SIX-PRONG SHORT-WAVE PLUG-IN COIL FORMS OF $1\frac{1}{4}$" DIAMETER, THE WINDING DATA AS GIVEN IN FIG. 11 WILL APPLY. FOR COILS L_2 AND L_3 YOU CAN USE #24 B&S ENAMELED WIRE SPACE WOUND - MAKING THE TOTAL WINDING LENGTH $1\frac{1}{2}$" AND #30 B&S ENAMELED WIRE FOR L_1 WITH 1/8" SEPARATION BETWEEN L_1 AND THE TUNED WINDINGS. WIND L_1 WITH ADJACENT TURNS SIDE BY SIDE.

THIS CONVERTER CAN BE HOUSED IN AN ATTRACTIVE AND COMPACT CABINET, WHICH CAN BE PLACED EITHER ON TOP OR NEXT TO THE BROADCAST RECEIVER. FOR SHORT-WAVE RECEPTION, CONNECT THE ANTENNA LEAD-IN AND GROUND WIRE TO THE EXTREMETIES OF THE CONVERTER'S COIL L_1 AS INDICATED IN FIG. 10. BE SURE THAT THE B- TERMINAL OF THE CONVERTER IS CONNECTED TO THE GROUND TERMINAL OF THE RECEIVER AND CONNECT THE ANTENNA TERMINAL OF THE BROADCAST RECEIVER TO THE CONVERTER TERMINAL SO LABELED IN FIG. 10. TUNE THE BROADCAST RECEIVER TO A FREQUENCY OF ABOUT 900 TO 1100 KC., WHERE NO BROADCAST SIGNALS COMES THROUGH AND THEN TUNE THE SHORT-WAVE CONVERTER TO BRING IN THE DESIRED SIGNALS. USE THE VOLUME CONTROL OF THE BROADCAST RECEIVER TO CONTROL THE VOLUME AS USUAL.

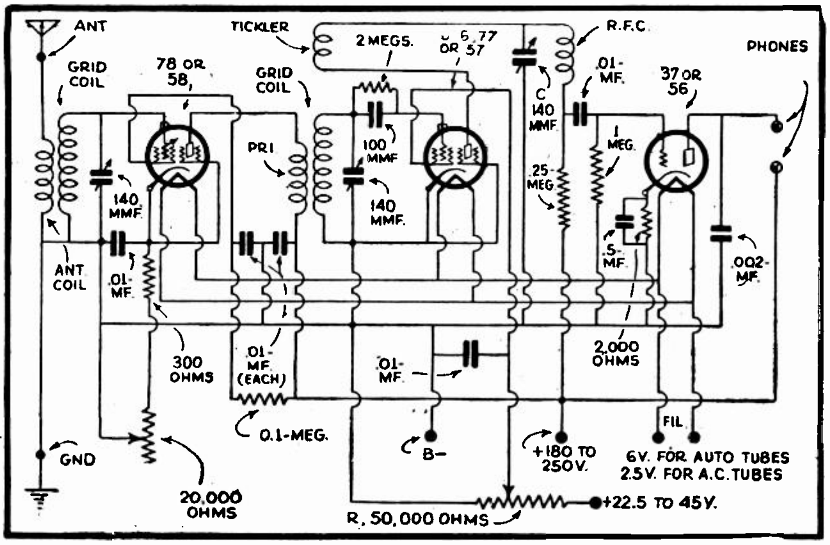


FIG. 12
The Three-Tube Receiver.

FOR BEST RESULTS WITH ANY SHORT-WAVE CONVERTER, THE BROADCAST RECEIVER SHOULD HAVE AT LEAST THREE STAGES OF R.F. AMPLIFICATION EMPLOYING SCREEN-GRID TUBES.

IF THE BROADCAST RECEIVER IS OF THE SUPERHETERODYNE TYPE, THEN WHEN USING THE SHORT-WAVE CONVERTER, THE COMBINED ARRANGEMENT WILL BE FUNCTIONING AS

A "DOUBLE-SUPERHETERODYNE", HAVING ONE INTERMEDIATE FREQUENCY IN THE BROADCAST CHANNEL BEING AMPLIFIED BY THE R.F. STAGES OF THE BROADCAST RECEIVER IN ADDITION TO THE REGULAR INTERMEDIATE FREQUENCY OF THE BROADCAST RECEIVER.

NOW THAT YOU ARE FAMILIAR WITH SHORT-WAVE ADAPTERS AND CONVERTERS, LET US LOOK AT SOME MORE STRAIGHT SHORT-WAVE RECEIVER CIRCUITS WHICH ARE A LITTLE MORE ELABORATE THAN THE ONES ALREADY SHOWN YOU.

A THREE-TUBE SHORT-WAVE RECEIVER

THE CIRCUIT DIAGRAM OF A THREE-TUBE SHORT-WAVE RECEIVER IS SHOWN YOU IN FIG. 12. AS YOU WILL OBSERVE, IT EMPLOYS A TUNED R.F. STAGE, FOLLOWED BY A REGENERATIVE DETECTOR AND A RESISTANCE CAPACITY COUPLED A.F. STAGE.

THIS CIRCUIT IS PRIMARILY DESIGNED FOR HEADPHONE RECEPTION AND CAN BE OPERATED WITH AN A.C. POWER SUPPLY BY USING A TYPE 56, 57 AND 58 TUBE AND WITH 250 VOLTS OF "B" SUPPLY.

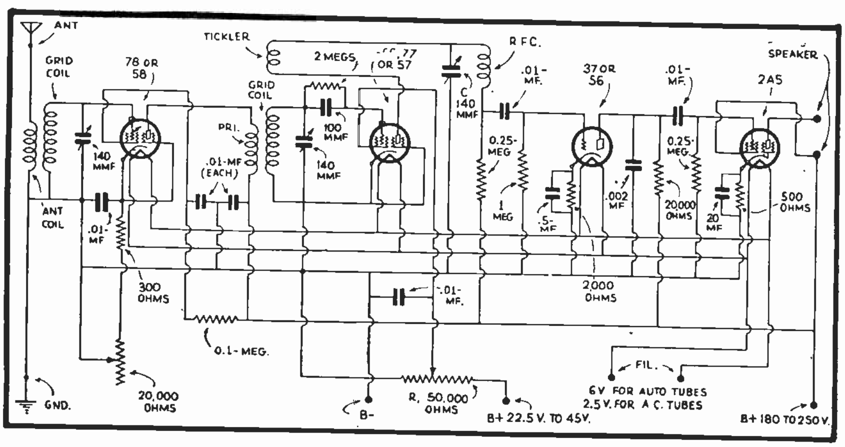


FIG. 13
The Four-Tube Receiver.

IT IS ALSO POSSIBLE TO USE 37, 77 AND 78 AUTOMOTIVE TYPE TUBES IN THIS SAME CIRCUIT BY USING A 6 VOLT HEATER SUPPLY, TOGETHER WITH A 180 VOLT "B" SOURCE.

THE VOLUME IS CONTROLLED BY REGULATING THE GRID BIAS VOLTAGE OF THE R.F. TUBE WITH THE AID OF THE 20,000 OHM VOLUME CONTROL. REGENERATION IS CONTROLLED BY MEANS OF THE 50,000 OHM POTENTIOMETER WHICH PERMITS REGULATING THE SCREEN-GRID VOLTAGE OF THE DETECTOR TUBE. THE ADDITIONAL 140 MMFD. VARIABLE CONDENSER IN THE PLATE CIRCUIT OF THE DETECTOR TUBE ALSO ACTS AS A REGENERATION CONTROL.

ALL NECESSARY SPECIFICATIONS FOR CONSTRUCTING THIS RECEIVER ARE GIVEN IN THE DIAGRAM AND THE COMPLETE DATA FOR CONSTRUCTING THE PLUG-IN R.F. TRANSFORMERS ARE FURNISHED IN LESSON #36.

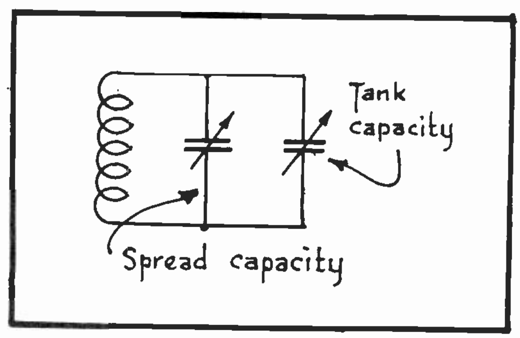


FIG. 14
Band-Spread With Two Condensers.

A FOUR-TUBE SHORT-WAVE RECEIVER

IN FIG. 13 YOU WILL SEE THE SAME

RECEIVER CIRCUIT ONLY THAT A POWER STAGE EMPLOYING A 2A5 TUBE HAS BEEN ADDED SO THAT SATISFACTORY LOUD SPEAKER PERFORMANCE MAY BE OBTAINED.

BAND-SPREAD FEATURES

THE 40 AND 80 METER AMATEUR BANDS ARE ESPECIALLY CONGESTED SO THAT WITH ONLY A FEW DEGREES MOVEMENT OF THE TUNING DIAL, A GREAT MANY DIFFERENT STATIONS CAN BE TUNED IN AND OUT. THIS NATURALLY ADDS DIFFICULTY TO TUNING IN THAT THE CONDENSER SETTING FOR BRINGING IN ONE PARTICULAR SIGNAL IS VERY CRITICAL.

TO SIMPLIFY TUNING BY SEPARATING THE STATIONS MORE ON THE TUNING DIAL BAND-SPREAD SYSTEMS ARE NOW BEING USED CONSIDERABLY.

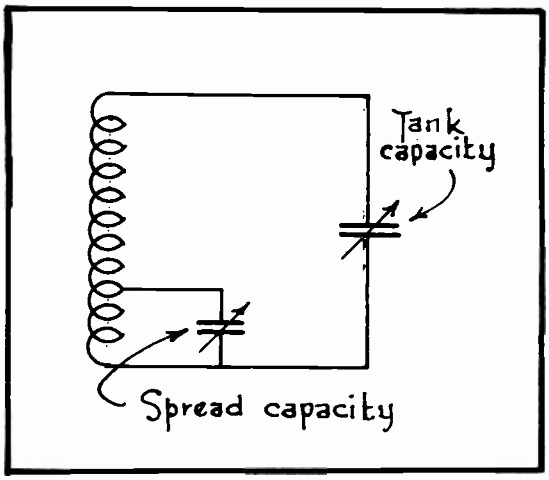


FIG. 15
Spread Capacity Across Portion of Coils.

THE SIMPLEST METHOD OF ACCOMPLISHING THIS FEATURE IS ILLUSTRATED IN FIG. 14. IN THIS CASE, ANOTHER VARIABLE CONDENSER IS SHUNTED ACROSS OR CONNECTED IN PARALLEL WITH THE MAIN CONDENSER. THIS ADDITIONAL CONDENSER IS OF SMALLER CAPACITY RATING THAN THE MAIN CONDENSER AND NOW BECOMES THE MAIN TUNING CONTROL OR "SPREAD CAPACITY" WHILE THE LARGER CONDENSER BECOMES THE "TANK" CAPACITY WHICH IS ADJUSTED SO THAT THE BAND SPREADER COVERS A FREQUENCY BAND CONTAINING THE DESIRED STATIONS.

THE OBJECTION TO THIS SIMPLE METHOD IS THAT IF THE SPREAD CAPACITY IS SMALL ENOUGH TO PROVIDE SUFFICIENT SEPARATION WHEN USING THE SMALLEST COIL, THE VARIATION WHEN USING THE LARGEST COIL WILL BE SO SMALL THAT IT WILL BE HARDLY SUFFICIENT TO TUNE A STATION IN AND OUT WITH A COMPLETE ROTATION OF THE DIAL. ON THE OTHER HAND, IF THE SPREAD CAPACITY IS MADE LARGE ENOUGH FOR PROPER SEPARATION WITH THE LARGEST COIL, THE TUNING WILL BE SO CONGESTED WITH THE SMALLEST COIL THAT THE PURPOSE OF THE BAND SPREAD WILL BE ENTIRELY DEFEATED.

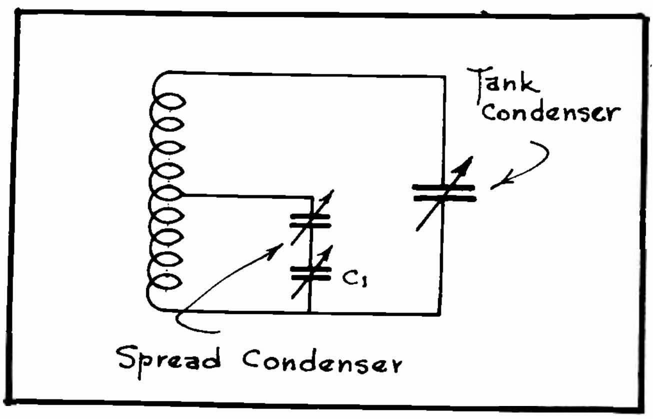


FIG. 16
Circuit for Constant Band-Spread.

THERE ARE SEVERAL METHODS OF OVERCOMING THIS DIFFICULTY, THE MOST COMMON PRACTICE BEING TO MAKE THE SPREAD CAPACITY LARGE ENOUGH TO PROVIDE SUFFICIENT BAND SPREAD WITH THE LARGEST COIL, WHILE ITS EFFECTIVE MAXIMUM CAPACITY IS DECREASED TO THE DESIRED VALUES FOR THE SMALLER COIL RANGES BY CONNECTING IT ACROSS ONLY A PORTION OF THE INDUCTANCE AS SHOWN IN FIG. 15.

ALTHOUGH THIS METHOD OF BAND SPREADING IS USED CON-

SIDERABLY, YET IF OFFERS A DISADVANTAGE IN THAT IT FURNISHES AN UNEQUAL BAND—SPREAD OVER THE RANGE OF THE TANK CONDENSER.

EVEN THIS DIFFICULTY CAN BE OVERCOME, HOWEVER, BY USING THE SYSTEM WHICH IS ILLUSTRATED IN FIG. 16. WITH THIS SYSTEM, SUBSTANTIALLY CONSTANT BAND—SPREAD IS OBTAINED REGARDLESS OF THE COIL EMPLOYED OR THE SETTING OF THE TANK CONDENSER.

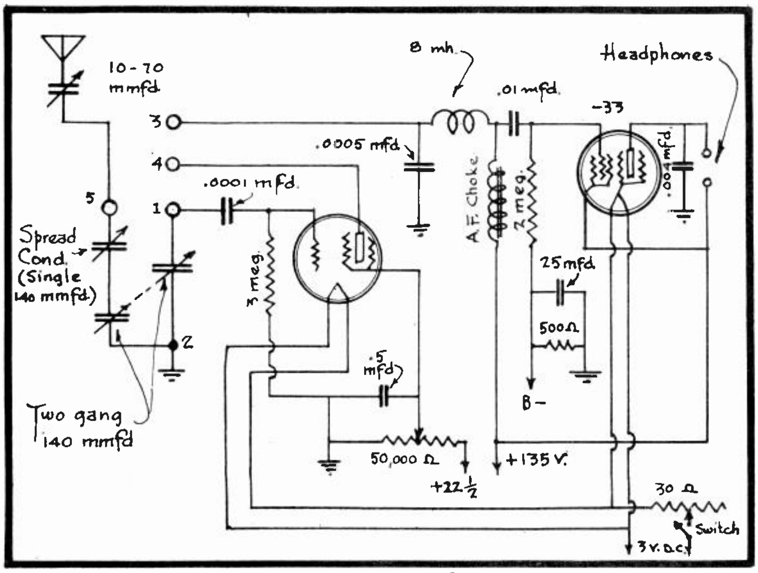


FIG. 17

Receiver Diagram With Constant Band Spread.

IN THE CIRCUIT OF FIG. 16 A TWO—GANG CONDENSER IS USED FOR THE TANK CONDENSER AND CONDENSER C_1, BOTH SECTIONS HAVING THE SAME CAPACITIVE VALUE OF COURSE. THE SPREAD CONDENSER IS A SEPARATE CONDENSER WHOSE CAPACITY IS REGULATED BY A SEPARATE CONTROL DIAL. THE PURPOSE OF CONDENSER C_1 IS TO MAINTAIN A UNIFORM BAND SPREAD AS THE TANK CAPACITY IS VARIED.

IN FIG. 17 YOU ARE SHOWN THE CIRCUIT DIAGRAM OF A SHORT—WAVE RECEIVER WHICH EMPLOYS THIS SYSTEM OF CONSTANT BAND SPREAD IN WHICH THE VALUES ARE SO CHOSEN AS TO MAINTAIN THE BAND SPREAD AT 500 KC. AS THE TANK CAPACITY IS VARIED.

FIG. 18 SHOWS YOU HOW THESE COILS ARE WOUND AND THE CONNECTIONS MADE TO THE BASE PRONGS OF THE WINDING FORMS. THESE PRONGS AND CONNECTIONS ARE HERE NUMBERED TO CORRESPOND WITH THE NUMBERED COIL TERMINALS IN FIG. 17.

NOTICE THAT TWO SETS OF CONNECTIONS ARE ILLUSTRATED IN FIG. 18. CODE #1 CORRESPONDS TO THE TWO COILS WHICH COVER THE 10—20 MC. AND THE 5—10 MC. BANDS, WHILE CODE #2 CORRESPONDS TO THE TWO COILS WHICH COVER THE 2.5—5 MC. AND THE 1.5—2 MC. BANDS THE DETAILED SPECIFICATIONS FOR THESE COILS ARE GIVEN IN FIG. 19.

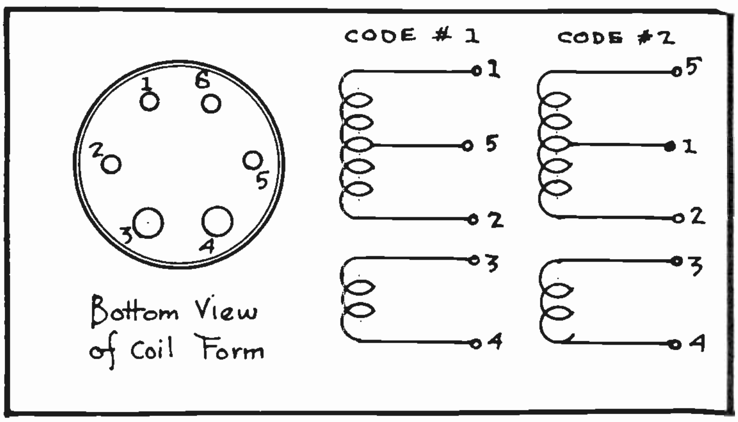


FIG. 18

The Coil Connections.

NOTICE THAT THE ABREVIATION "MC." DESIGNATES MEGACYCLES. ONE MEGACYCLE IS EQUAL TO ONE-MILLION CYCLES PER SECOND.

WHEN TUNING THIS RECEIVER, THE ACTUAL TUNING PROCESS IS ACCOMPLISHED BY THE SPREAD CONDENSER.

THE DUAL OR TWO-GANG CONDENSER IS INITIALLY ADJUSTED SO THAT THE

TUNED WINDING							TICKLER WINDING	
FREQUENCY RANGE	COIL NO.	CODE NO.	NO. OF TURNS	WIRE SIZE	TURNS PER INCH	TAP AT TURN NO.	NO. OF TURNS	WIRE SIZE
10-20 Mc.	1	1	7.3	#22 EN.	5	3	5	#30 DSC.
5-10 Mc.	2	1	14	#22 EN.	10	9	7	#30 DSC.
2.5- 5 Mc.	3	2	27	#22 EN.	10	25.5	9	#30 DSC.
1.5-2.5Mc.	4	2	54.5	#24 DSC	NO SPACE	33	10	#30 DSC.

FIG.19
Winding Data For Coils of Circuit of Fig. 17.

SPREAD CONDENSER COVERS THE DESIRED 500 KC. BAND.

IN THE FOLLOWING LESSON, WE ARE GOING TO INVESTIGATE A RATHER NEW TYPE OF RECEIVER WHICH IS RAPIDLY GAINING POPULARITY WITH RADIO LISTENERS — NAMELY, THE MODERN ALL-WAVE RECEIVERS WHICH FURNISH BOTH BROADCAST AND SHORT-WAVE RECEPTION WITHOUT THE USE OF ACCESSORY EQUIPMENT.

DON'T OVERLOOK THE FACT, HOWEVER, THAT ALTHOUGH ALL-WAVE RECEIVERS ARE BEING SOLD, THERE IS ALSO A DEMAND FOR SHORT-WAVE CONVERTERS. MANY SET OWNERS HAVE A GOOD HIGH-PRICED STANDARD BROADCAST RECEIVER AND DESIRE THE ADDED FEATURES OF SHORT-WAVE RECEPTION WITHOUT HAVING TO PURCHASE A COMPLETELY NEW RECEIVER. THE SHORT-WAVE CONVERTER IS A SOLUTION TO THEIR PROBLEM AND FOR THIS REASON, UNITS OF THIS TYPE ARE BEING BUILT BY QUITE A NUMBER OF RADIO MANUFACTURING CONCERNS.

IT IS THEREFORE ESSENTIAL THAT YOU BE WELL ACQUAINTED WITH SHORT-WAVE CONVERTERS. IN FACT, IN LATER LESSONS WHERE YOU WILL BE INTRODUCED TO SOME NEWER TUBES, YOU WILL ALSO RECEIVE THE NECESSARY INFORMATION FOR USING THEM IN THE MORE RECENT SHORT-WAVE CONVERTER CIRCUITS.

Examination Questions

LESSON NO. 47

> Work is for the worker. Love is for the lover. Art is for the artists. The menial is a man who is disloyal to his work. All useful service is raised to the plane of art when love for the task - loyalty - is fused with the effort.

1. - DESCRIBE A TYPICAL SHORT-WAVE ADAPTER WHICH IS TO BE PLUGGED INTO THE DETECTOR CIRCUIT OF A BROADCAST RECEIVER IN ORDER TO OBTAIN SHORT-WAVE RECEPTION.

2. - EXPLAIN HOW A SHORT-WAVE CONVERTER PERMITS THE ENTIRE BROADCAST RECEIVER TO BE USED FOR SHORT-WAVE RECEPTION.

3. - DRAW A CIRCUIT DIAGRAM OF AN A.C. OPERATED SHORT-WAVE CONVERTER.

4. - DRAW A CIRCUIT DIAGRAM OF A SHORT-WAVE CONVERTER IN WHICH ONLY A SINGLE TUBE IS EMPLOYED AND YET PERMITS USE OF THE ENTIRE BROADCAST RECEIVER FOR SHORT-WAVE RECEPTION.

5. - EXPLAIN IN DETAIL HOW A SHORT-WAVE CONVERTER PERMITS AN ENTIRE SUPERHETERODYNE BROADCAST RECEIVER TO BE USED FOR SHORT-WAVE RECEPTION.

6. - WHAT DO WE MEAN BY THE EXPRESSION "BAND-SPREAD" AS APPLIED TO SHORT WAVE RECEIVERS?

7. - HOW MAY THE BAND-SPREAD FEATURE BE ACCOMPLISHED IN A RECEIVER CIRCUIT?

8. - DRAW A COMPLETE CIRCUIT DIAGRAM OF A SHORT-WAVE RECEIVER EMPLOYING BAND-SPREAD PRINCIPLES.

9. - DESCRIBE A METHOD WHEREBY THE TUNING RANGE OF A SHORT-WAVE RECEIVER OR CONVERTER CAN BE CHANGED FROM ONE WAVE-BAND TO ANOTHER WITHOUT USING PLUG-IN COILS.

10. - CAN SATISFACTORY RESULTS BE OBTAINED FROM A SHORT-WAVE CONVERTER WHEN USED WITH ANY TYPE OF BROADCAST RECEIVER? EXPLAIN YOUR ANSWER TO THIS QUESTION.

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LESSON NO. 48

ALL-WAVE RECEIVERS

You are by this time thoroughly familiar with broadcast receivers, short-wave receivers and short-wave converters. Soon after short-wave converters became popular, the radio industry went another big step ahead by offering receivers of still newer design which made both broadcast and short-wave reception possible with a single receiver and without the need for accessory equipment such as an adapter or converter. This new type of receiver is known as the ALL WAVE RECEIVER, and in this lesson you are going to learn about its principles of construction and operation.

One of the most modern all-wave receivers is shown you in Fig. 1, while an earlier model all-wave receiver appears in Fig. 2. The receiver of Fig. 2, you will observe, has two sets of controls, one set for broadcast reception and one set for short-wave reception, whereas the modern receiver in Fig. 1 has only a single set of controls which serves for both broadcast and short-wave reception.

The logical way to begin this study of all-wave receivers is to begin with the older models and then gradually work on through the more recent designs so that you can obtain a good general knowledge of this field.

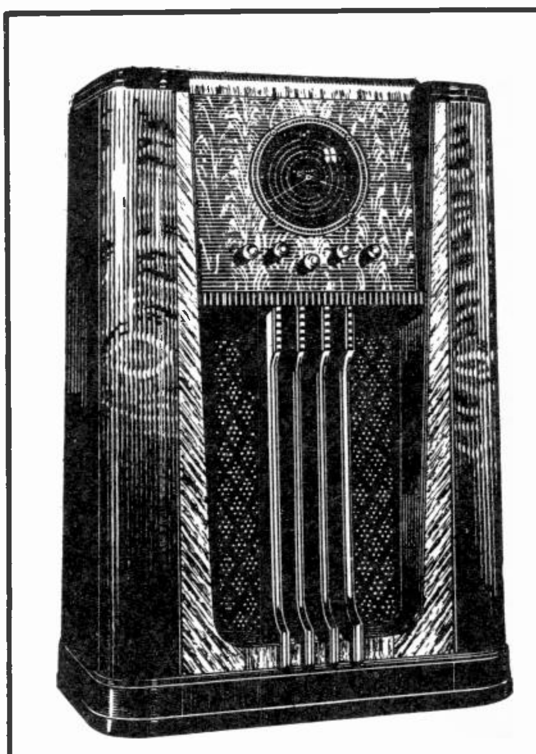

FIG. 1
A Modern All-Wave Receiver.

In Fig. 3 you are shown the circuit diagram of the same receiver

WHOSE PHOTOGRAPH APPEARS IN FIG.2. FROM A GENERAL INSPECTION OF FIG. 3, YOU WILL IMMEDIATELY RECOGNIZE THIS RECEIVER AS BEING OF THE SUPERHETERODYNE TYPE.

FIG.2
Early Model "All-Wave" Receiver.

OPERATION OF CIRCUIT FOR BROADCAST RECEPTION

IN ORDER TO SIMPLIFY THE EXPLANATION OF THE OPERATING PRINCIPLES OF THIS CIRCUIT AS MUCH AS POSSIBLE, LET US FIRST CONSIDER THE MANNER IN WHICH IT RECEIVES BROADCAST PROGRAMS.

FOR BROADCAST RECEPTION, SWITCH SW_a IS CLOSED TOWARD THE RIGHT. THIS SERVES TO CONNECT THE ANTENNA TO THE PRIMARY WINDING OF COIL L_1, SO THAT SIGNALS AS PICKED UP BY THE ANTENNA CAN BE TRANSFERRED TO THE 1ST STAGE CONTAINING THE TYPE -35 VARIABLE MU TUBE. THIS IS THE PRE-SELECTOR OR R.F. AMPLIFIER STAGE AND IT IS TUNED BY CONDENSER C_1. NOTICE CAREFULLY THAT THIS CONDENSER C_1, CONDENSER C_2 OF THE 1ST DETECTOR STAGE AND CONDENSER C_3 OF THE BROADCAST OSCILLATOR ARE ALL CONTROLLED BY A COMMON SHAFT.

AT THE SAME TIME THAT SWITCH SW_a IS CLOSED TOWARD THE RIGHT, SWITCH SW_c WILL BE AUTOMATICALLY OPENED BECAUSE THESE TWO SWITCHES ARE MECHANICALLY INTER-CONNECTED AND THEREFORE OPERATE AS ONE.

TWO STAGES OF INTERMEDIATE FREQUENCY AMPLIFICATION FOLLOW THE 1ST DETECTOR, AND TYPE-35 TUBES ARE USED IN ALL OF THESE INTERMEDIATE STAGES. THE OPERATING FREQUENCY FOR THIS INTERMEDIATE FREQUENCY AMPLIFIER IS 175 KC. AND IT WORKS INTO A SECOND DETECTOR IN WHICH A TYPE -27 TUBE IS EMPLOYED.

AFTER DETECTION, THE AUDIO FREQUENCIES ARE AMPLIFIED BY THE POWER STAGE, WHICH CONSISTS OF TWO TYPE -47 PENTODE TUBES IN PUSH-PULL. SO YOU SEE, FOR RECEPTION AT THE BROADCAST FREQUENCIES, WE HAVE CUSTOMARY SUPERHETERODYNE ACTION.

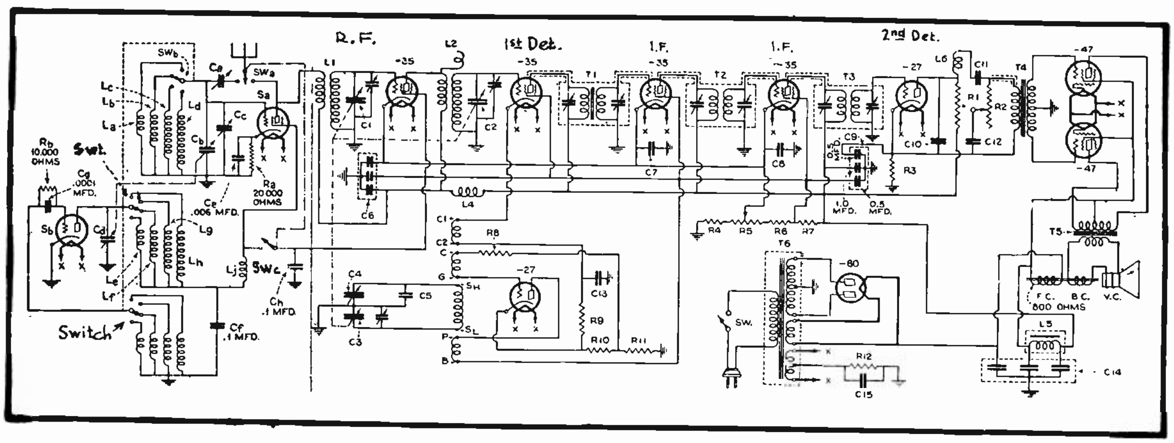

FIG.3
Circuit Diagram of a Silver-Marshall "All-Wave" Receiver.

Operation of Circuit for Short-Wave Reception

Now then, for the reception of short-wave programs, switch SWa is closed toward the left and the broadcast tuning dial, which controls condensers C_1 ; C_2 and C_3 is set at 650 Kc. by the listener. At the same time, that switch SWa is closed toward the left, switch SWc will simultaneously make contact with the upper end of coil L_j.

Tube Sa will now be used as the mixer tube for short wave reception and tube Sb as the short wave oscillator. A single knob controls switches SWb, SWd and SWe and by means of this control knob, one can connect the proper set of coils into the circuit so that this short-wave tuner will operate over the desired portion of the short wave band.

Condenser Cb and Cd of the short wave tuner are operated by a single control dial separate from that used for broadcast reception. By tuning

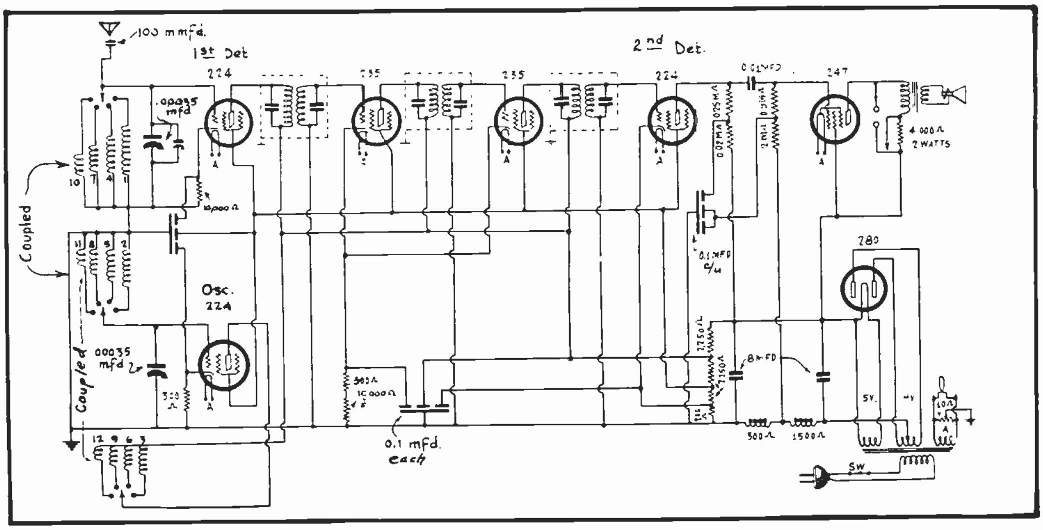

FIG. 4
A Superheterodyne For "All-Wave" Reception.

in a station with this short wave dial, an intermediate frequency of 650 Kc. will be generated by the heterodyne interaction between the short wave mixer circuit containing tube Sa and the short wave oscillator circuit containing tube Sb.

Since the circuits of the broadcast pre-selector stage and the broadcast 1st detector stage have already been tuned to a 650 Kc. frequency, it is obvious that they will amplify the 650 Kc. beat frequency as provided by the short wave input circuit.

The tuning condenser of the broadcast oscillator (C_3 in Fig. 3) will at this time be automatically tuned to a frequency 175 Kc above 650 Kc. or to 825 Kc. and so the frequency generated by the broadcast oscillator will heterodyne with the 650 Kc. frequency which is now present in the broadcast pre-selector and 1st detector stages, in order to produce another beat frequency of 175 Kc. This you will note is equal to the arithmetical difference between the 825 Kc. broadcast oscillator frequency

AND THE 650 KC. BEAT FREQUENCY EXISTING IN THE PRE-SELECTOR AND 1ST DETECTOR STAGE OF THE BROADCAST PORTION OF THE RECEIVER.

THIS 175 KC. BEAT FREQUENCY WILL BE SUCCESSIVELY AMPLIFIED BY THE I.F. STAGES AND CUSTOMARY DETECTION THEN TAKES PLACE AT THE SECOND DETECTOR. FROM HERE TO THE SPEAKER, THE AUDIBLE SIGNALS, WHICH HAVE BEEN EXTRACTED FROM THE SHORT WAVE CARRIER FREQUENCY, ARE HANDLED IN EXACTLY THE SAME MANNER AS ARE THE SIGNALS RECEIVED FROM BROADCAST STATIONS..

THE ENTIRE APPARATUS, WHICH IS ILLUSTRATED BY THE CIRCUIT DIAGRAM OF FIG. 3 IS ALL CONTAINED IN ONE CHASSIS ASSEMBLY. THE CONDENSER C_A IS ADJUSTED TO THE POSITION MOST SUITED TO THE ANTENNA AT THE TIME THE RECEIVER IS INSTALLED AND IS NOT INTENDED TO BE USED BY THE SET OWNER. THE CONTROLS SUPPLIED FOR THE USE OF THE OWNER CONSIST ONLY OF AN "OFF-ON" SWITCH, A SHORT WAVE TUNING CONTROL, TONE CONTROL, VOLUME CONTROL, BROADCAST TUNING CONTROL, THE SHORT WAVE RANGE SELECTOR (SW_B IN FIG.3), AND A SELECTOR SWITCH TO CHANGE FROM BROADCAST TO SHORT-WAVE RECEPTION (SW_A IN FIG.3). TWO TUNING DIALS ARE PROVIDED — ONE FOR BROADCAST RECEPTION AND THE OTHER FOR SHORT WAVE RECEPTION.

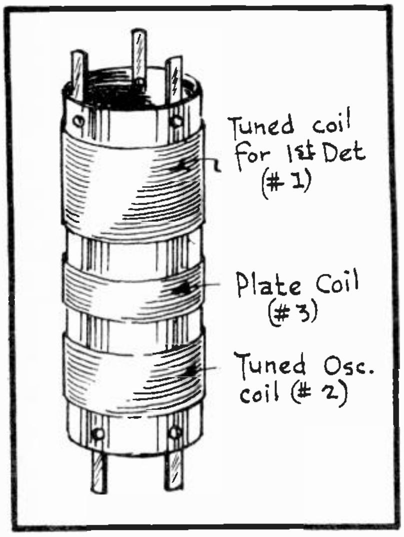

FIG. 5
All-Wave Coil Construction.

ALL OF THE OPERATING PRINCIPLES USED IN THIS RECEIVER ARE FAMILIAR TO YOU. IN FACT, THE UNIT CONSISTS OF NOTHING MORE THAN A STANDARD BROADCAST TYPE SUPERHETERODYNE WITH A SUPERHETERODYNE TYPE SHORT WAVE CONVERTER ADDED TO THE INPUT OF THE BROADCAST PRE-SELECTOR STAGE. THEN INSTEAD OF USING PLUG-IN TYPE SHORT WAVE TUNING COILS, THE REQUIRED COILS ARE ALL PERMANENTLY MOUNTED ON THE RECEIVER CHASSIS AND THE PROPER COMBINATION FOR TUNING WITH THE SHORT-WAVE CONDENSERS OVER A GIVEN RANGE IS OBTAINED BY THE THREE COMMONLY CONNECTED SELECTOR SWITCHES.

ANOTHER TYPE OF SUPERHETERODYNE ALL-WAVE RECEIVER

AS WE CONTINUE OUR INVESTIGATION OF ALL-WAVE RECEIVERS, LET US NEXT STUDY THE CIRCUIT ARRANGEMENT WHICH IS ILLUSTRATED IN FIG. 4. IN THIS CASE, A SYSTEM HAS BEEN WORKED OUT WHEREBY IT IS POSSIBLE FOR A SUPERHETERODYNE RECEIVER TO COVER A 15 TO 550 METER RANGE. THIS RECEIVER CONSISTS OF A MIXER CIRCUIT OR 1ST DETECTOR DIRECTLY AT THE INPUT OF THE ANTENNA AND THE OSCILLATOR CAN BE SEEN LOCATED DIRECTLY BELOW IT. TYPE -24 TUBES ARE USED IN BOTH OF THESE CIRCUITS.

THE MIXER CIRCUIT IS FOLLOWED BY THE CUSTOMARY I.F. STAGES, WHICH ARE TUNED TO 175 KC. AND IN WHICH VARIABLE MU TUBES ARE USED. A TYPE -24 TUBE IS USED AS A POWER DETECTOR AND IT WORKS INTO A TYPE -47 PENTODE POWER TUBE THROUGH RESISTANCE - CAPACITY COUPLING.

NOW AS FAR AS THE I.F., 2ND DETECTOR AND POWER STAGES ARE CONCERNED, YOU HAVE NOTHING NEW TO LEARN, AS THESE ARE CONVENTIONAL. SO WE SHALL CONFINE OUR ATTENTION SOLELY TO THE MIXER AND OSCILLATOR CIRCUITS AROUND

WHICH THE ALL-WAVE FEATURES OF THE RECEIVER ARE REALLY CENTERED.

As you will observe in Fig. 4, the tuning circuit of the mixer or 1st detector is provided with 4 separate tuning coils and a switch. These 4 coils are shunted by a tuning condenser having a capacity of .00035 mfd.

The set of 4 coils which are shown directly below the upper group in Fig. 4 are the tuning coils for the oscillator and in this case, the oscillator condenser also has a capacity rating of .00035 mfd. A switch is also provided so that the desired oscillator coil can be selected.

The group of coils directly below the oscillator tuning coils are the feed-back, plate, or tickler coils, whichever you choose to call them.

COIL CONSTRUCTION FOR ALL-WAVE RECEIVER

The construction of the coil group for this same all-wave receiver is illustrated for you in Fig. 5. Observe carefully that there are three separate windings on a single coil form. That is to say, coils #1, #2 and #3 of Fig. 4 are all wound on the same form as shown in Fig. 5, only that the plate coil in the actual construction is placed between the 1st detector and oscillator coils. (Coils #1 - #2 and #3 of Fig. 5 correspond to the coils which are numbered in like manner in the circuit diagram of Fig. 4.) Coils #4, #5 and #6 of Fig. 4 would then be wound together on another coil form in the same manner as illustrated relative to coils #1, #2 and #3 in Fig. 5. Coils #7, #8 and #9 would be wound together on a third form and coils #10, #11, and #12 on a fourth form. So altogether, there would be four of these separate coil forms, with three windings on each.

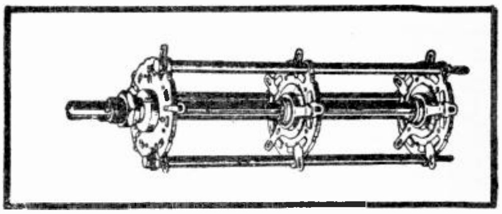

FIG. 6
A Typical Wave-Band Changing Switch.

Provided that the two tuning condensers have a capacity rating of .00035 mfd., then in order for the receiver to cover both the short and broadcast wavelengths the coils should consist of the following number of turns wound on tubular forms 1" in diameter: Coil #1 = 127 turns; coil #2 = 114 turns; coil #3 = 40 turns. Coil #1 should be wound at one end of the coil form as shown in Fig. 5; coil #3 should be wound at a distance of 1" below coil #1 and Coil #2 a distance of 1/8" below coil #3. With all three switches of Fig. 3 respectively closing the circuits for coils #1, #2 and #3, broadcast reception will be available.

Coil #4 = 45 turns; coil #5 = 45 turns and coil #6 = 20 turns. Coil #4 should be wound at one end of the coil form and coil #6 should be wound at a distance of 1½" below coil #4 and coil #5 a distance of 1/8" below coil #6. With all three switches respectively closing the circuits for coils #4, #5 and #6, the first short wave band will be covered.

Coil #7 = 18 turns; coil #8 = 18 turns and coil #9 = 9 turns. Coil #7 should be wound at one end of the coil form and coil #9 should be wound at a distance of 2" below coil #7 and coil #8 at a distance of 1/8" below

COIL #9. WITH ALL THREE SWITCHES RESPECTIVELY CLOSING THE CIRCUITS FOR COILS #7, #8, AND #9, THE SECOND SHORT-WAVE BAND WILL BE COVERED.

COIL #10 = 7.5 TURNS; COIL #11 = 7.5 TURNS AND COIL #12 = 4 TURNS. COIL #10 SHOULD BE WOUND AT ONE END OF THE COIL FORM AND COIL #12 SHOULD BE WOUND AT A DISTANCE OF 2½" BELOW COIL #10 AND COIL #11 AT A DISTANCE OF 1/8" BELOW COIL #12. WITH ALL THREE SWITCHES RESPECTIVELY CLOSING THE CIRCUITS FOR COILS #10, #11 AND #12, THE THIRD SHORT-WAVE BAND WILL BE COVERED.

ALL COILS FOR THIS PARTICULAR RECEIVER SHOULD BE WOUND WITH #30 B&S ENAMELED WIRE. ALSO NOTE THAT FOR THE SPECIFICATIONS GIVEN, TNE OSCILLATOR CONDENSER HAS ITS INDIVIDUAL TUNING DIAL, SO THAT THE RECEIVER IS EQUIPPED WITH TWO TUNING DIALS.

THE WAVE-BAND CHANGING SWITCH

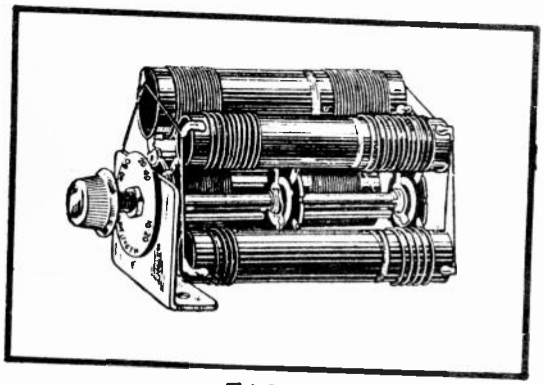

FIG. 7
Complete Coil Assembly With Switch.

IN FIG. 6 YOU WILL SEE A TYPICAL SWITCH AS USED IN ALL-WAVE RECEIVERS FOR CHANGING FROM ONE WAVE BAND TO ANOTHER. HERE YOU CAN SEE CLEARLY HOW THE THREE SWITCH BLADES ARE ALL OPERATED SIMULTANEOUSLY BY A SINGLE CONTROL SHAFT.

IT IS FREQUENTLY THE PRACTICE TO MOUNT THE VARIOUS COIL FORMS WITH THEIR RESPECTIVE WINDINGS INTO A GROUPED ARRANGEMENT AS SHOWN YOU IN FIG. 7. THE SWITCH ASSEMBLY CAN BE SEEN MOUNTED HORIZONTALY THROUGH THE CENTER OF THE COIL MOUNTING, THEREBY FACILITATING THE WIRING BETWEEN THE SWITCHES AND THE COIL WINDINGS.

ALL-WAVE TUNED R.F. RECEIVER

NOW IN FIG. 8 YOU ARE LOOKING AT AN ALL-WAVE TUNED R.F. RECEIVER, IN WHICH CASE A SHORT-WAVE CONVERTER IS INCORPORATED IN ITS CIRCUITS. ALTHOUGH A RECEIVER OF THIS TYPE WILL NOT GIVE SUCH HIGH QUALITY SHORT WAVE PERFORMANCE AS WILL THE MORE ELABORATE DESIGNS SHOWN YOU PREVIOUSLY IN THIS LESSON, YET IT OFFERS AN ECONOMICAL METHOD OF CONSTRUCTING AN ALL-WAVE RECEIVER WHICH WILL OFFER FAIR PERFORMANCE. IN FACT, THE SAME PRINCIPLES AS WORKED OUT IN THE CIRCUIT OF FIG. 8 CAN ALSO BE INCORPORATED INTO ANY EXISTING TUNED R.F. RECEIVER, WHICH HAS AT LEAST THREE TUNING CIRCUITS, USING SCREEN-GRID TUBES.

REFERRING TO FIG. 8, THE TWO SWITCHES SW_1 AND SW_2 ARE BOTH SECTIONS OF A REGULAR WAVE-BAND CHANGING SWITCH AND ARE THEREFORE BOTH OPERATED BY A SINGLE CONTROL.

FOR BROADCAST RECEPTION, SWITCHES SW_1 AND SW_2 ARE BOTH CLOSED TO POSITION #4. THE ENERGY PICKED UP BY THE ANTENNA IS NOW PASSED INTO THE TUNING CIRCUIT OF THE FIRST TUBE THROUGH THE ANTENNA SERIES CONDENSER, WHICH MAY BE A TRIMMER CONDENSER ADJUSTABLE BETWEEN THE LIMITS OF APPROXIMATELY 20 - 100 MMFD.

THE TUNING CIRCUIT OF THIS FIRST TUBE WILL AT THIS TIME CONSIST OF THE .00035 MFD. VARIABLE CONDENSER AND THE TUNING INDUCTANCE L_5. THIS CONDENSER IS A SINGLE UNIT AND NOT A SECTION OF A GANGED CONDENSER. THE TUNING CONDENSERS OF THE FOLLOWING THREE STAGES, HOWEVER, ARE ALL SECTIONS OF A THREE GANG CONDENSER UNIT OF ANY STANDARD CAPACITY RATING, SUCH AS .00035 MFD.

THE TUNING INDUCTANCE L_5 IS A SECONDARY OR TUNING WINDING OF THE REGULAR BROADCAST TYPE, MATCHED TO THE CONDENSER TO COVER THE BROADCAST WAVE BAND. THIS INDUCTANCE IS CONTAINED WITHIN AN INDIVIDUAL SHIELD CAN WHICH IS GROUNDED.

DUE TO THE FACT THAT THE LOWER END OF COIL L_5 IS MUTUALLY GROUNDED WITH THE ROTOR PLATES OF ITS TUNING CONDENSER, THE SAME NEGATIVE BIAS VOLTAGE WILL BE IMPRESSED UPON THE CONTROL GRID OF THIS FIRST TUBE AS UPON THE OTHER VARIABLE-MU TUBES. THEREFORE, THE FIRST TUBE WILL NOW FUNCTION AS AN R.F. AMPLIFIER.

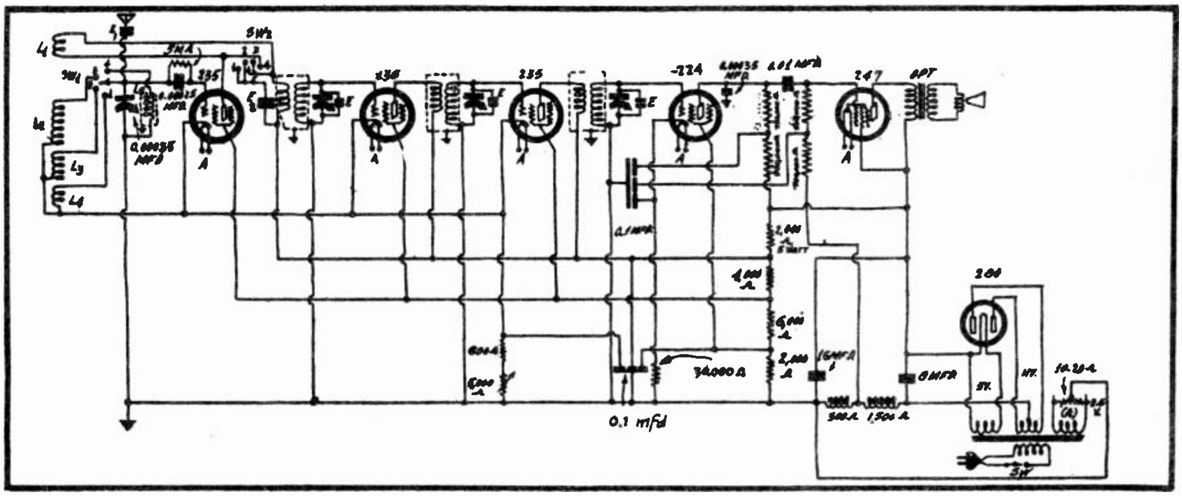

FIG. 8

A Tuned R.F. Receiver With "Built-in" Converter.

WITH SWITCH SW_2 ALSO CLOSED TO POSITION #4 AT THIS TIME, THE REGENERATION COIL L_1 WILL BE SHORT CIRCUITED AND CAN THEREFORE NOT OFFER ANY REGENERATIVE CHARACTERISTICS. THE FOLLOWING STAGES ARE CONVENTIONAL AND SO THE RECEIVER IS NOW OPERATING AS A STANDARD BROADCAST RECEIVER, CONSISTING OF 3-R.F., 1-DETECTOR, AND ONE POWER STAGE.

"AUTODYNE ACTION" FOR SHORT-WAVE RECEPTION

NOW THEN, IN ORDER TO COVER THE FIRST SECTION OF THE SHORT WAVE BAND DIRECTLY BELOW THE BROADCAST CHANNELS, BOTH SWITCHES ARE CLOSED TO POSITION #3. AT THIS TIME, COIL L_2 WILL BE CONNECTED ACROSS THE TUNING CONDENSER OF THE INPUT STAGE. THE LOWER END OF COIL L_2, HOWEVER, IS CONNECTED DIRECTLY TO THE CATHODE OF THE FIRST TUBE AND CONSEQUENTLY, THE FIRST TUBE IS OPERATED AT ZERO GRID BIAS. THE RESULT IS THAT THE OPERATING CHARACTERISTIC OF THE FIRST TUBE ARE NOW CHANGED, SO THAT THE TUBE ACTS AS A MODULATOR.

SWITCH SW_2, IS ALSO NOW CLOSED TO POSITION #3 AND SO A CERTAIN PER

CENTAGE OF THE R.F. ENERGY CAN BE IMPRESSED UPON THE TUNING COIL L_2 IN ORDER TO PRODUCE OSCILLATION. THE COMBINED RESULTS OF MODULATION AND OSCILLATION, WHICH THIS FIRST TUBE NOW UNDERGOES, MAKE THIS TUBE SERVE A DUAL PURPOSE, FOR WHICH REASON IT IS REFERRED TO AS AN "OSCILLATING-MODULATOR". IN OTHER WORDS, IT IS THE 1ST DETECTOR OF A SUPERHETERODYNE AND OSCILLATOR COMBINED AND SUCH A COMBINATION IS KNOWN AS THE "AUTODYNE SYSTEM". THIS TUBE IN ITSELF IS IN THIS CASE QUITE OFTEN SPOKEN OF AS BEING AN "AUTODYNE OSCILLATOR."

SO FROM NOW ON, WHENEVER YOU HEAR OF A SUPERHETERODYNE RECEIVER BEING OF AN "AUTODYNE TYPE", YOU WILL IMMEDIATELY KNOW THAT IN THIS PARTICULAR SUPERHETERODYNE RECEIVER, A SINGLE TUBE SERVES BOTH AS THE FIRST DETECTOR AND OSCILLATOR.

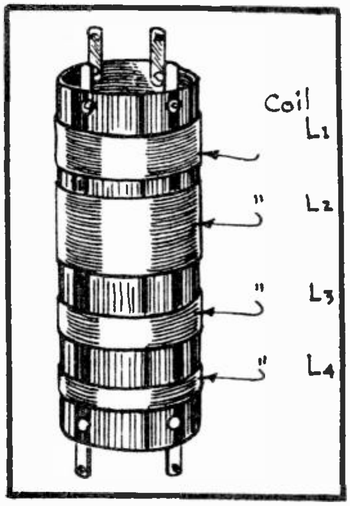

FIG.9
Short-Wave Coil Assembly for Circuit of Fig. 8

NOW THEN, TO RECEIVE SHORT WAVE RECEPTION WITH THE CIRCUIT OF FIG.8, THE GANGED TUNING CONDENSERS CAN BE SET TO TUNE THEIR CIRCUITS TO SOME CONVENIENT BROADCAST FREQUENCY SUCH AS 550 KC., FOR EXAMPLE. THIS WOULD MEAN THAT ALL OF THE ROTOR PLATES OF THE GANGED CONDENSER WILL BE PRACTICALLY ENTIRELY IN MESH WITH THEIR RESPECTIVE STATOR PLATES. HENCE BY TUNING THE CIRCUIT OF THE FIRST TUBE TO A FREQUENCY 550 KC. ABOVE THE FREQUENCY OF THE SHORT WAVE SIGNAL BEING RECEIVED, A BEAT FREQUENCY OF 550 KC. WILL BE PRODUCED IN THE OUTPUT OF THIS TUBE, TO BE AMPLIFIED BY THE SUCCEEDING STAGES WHICH ARE TUNED TO THIS BEAT FREQUENCY.

IN ORDER TO ENABLE THE INPUT CIRCUIT TO COVER THE NECESSARY OSCILLATOR FREQUENCIES REQUIRED FOR THE RECEPTION OF ALL OF THE SHORT WAVE STATIONS, THE THREE COILS L_2, L_3 AND L_4 ARE PROVIDED WITH DIFFERENT INDUCTIVE VALUES THE SAME AS ALREADY DESCRIBED RELATIVE TO THE PREVIOUS ALL-WAVE RECEIVER CIRCUITS IN THIS LESSON.

THE FIXED CONDENSER E_2 IS EMPLOYED TO BY-PASS THE HIGH FREQUENCY ENERGY IN THE OUTPUT OF THE FIRST TUBE, IN ORDER TO PREVENT IT FROM CAUSING TROUBLE IN THE OTHER STAGES. THIS CONDENSER MAY BE OF THE SAME TYPE AND CAPACITY RATING AS THE ANTENNA SERIES CONDENSER E_1.

COIL CONSTRUCTION FOR THE CIRCUIT OF FIG.8

COILS L_1, L_2, L_3 AND L_4 MAY ALL BE WOUND ON A SINGLE TUBE FORM. WITH A .00035 MFD. TUNING CONDENSER, AND A COIL FORM 1" IN DIAMETER, COIL L_1 MAY CONSIST OF 15 TURNS; COIL L_2 OF 45 TURNS; COIL L_3 OF 18 TURNS; AND COIL L_4 OF 7.5 TURNS. ALL OF THESE COILS CAN BE WOUND WITH #30 B&S ENAMELED WIRE.

FIG. 9 SHOWS YOU HOW THESE FOUR COILS SHOULD BE WOUND ON THE FORM. THE SEPARATION BETWEEN COIL L_1 AND COIL L_2 SHOULD BE 1/8" AND THE SEPERATION BETWEEN COILS L_2 AND L_3, AS WELL AS THE SEPARATION BETWEEN COILS L_3 AND L_4 SHOULD BE ½". COIL L_5 MAY CONSIST OF 127 TURNS OF THE SAME WIRE WOUND ON AN INDIVIDUAL TUBE FORM OF 1" DIAMETER AND PLACED IN THE SHIELD CAN AS SHOWN IN THE CIRCUIT DIAGRAM OF FIG. 8.

A TABLE MODEL ALL-WAVE RECEIVER

NOT ONLY ARE MODERN ALL-WAVE RECEIVERS BEING BUILT INTO THE LARGER CONSOLE CABINETS BUT INTO TABLE MODEL CABINETS AS WELL. IN FIG. 10 YOU ARE SHOWN AN EXAMPLE OF A NEW TABLE MODEL ALL-WAVE RECEIVER.

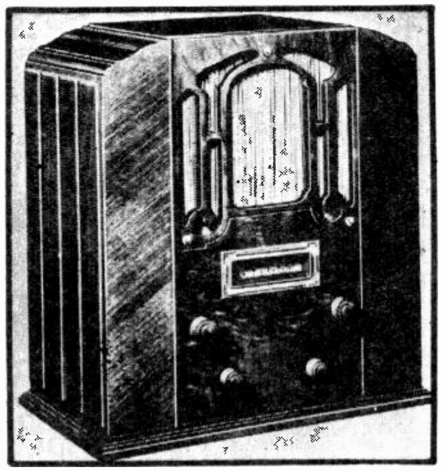

FIG. 10
Table Model "All-Wave" Receiver.

IN THIS PARTICULAR RECEIVER, THE BAND SWITCHING ARRANGEMENT IS MECHANICALLY CONNECTED TO AND CONTROLS THE MULTI-TUNING SCALE. THIS SCALE ARRANGEMENT CONSISTS OF FOUR ACCURATELY CALIBRATED SCALES MARKED OFF IN MEGACYCLES.

EACH SCALE HAS A DIFFERENT COLOR AND APPEARS BEHIND THE SCALE WINDOW AS THE BAND-SWITCHING CONTROL IS ADJUSTED. THAT IS, IF YOU SET THE BAND-SELECTING SWITCH, A SCALE CALIBRATED FOR THE TUNING RANGE OF THAT BAND AUTOMATICALLY APPEARS BEHIND THE WINDOW. THE 20 TO 8 MEGACYCLE SCALE IS GREEN, THE 9 TO 3 MEGACYCLE SCALE IS RED, THE 4 TO 1.6 MEGACYCLE SCALE IS YELLOW AND THE 1.5 TO .55 MEGACYCLE SCALE IS BLACK. IN OTHER WORDS, THE BLACK SCALE IS FOR THE REGULAR BROADCAST BAND AND THE OTHER THREE SCALES ARE FOR THE VARIOUS SHORT-WAVE BANDS.

THE CIRCUIT DIAGRAM FOR THIS SAME RECEIVER APPEARS IN FIG. 11. BY STUDYING THIS DIAGRAM, YOU WILL IMMEDIATELY NOTE THAT THIS RECEIVER IS BY NO MEANS A "MIDGET" BUT USES SEVEN TUBES, ONE OF WHICH SERVES A THREE-FOLD PURPOSE.

A BAND-PASS CIRCUIT FEEDS INTO THE 58 FIRST DETECTOR SO THAT AMPLE PRE-SELECTION IS OBTAINED ON ALL FOUR WAVE-BANDS. A 56 TUBE IS USED IN THE OSCILLATOR AND A SWITCHING ARRANGEMENT IS ALSO PROVIDED IN THIS CIR-

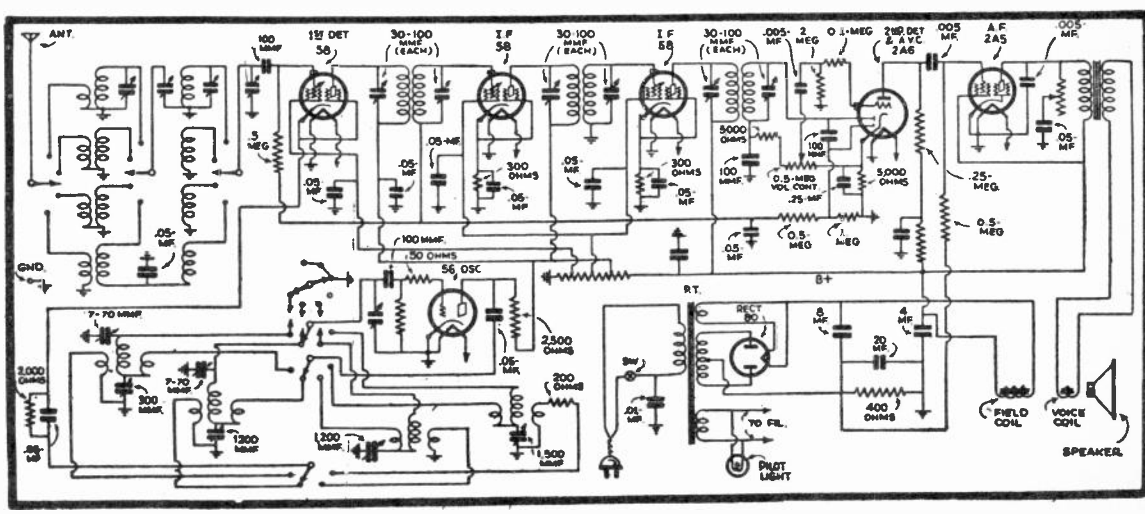

FIG. 11
Circuit Diagram of the Table Model Receiver.

CUIT SO THAT FOUR SETS OF OSCILLATOR COILS ARE AVAILABLE TO COVER THE FOUR WAVE BANDS TOGETHER WITH THE COIL ASSEMBLIES OF THE PRE-SELECTOR CIR CUIT.

NOTICE CAREFULLY THAT THIS ALL-WAVE COIL SET DOES NOT CONSIST OF TAPPED WINDINGS TO PERMIT VARIATIONS IN THE INDUCTANCE VALUE BUT RATHER INDIVIDUAL COILS. IN OTHER WORDS, WHEN CHANGING FROM ONE WAVE BAND TO ANOTHER, AN ENTIRELY DIFFERENT SET OF THREE COILS IS BEING USED. EACH OSCILLATOR COIL HAS ITS INDIVIDUAL TUNED WINDING, FEED- BACK COIL AND COUPLING COIL FOR THE FIRST DETECTOR. IN LIKE MANNER, EACH OF THE INPUT COIL ASSEMBLIES HAS ITS INDIVIDUAL TUNED WINDING TOGETHER WITH ITS CORRESPONDING PRIMARY ETC.

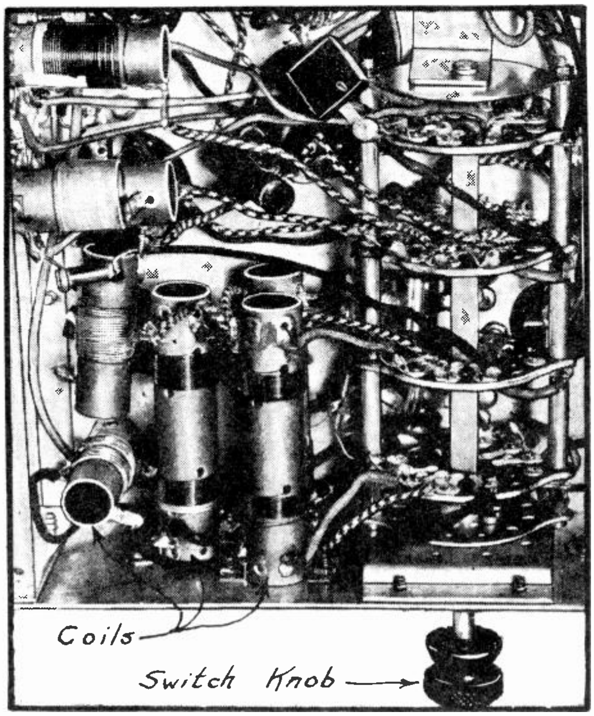

FIG. 12
The Coil Arrangement.

THERE ARE TWO STAGES OF I.F. AMPLIFICATION AND THEY WORK INTO A 2A6 TUBE WHICH FUNCTIONS SIMULTANEOUSLY AS A DIODE DETECTOR, AUTOMATIC VOLUME CONTROL TUBE AND A TRIODE A.F. AMPLIFIER. A 2A5 IS USED IN THE FINAL POWER STAGE AND THE SPEAKER FIELD SERVES AS THE FILTER CHOKE FOR THE "B" SUPPLY OF THE ENTIRE RECEIVER. A TONE CONTROL, CONSISTING OF A 10,000 OHM VARIABLE RESISTANCE UNIT IN SERIES WITH A .05 MFD. CONDENSER, IS CONNECTED BETWEEN GROUND AND THE PLATE TERMINAL OF THE 2A5 POWER TUBE.

FIG. 12 SHOWS YOU A BOTTOM VIEW OF A PORTION OF THIS SAME RECEIVER'S CHASSIS SO THAT YOU CAN SEE HOW THE SELECTOR SWITCH AND THE VARIOUS COILS ARE ALL MOUNTED.

SPECIAL ALL-WAVE ANTENNAS

AS YOU WILL RECALL FROM YOUR STUDIES OF SHORT-WAVE RECEIVERS, SPECIAL ANTENNA SYSTEMS WITH DUAL TRANSPOSED LEAD-IN WIRES ARE PREFERABLE FOR SHORT WAVE RECEPTION. THIS ALSO APPLIES TO SHORT-WAVE RECEPTION WHEN USING AN ALL-WAVE RECEIVER.

SOME FANS USE TWO INDEPENDENT ANTENNA SYSTEMS WITH THEIR ALL-WAVE RECEIVERS, A STANDARD INVERTED "L" TYPE FOR BROADCAST RECEPTION AND THE SPECIAL SHORT-WAVE OR DOUBLET TYPE ANTENNA FOR SHORT WAVE RECEPTION.

SEVERAL MANUFACTURING CONCERNS ARE NOW OFFERING SPECIALLY DESIGNED ANTENNAS IN KIT FORM WHICH WILL OFFER MAXIMUM PERFORMANCE ON BOTH THE BROADCAST AND SHORT-WAVE BANDS WITH A SINGLE ANTENNA SYSTEM. IN ANOTHER PORTION OF YOUR COURSE YOU ARE GIVEN MORE DETAILED INSTRUCTION REGARDING THESE NEWER ANTENNA SYSTEMS. YOU WILL ALSO RECEIVE ADDITIONAL INSTRUCTION

REGARDING ALL-WAVE RECEIVERS IN LATER LESSONS.

YOU WILL FIND CONSIDERABLE VARIATIONS IN THE DESIGN OF MODERN COMMERCIAL ALL-WAVE RECEIVERS. SOME, FOR INSTANCE, USE AN ARRANGEMENT AS THAT ILLUSTRATED IN FIG. 11, WHERE A SINGLE OSCILLATOR TUBE, TOGETHER WITH THE FIRST DETECTOR, COVER THE BROADCAST, AS WELL AS ALL SHORT-WAVE BANDS. ON THE OTHER HAND, SOME OF THE MODERN ALL-WAVE RECEIVERS EMPLOY THE "DOUBLE-SUPERHETERODYNE" PRINCIPLE SIMILAR TO THAT DESCRIBED WITH RESPECT TO FIG. 3 OF THIS LESSON, ONLY THAT A MORE MODERN SET-UP WITH LATER TYPE TUBES IS USED. REGARDLESS OF THE SYSTEM EMPLOYED, YOU WILL FIND THE BASIC PRINCIPLES OF OPERATION TO BE COVERED IN THIS LESSON.

FOR A LONG TIME, ONLY THOSE WHO WERE INTERESTED IN RADIO FROM A TECHNICAL STANDPOINT, SUCH AS ENGINEERS, EXPERIMENTERS, AMATEURS, ETC., ENJOYED THE THRILL OF SHORT-WAVE RECEPTION. THIS COMPARATIVELY NEW FIELD OF RADIO ENTERTAINMENT WAS NOT AT THAT TIME BROUGHT TO THE ATTENTION OF THE GENERAL RADIO LISTENERS FORCEFULLY ENOUGH TO CAPTURE THEIR INTEREST.

CONTINUALLY RADIO RECEIVER MANUFACTURERS ARE INCORPORATING NEW FEATURES IN THEIR LATEST MODELS SO AS TO STIMULATE SALES. THIS HAS BEEN ACCOMPLISHED WITH SUCH THINGS AS NEWER TUBE TYPES, AUTOMATIC VOLUME CONTROL, TONE CONTROL, VISUAL TUNING, ETC., AND FINALLY SHORT-WAVE RECEPTION, TOGETHER WITH STANDARD BROADCAST RECEPTION.

WITH THE INTRODUCTION OF THE ALL-WAVE RECEIVER TO THE RADIO MARKET, A NEW INTEREST WAS CREATED IN SHORT-WAVE AND THE ARMY OF LONG-DISTANCE LISTENERS VIA SHORT-WAVE HAS INCREASED BY THE THOUSANDS, AND WITH THE COMING YEARS AND STILL NEWER DEVELOPMENTS, SHORT-WAVE RECEPTION WILL WITHOUT A DOUBT BECOME TREMENDOUSLY POPULAR.

CONDITIONS BEING SUCH, YOU CAN READILY SEE THAT THE MODERN RADIO TECHNICIAN MUST BE THOROUGHLY INFORMED OF THE TECHNICALITIES CONCERNING SHORT-WAVE COMMUNICATION AND IT IS FOR THIS REASON THAT NATIONAL INCLUDES SUCH COMPLETE INSTRUCTIONS IN THIS PARTICULAR FIELD. WE FEEL CERTAIN THAT YOU APPRECIATE NATIONAL'S EFFORT IN OFFERING OUR STUDENTS THE MOST COMPLETE AND MODERN INSTRUCTION POSSIBLE -- SO THAT THEIR SUCCESS IN THE INDUSTRY MAY BE ASSURED.

FOR THE PRESENT, WE ARE GOING TO LEAVE THE SUBJECT OF RECEIVERS FOR A WHILE AND IN THE FOLLOWING FEW LESSONS DIRECT YOUR ATTENTION TO THE CONSTRUCTION AND DESIGN OF VARIOUS TYPES OF RADIO TESTING EQUIPMENT, SUCH AS MULTI-RANGE VOLTMETERS, MILLIAMMETERS, ANALYZERS, TUBE CHECKERS, OHMMETERS, ETC. YOU ARE GOING TO FIND THIS INFORMATION OF GREAT VALUE AND ESPECIALLY INTERESTING.

EXAMINATION QUESTIONS

LESSON NO. 48

1. - IS IT POSSIBLE FOR SHORT-WAVE, AS WELL AS STANDARD BROADCAST RECEPTION, TO BE OBTAINED WITH A RECEIVER OPERATING UPON THE STRAIGHT T.R.F. PRINCIPLE?

2. - WHAT PROVISIONS ARE GENERALLY MADE SO THAT THE ALL-WAVE RECEIVER IS ENABLED TO COVER VARIOUS FREQUENCY BANDS?

3. - DESCRIBE A TYPICAL BAND-SELECTOR SWITCH AS USED IN ALL-WAVE RECEIVERS.

4. - DESCRIBE THE OPERATION OF THE RECEIVER, WHOSE CIRCUIT DIAGRAM APPEARS IN FIG. 3 OF THIS LESSON, FOR BROADCAST RECEPTION ONLY.

5. - DESCRIBE THE OPERATION OF THIS SAME RECEIVER FOR SHORT-WAVE RECEPTION.

6. - IF THE RECEIVER OF FIG. 3 IS RECEIVING A SHORT-WAVE PROGRAM FROM A TRANSMITTER OPERATING AT A FREQUENCY OF 20,000 KC., AND THE FIRST DETECTOR CIRCUIT IS TUNED TO A FREQUENCY OF 650 KC., THEN TO WHAT FREQUENCY WILL THE SHORT-WAVE OSCILLATOR OF THIS RECEIVER BE TUNED?

7. - UNDER THE SAME CONDITIONS AS OUTLINED IN QUESTION #6 OF THIS EXAMINATION, TO WHAT FREQUENCY WILL THE BROADCAST OSCILLATOR BE TUNED WHILE LISTENING TO THIS SHORT-WAVE STATION WHICH IS TRANSMITTING AT 20,000 KC.?

8. - WHAT IS AN "AUTODYNE OSCILLATOR"?

9. - DESCRIBE A MODERN ALL-WAVE RECEIVER CIRCUIT WHICH DOES NOT OPERATE UPON THE SHORT-WAVE CONVERTER PRINCIPLE DURING SHORT-WAVE RECEPTION?

10. - IS THE ORDINARY TYPE OF ANTENNA CONSIDERED AS BEING ENTIRELY SATISFACTORY FOR AN ALL-WAVE RECEIVER?

RADIO - TELEVISION

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LESSON NO. 49

METERS AS USED IN RADIO

We have made use of various types of meters and other electrical testing equipment so far in the course and you have no doubt by this time become impressed with the fact that testing instruments play a very important role in modern Radio practice. Your only contact with meters etc. up to this time however, has been chiefly relative to their use rather than with their internal construction and operating principles. In this lesson, we are going to go into greater detail concerning such testing apparatus.

No doubt, the simplest way to demonstrate the fundamental principle of meter operation is by means of a rather crude galvanometer, which can be built by yourself for experimental purpose.

THE SIMPLE GALVANOMETER

This homemade galvanometer is shown in Fig.2 and in this case, several turns of small size wire are wrapped around a pocket compass. Now the compass needle has a natural tendency to point in a north and south direction, due to the effect of the earth's magnetic lines of force upon it. Should we connect the winding of this simple galvanometer in series with a rheostat and a battery as shown in Fig.2, then a certain amount of battery current will flow through the winding.

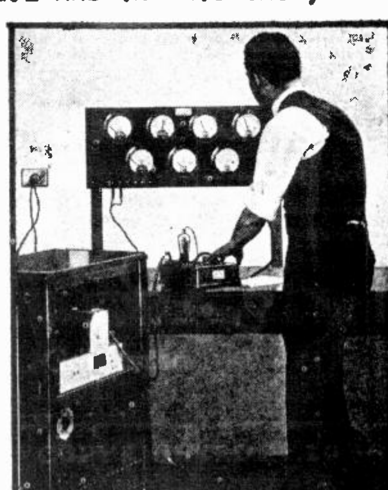

FIG.1

Accurate Testing is Essential in Radio.

This flow of battery current through the winding will produce a magnetic field around the compass, which will exert its influence upon the needle in such a way, so as to cause the needle to alter its position. Then by regulating the amount of resistance in this circuit, the current flow will respond accordingly and will thus vary the amount of motion of the magnetized needle. Should the battery connections now

BE REVERSED, SO THAT THE CURRENT WILL FLOW THROUGH THE WINDING IN AN OPPOSITE DIRECTION, THEN THE MAGNETIC LINES OF FORCE SET UP AROUND THE COIL WILL ALSO BE REVERSED, THEREBY CAUSING THE NEEDLE TO SWING IN THE OPPOSITE DIRECTION.

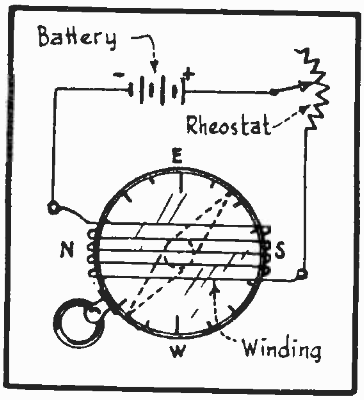

FIG.2
A Simple Galvanometer.

WHEN WINDING THE COIL FOR SUCH A GALVANOMETER, IT IS ADVISABLE TO WIND THE COIL PARALLEL TO THE MAGNETIZED NEEDLE, WHEN THE NEEDLE IS AT REST AND IN ITS NORMAL POSITION. IN THIS WAY, THE MAGNETIC FIELD, PRODUCED BY THE CURRENT FLOW THROUGH THE WINDING, WILL ACT AT RIGHT ANGLES TO THE EARTH'S MAGNETIC FIELD AND THUS PROVIDE A BETTER POISED INSTRUMENT. THEN TOO, BY INCREASING THE NUMBER OF TURNS ON THE WINDING, THE ARRANGEMENT WILL BE MADE MORE SENSITIVE.

SO YOU SEE, EVEN A SIMPLE GALVANOMETER AS THIS WILL INDICATE THE PRESENCE OF AN ELECTRIC CURRENT AND NOT ONLY THIS, BUT IT WILL ALSO INDICATE THE DIRECTION IN WHICH THE CURRENT IS FLOWING. WITH THIS BASIC PRINCIPLE IN MIND, LET US NOW CONTINUE WITH A STUDY OF METERS, SUCH AS ARE USED IN EVERYDAY RADIO AND ELECTRICAL PRACTICE.

THE "PLUNGER-TYPE" AMMETER

THE INTERNAL CONSTRUCTION OF A "PLUNGER-TYPE" AMMETER IS SHOWN IN FIG. 3. IN THIS CASE, AN INDICATING NEEDLE IS PIVOTED AT ITS UPPER END, SO THAT ITS LOWER END IS FREE TO SWING ACROSS A CALIBRATED DIAL OR SCALE. A SOFT IRON PLUNGER OR ARM IS FASTENED TO THE INDICATING NEEDLE AND ONE END OF THIS PLUNGER IS SURROUNDED BY A COIL OF WIRE, WHOSE DIAMETER IS LARGE ENOUGH TO PERMIT THE PLUNGER TO PASS UP THROUGH THE CENTER OF THE COIL WITHOUT TOUCHING IT.

THE INSTRUMENT IS SO BALANCED THAT THE INDICATING NEEDLE NORMALLY RESTS OVER THE ZERO MARK OF THE SCALE. NOW IF THE METER TERMINALS ARE CONNECTED IN SERIES WITH A CIRCUIT, WHICH IS CARRYING A DIRECT CURRENT, THEN THIS CURRENT WILL FLOW INTO ONE METER TERMINAL, THROUGH THE METER COIL AND THENCE TO THE OTHER METER TERMINAL AND BACK TO THE CIRCUIT. THIS SAME CURRENT, WHILE FLOWING THROUGH THE METER COIL, WILL CAUSE A MAGNETIC FIELD TO BUILD UP AROUND THE COIL, WHICH WILL PULL THE IRON PLUNGER UP INTO THE CENTER OF THE COIL. WE CALL THIS, "SOLENOID ACTION" AND THE METER COIL AND IRON PLUNGER IN THIS CASE CONSTITUTE A SOLENOID.

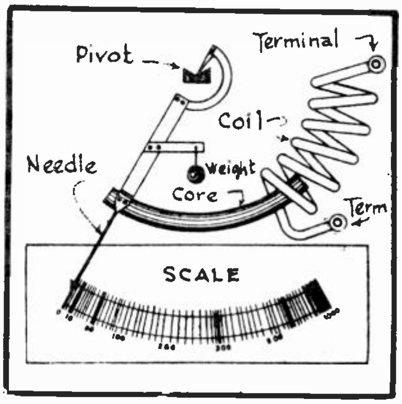

FIG.3
The "Plunger Type" Ammeter.

SINCE THE PLUNGER IN FIG. 3 IS NOW BEING PULLED TOWARD THE RIGHT, IT PULLS THE PIVOTED NEEDLE WITH IT, THUS CAUSING THE INDICATOR TO SWING ACROSS THE SCALE. THE GREATER THE CURRENT FLOW THROUGH THE METER COIL, THE GREATER WILL BE THE DEFLECTION OF THE INDICATING NEEDLE AND SINCE THE MOVEMENT OF THE NEEDLE VARIES WITH THE CURRENT FLOW, IT IS OBVIOUS THAT

BY PROPERLY CALIBRATING THE SCALE, A MEANS IS PROVIDED WHEREBY THE CURRENT FLOW THROUGH THE METER COIL CAN BE MEASURED.

THE SMALL WEIGHT WHICH IS CONNECTED TO THE INDICATING NEEDLE ACTS AS A COUNTERWEIGHT AND IN THIS WAY AIDS IN CONTROLLING THE ACTION OF THE PLUNGER.

THE "MAGNETIC VANE" TYPE METER

IN FIG. 4, YOU WILL SEE AN AMMETER OF THE "MAGNETIC VANE" TYPE, WHICH IS ALSO KNOWN AS THE "POLARIZED VANE" TYPE. METERS AS THIS ARE QUITE COMMON AND THEY ARE GENERALLY USED FOR PORTABLE PURPOSES, WHERE LABORATORY ACCURACY IS NOT REQUIRED. THIS IS THE SAME TYPE METER, WHICH IS MOUNTED ON THE INSTRUMENT PANEL OF MOST AUTOMOBILES AND IT IS AN INEXPENSIVE TYPE METER.

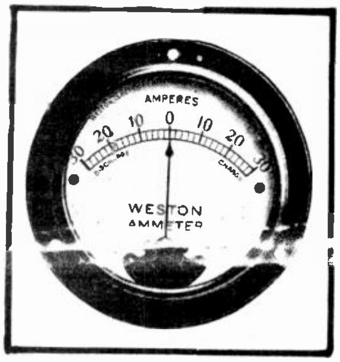

FIG. 4
The Magnetic Vane Type Ammeter.

THE INTERNAL CONSTRUCTION OF THE MAGNETIC VANE TYPE AMMETER IS SHOWN IN FIG. 5. HERE A PIECE OF SOFT IRON (THE VANE) IS MOUNTED ON A PIVOT BETWEEN THE POLES OF A HORSESHOE MAGNET, WHICH IS A PERMANENT MAGNET. THE VANE TENDS TO REST IN A HORIZONTAL POSITION OR TO STAY IN LINE WITH THE POLES OF THE PERMANENT MAGNET, SO AS TO ACT AS A PATH FOR THE LINES OF FORCE GOING FROM THE NORTH POLE OVER TO THE SOUTH POLE. THE NEEDLE AT THIS TIME POINTS TO ZERO ON THE SCALE.

A COIL OF HEAVY COPPER WIRE SURROUNDS THE METER NEEDLE AT A POINT SLIGHTLY ABOVE THE VANE. THIS COIL IS QUITE LARGE IN DIAMETER SO AS NOT TO INTERFERE WITH THE MOTION OF THE NEEDLE. THE METER TERMINALS ARE CONNECTED TO THE ENDS OF THIS COIL AND BY CONNECTING THESE METER TERMINALS IN SERIES WITH A D.C. CIRCUIT, CURRENT WILL FLOW THROUGH THE METER COIL.

LET US ASSUME THAT THE DIRECTION OF CURRENT FLOW THROUGH THE METER COIL IS SUCH AS TO PRODUCE A NORTH POLE AT THE LOWER END OF THE COIL. THIS BEING THE CASE, THE TOTAL NORTH POLE EFFECT WILL THEN BE DIVIDED AND WILL NO LONGER BE STRAIGHT TO THE RIGHT OF THE VANE BUT SLIGHTLY ABOVE IT. THIS SLIGHT UPWARD SHIFT IN THE TOTAL OR EFFECTIVE NORTH POLE WILL CAUSE THE PIVOTED VANE TO TURN COUNTER CLOCKWISE BY A DEFINITE AMOUNT BECAUSE IT ALWAYS TENDS TO ALIGN ITSELF BETWEEN THE NORTH AND SOUTH POLES. THIS CHANGE IN THE VANE'S POSITION WILL CAUSE THE INDICATING NEEDLE TO SWING ACROSS THE DIAL TOWARD THE LEFT OR "DISCHARGE" SIDE OF THE SCALE. THE GREATER THE CURRENT FLOW THROUGH THE COIL, THE GREATER WILL BE THE EFFECT UPON THE MAGNETIC FIELD AND THE GREATER WILL BE THE DEFLECTION OF THE NEEDLE.

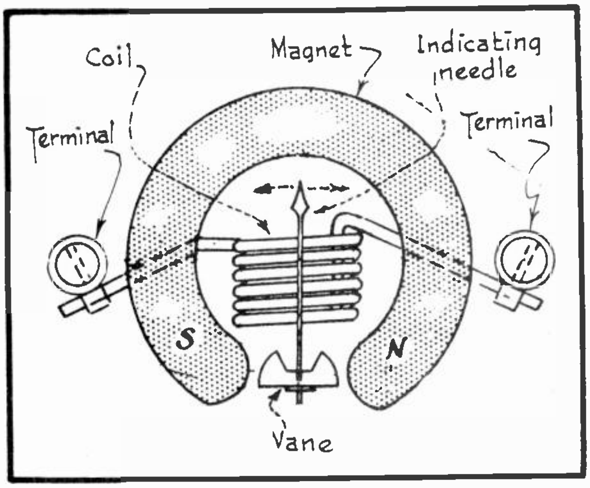

FIG. 5
Contruction of the Vane Type Ammeter.

SHOULD THE CURRENT BE SENT THROUGH THE COIL OF FIG. 5 IN THE OPPOSITE DIRECTION, THEN THE LOWER

END OF THE COIL WILL BECOME A SOUTH POLE, THEREBY CAUSING THE TOTAL OR EFFECTIVE SOUTH POLE TO SHIFT SLIGHTLY TOWARD THE UPPER LEFT OF THE VANE AND THIS WILL SWING THE VANE ABOUT ITS PIVOT IN A CLOCKWISE DIRECTION, SO THAT THE METER NEEDLE WILL NOW REGISTER ON THE CHARGE SIDE OF THE SCALE. THIS METER IS ONLY SUITABLE FOR USE WHEN TESTING IN A D.C. CIRCUIT.

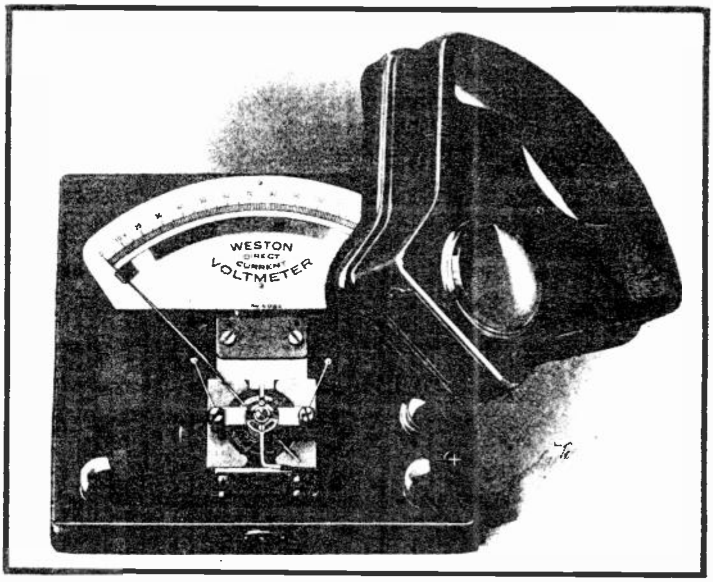

FIG. 6

The Moving Coil Type Meter.

THE "MOVING-COIL" TYPE METER

A MOVING COIL OR D'ARSONVAL TYPE D.C. VOLTMETER IS SHOWN YOU IN FIG. 6, WITH ITS COVER REMOVED, SO THAT YOU MAY CLEARLY SEE ITS INTERNAL WORKING PARTS. METERS OF THE MOVING COIL TYPE ARE THE MOST ACCURATE OF ALL THOSE SHOWN YOU SO FAR AND IT IS THE TYPE USED IN MAKING PRECISE MEASUREMENTS. IN FIG. 7, YOU WILL SEE THE PRINCIPLES OF CONSTRUCTION OF THIS TYPE OF METER. THIS METER IS REALLY NOTHING MORE THAN A SMALL ELECTRIC MOTOR, ONLY THAT ITS ARMATURE IS PREVENTED FROM COMPLETING A FULL REVOLUTION.

NOTICE IN FIG. 7 THAT WE HAVE A PERMANENT MAGNET OF THE HORSESHOE TYPE AND THAT A COIL OF WIRE IS MECHANICALLY SUPPORTED IN JEWELLED BEARINGS SO THAT IT IS FREE TO TURN BETWEEN THE POLE PIECES OF THE MAGNET—THE WINDING ASSEMBLY THUS BECOMING A SMALL MOTOR ARMATURE. THE LOWER END OF THE INDICATING NEEDLE IS FASTENED TO THE ARMATURE AND A LIGHT SPRING AT EACH END OF THE ARMATURE NORMALLY HOLDS THE ARMATURE IN THE POSITION AT WHICH THE NEEDLE POINTS TO ZERO ON THE SCALE. VERY OFTEN, THESE SPRINGS SERVE AS ELECTRICAL CONDUCTORS BETWEEN THE METER TERMINALS AND THE METER COIL.

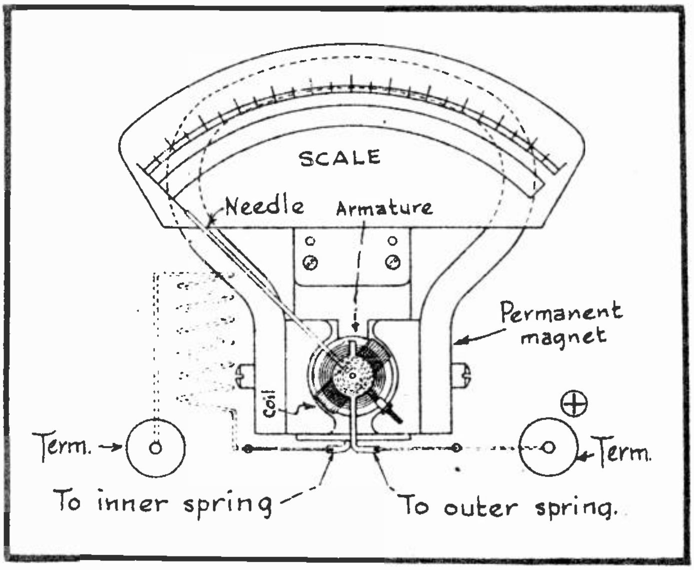

FIG. 7

Construction of the Moving Coil Meter.

THE OPERATING PRINCIPLE OF THIS EXTENSIVELY USED METER IS ILLUSTRATED SOMEWHAT CLEARER IN FIGS. 8 AND 9.

IN FIG. 8 THE INSTRU-

MENT IS SHOWN AT REST AND AT WHICH TIME NO CURRENT IS FLOWING THROUGH ITS WINDING. CONDITIONS BEING SUCH, THE MAGNETIC FIELD, AS ESTABLISHED BY THE PERMANENT MAGNET, WILL FLOW HORIZONTALY FROM LEFT TO RIGHT AND THE SPRINGS WILL HOLD THE ARMATURE COIL IN THE POSITION AS HERE ILLUSTRATED, SO THAT THE INDICATING NEEDLE WILL POINT TO THE ZERO MARK OF THE SCALE.

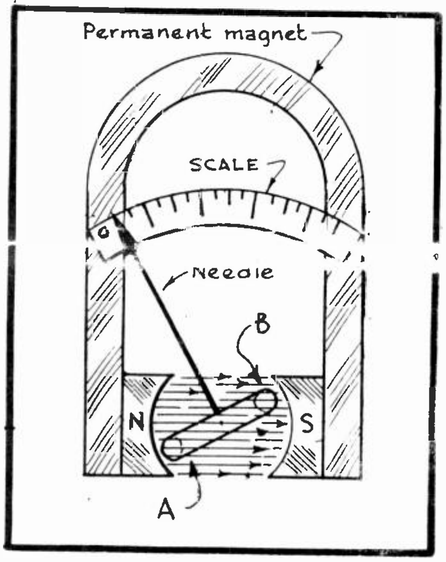

FIG. 8
The Meter at Rest.

NOW THEN, IF THE TERMINALS OF THIS METER ARE CONNECTED TO AN ELECTRICAL CIRCUIT SO THAT CURRENT THEREFROM FLOWS IN ON SIDE "B" OF THE ARMATURE WINDING AND OUT ON SIDE "A" OF THIS SAME WINDING, WE FIND THAT LINES OF FORCE WILL BE ESTABLISHED AROUND THIS WINDING. THESE LINES OF FORCE WILL ENCIRCLE SIDE "A" IN A COUNTER-CLOCKWISE DIRECTION AND SIDE "B" IN A CLOCKWISE DIRECTION.

THESE ENCIRCLING FIELDS WILL REACT WITH THE MAIN MAGNETIC FIELD IN SUCH A MANNER THAT THE LINES OF FORCE OF THE ENCIRCLING FIELD WILL OPPOSE THOSE OF THE MAIN FIELD AT THE REGION BELOW SIDE "B" OF THE ARMATURE, RESULTING IN A WEAKENING OF THE COMBINED FIELD AT THIS POINT. AT THE SAME TIME, WE FIND THAT AT THE UPPER SIDE OF "B", THE ENCIRCLING LINES OF FORCE ACT IN THE SAME DIRECTION WITH THOSE OF THE MAIN FIELD AND THEREFORE CAUSE A STRENGTHENING OF THE COMBINED FIELD AT THIS POINT. THIS IS ILLUSTRATED IN FIG. 9.

IN LIKE MANNER, THE COMBINED FIELD AT THE UPPER REGION OF SIDE "A" IS WEAKENED WHILE THE LOWER REGION OF SIDE "A" IS STRENGTHENED. THERE IS A NATURAL TENDENCY FOR THE WINDING TO BE FORCED FROM THE STRONGER REGIONS OF THE MAGNETIC FIELD INTO THE WEAKER REGIONS AND FOR THIS REASON, THE ARMATURE ROTATES ABOUT ITS AXIS IN A CLOCKWISE DIRECTION AS SHOWN IN FIG. 9.

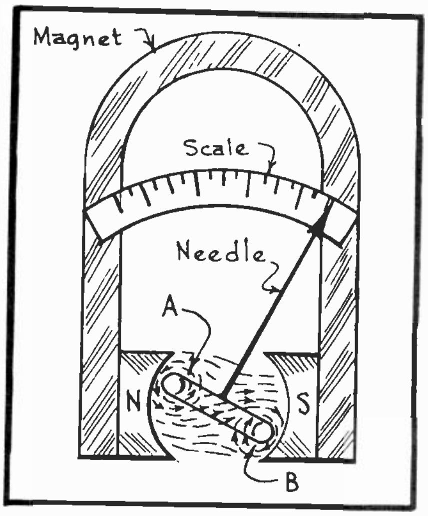

FIG. 9
Full-scale Deflection.

THIS MOTION OF THE METER COIL WILL CAUSE THE INDICATING NEEDLE TO SWING ACROSS THE SCALE TOWARDS THE RIGHT AND THIS NEEDLE DEFLECTION WILL BE PROPORTIONAL TO THE AMOUNT OF MOVEMENT OF THE COIL, WHICH IN TURN DEPENDS UPON THE QUANTITY OF CURRENT FLOWING THROUGH IT OR TO THE VOLTAGE IMPRESSED ACROSS IT. THE INSTANT THAT CURRENT FLOW THROUGH THE COIL IS INTERRUPTED, THE SPRINGS WILL RESTORE THE NEEDLE TO ITS ZERO READING. THIS TYPE OF METER IS ONLY SUITABLE FOR USE ON D.C. CIRCUITS.

THE MOVING COIL, TOGETHER WITH ITS SPRINGS AND INDICATING NEEDLE, ARE SHOWN YOU IN FIG. 10. IN THIS SAME ILLUSTRATION YOU ARE SHOWN ANOTHER POINT OF INTEREST, NAMELY THE USE OF A SOFT IRON CORE WHICH IS CEN-

TRALLY LOCATED BETWEEN THE POLE PIECES OF THE PERMANENT MAGNET AND AROUND WHICH THE MOVING COIL OSCILLATES.

THE OBJECT FOR USING THIS IRON CORE IS TO PROVIDE AN EASY PATH FOR THE PERMANENT MAGNET'S LINES OF FORCE BETWEEN THE POLE PIECES AND WHICH AT THE SAME TIME AIDS TO PREVENT LOSS OF MAGNETISM.

WITH THE CORE CENTRALLY LOCATED AS PICTURED AT THE LOWER LEFT OF FIG. 10, ONLY A SMALL AIR GAP IS ALLOWED BETWEEN THE CORE AND THE POLE PIECES AND THROUGH WHICH THE COIL IS FREE TO MOVE WITHOUT TOUCHING EITHER THE CORE OR THE POLE PIECES.

THE DIFFERENCE BETWEEN A VOLTMETER AND AN AMMETER

NO DOUBT, YOU ARE NOW BEGINNING TO WONDER AS TO WHAT THE DIFFERENCE REALLY IS BETWEEN A VOLTMETER AND AN AMMETER. THE OPERATING PRINCIPLES OF BOTH THESE INSTRUMENTS ARE FUNDAMENTALLY THE SAME AND IF YOU ARE FAMILIAR WITH THE OPERATION OF ONE, YOU ARE ALSO FAMILIAR WITH THE OPERATION OF THE OTHER. THE MAIN DIFFERENCE BETWEEN A VOLTMETER AND AN AMMETER IS THAT THE WINDING WITHIN THE AMMETER IS OF LOW RESISTANCE. THAT IS, THE WIRE USED FOR THIS PURPOSE IS LARGE IN SIZE AND CONSISTS OF BUT A FEW TURNS, THEREBY PERMITTING THE PASSAGE OF CONSIDERABLE CURRENT. IN THIS WAY, THE AMMETER OFFERS COMPARATIVELY LOW RESISTANCE TO THE CIRCUIT WITH WHICH IT IS CONNECTED IN SERIES WHILE TAKING A READING.

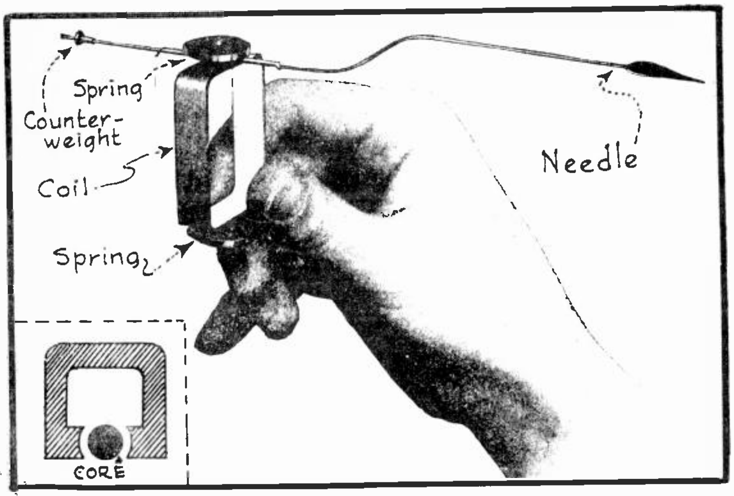

FIG. 10
Constructional Details of the Moving Coil.

THE VOLTMETER, ON THE OTHER HAND, HAS A HIGH INTERNAL RESISTANCE BECAUSE ITS WINDING IS MADE UP OF A GREAT MANY TURNS OF VERY SMALL WIRE. THIS BEING THE CASE, IT IS OBVIOUS THAT WHEN A VOLTMETER IS CONNECTED ACROSS A CIRCUIT FOR MEASURING PURPOSES, IT DRAWS BUT VERY LITTLE CURRENT FROM THE CIRCUIT, IN ORDER TO ACTUATE THE NEEDLE. IN FACT, THE HIGHER THE INTERNAL RESISTANCE OF THE VOLTMETER, THE GREATER WILL BE ITS DEGREE OF ACCURRACY AND HIGH GRADE D.C. VOLTMETERS FOR RADIO PURPOSES GENERALLY HAVE AN INTERNAL RESISTANCE OF ABOUT 1000 OHMS PER VOLT, WHICH MEANS THAT A METER WITH A 250 VOLT SCALE HAS AN INTERNAL RESISTANCE OF 250,000 OHMS.

THE OTHER BIG DIFFERENCE BETWEEN A VOLTMETER AND AN AMMETER IS OF COURSE THE FACT THAT THE SCALE OF THE VOLTMETER HAS BEEN CALIBRATED TO READ VOLTAGE, WHILE THE SCALE OF THE AMMETER HAS BEEN CALIBRATED TO READ THE AMPERAGE.

IT IS NOW THE PRACTICE TO CONSTRUCT THE MOVEMENT OF HIGH GRADE D.C.

voltmeters exactly the same as used in milliammeters. That is, the moving coil in both cases actually contains only a few ohms of resistance and is so sensitive that a current flow of one milliampere or less flowing through it is sufficient to cause the indicating needle to swing across the entire scale. Then to use this instrument as a voltmeter, it is only necessary to add sufficient resistance in series with the moving coil so that only a small current will flow through the coil even when the meter terminals are connected across a source of high voltage. Such resistance units are mounted inside of the meter case.

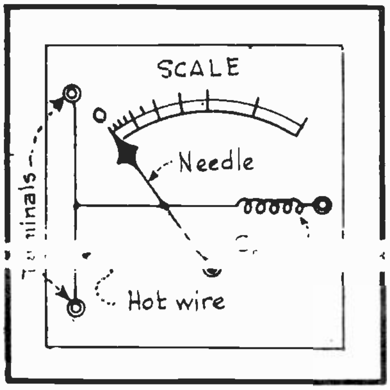

FIG. 11.
Principle of the Hot-wire Ammeter.

In like manner, many ammeters are in reallity milliammeters calibrated in "amperes" but the moving coil receives only a small fraction of the current being measured. This is accomplished through bypassing a definite portion of the total current around the moving coil through a SHUNT.

All of these details will appear clearer to you as you continue with this lesson. However, before going into this work let us first study the hot-wire type meters.

THE "HOT-WIRE" METER

When dealing with alternating currents, whose frequency is very high, such as the electrical oscillations occurring at radio frequencies, then we must depart from the magnetic principles in meter construction. That is, for taking measurements in high frequency circuits, it is better to use some meter operating principle which does not depend upon magnetic action to actuate the needle. Most meters for high frequency use therefore depend upon the HEATING effect of an electric current flowing through a conductor and we generally classify meters as this as being of the "thermo" type.

In Fig. 11 you are shown the basic constructional features of an ammeter, which can be used for taking measurements in circuits operating at radio frequencies. The meter here shown can also be classified as a "hot wire" ammeter. In this case, a special wire, which is made of non-oxidizable metal, having a low temperature coefficient, is connected across the two meter terminals inside of the meter body. The tension of this heating wire and the tension of the spring are so balanced with eachother that the meter needle normally lines up with the zero mark on the scale.

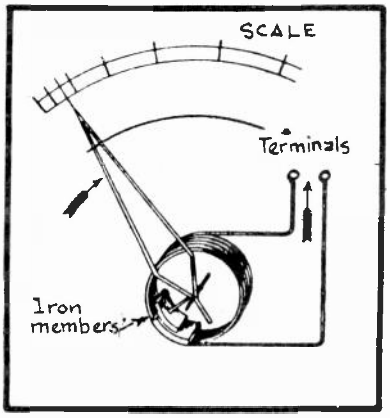

FIG. 12
The A.C. Voltmeter.

Now if the terminals of this ammeter are properly connected into a circuit carrying high frequency currents, the heating wire will be connected in SERIES with this circuit, so that all of these high frequency currents must flow thru

IT. IT IS A WELL KNOWN FACT THAT CURRENT FLOW THROUGH A CONDUCTOR PRODUCES HEAT AND THIS HEATING EFFECT IS PROPORTIONAL TO THE SQUARE OF THE CURRENT AND TO THE RESISTANCE OFFERED BY THE CONDUCTOR.

THE HEAT PRODUCED BY THE FLOW OF THE HIGH FREQUENCY CURRENTS THRU THE HEATING WIRE, CAUSES THE WIRE TO EXPAND OR BECOME LONGER AND IN DOING SO, ADDITIONAL SLACK IS INTRODUCED INTO IT AND THIS WILL PERMIT THE SPRING TO PULL THE INDICATING NEEDLE TOWARD THE RIGHT, THUS INDICATING THIS CURRENT FLOW ON A PROPERLY CALIBRATED SCALE. THIS DEFLECTION OF THE NEEDLE WILL INCREASE WITH AN INCREASE IN CURRENT FLOW, DUE TO THE ADDITIONAL SLACK, WHICH IS INTRODUCED INTO THE HEATING WIRE.

MOVABLE-IRON A.C. METERS

FOR TAKING MEASUREMENTS IN RADIO CIRCUITS THROUGH WHICH ALTERNATING CURRENTS OF A 50 OR 60 CYCLE FREQUENCY FLOW, THE MOVABLE-IRON TYPE METER IS BEING MOST USED. THE INTERNAL CONSTRUCTION OF SUCH A METER IS ILLUSTRATED IN FIG. 12.

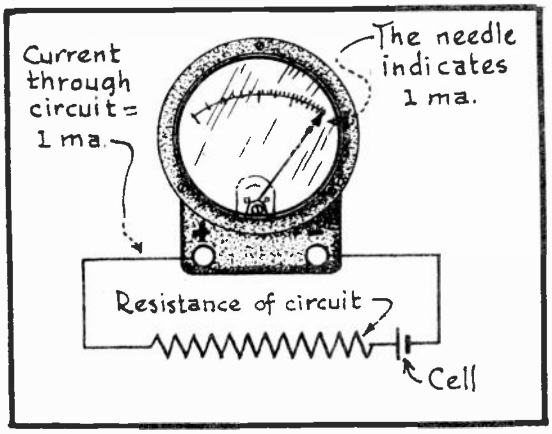

FIG. 13
Milliammeter Reading "Full-scale".

AS YOU WILL OBSERVE, A COIL OF INSULATED WIRE IS LOCATED WITHIN THE HOUSING OF THIS INSTRUMENT AND THE ENDS OF THIS COIL ARE CONNECTED TO THE TERMINALS OF THE METER.

THE INDICATING NEEDLE IS FASTENED TO A SHAFT OR AXIS WHICH IS SUPPORTED IN SAPHIRE JEWEL BEARINGS. A SMALL CURVED PIECE OF IRON, (THE ARMATURE) IS ALSO FASTENED TO THE CENTER SHAFT THROUGH AN ARM AND THIS ARMATURE RESTS DIRECTLY IN FRONT OF ANOTHER SIMILARLY SHAPED PIECE OF IRON WHICH IS ATTACHED TO THE COIL AND WHICH REMAINS STATIONARY.

UPON PASSING CURRENT THROUGH THE COIL, THE TWO PIECES OF IRON BECOME MAGNETIZED, BUT SINCE BOTH PIECES OF IRON ARE LOCATED ON THE SAME SIDE OF THE COIL, THEY WILL HAVE THE SAME POLARITY. THIS MEANS THAT THERE WILL BE A REPELLING FORCE BETWEEN THEM BECAUSE LIKE MAGNETIC POLES REPEL.

THE COIL AND ITS IRON MEMBER ARE FIXED AND THEREFORE THE ARMATURE WILL BE REPELLED AND THEREBY CAUSE THE INDICATING NEEDLE TO ROTATE CLOCKWISE ON ITS AXIS AND THUS SWING THE INDICATING NEEDLE TOWARDS THE RIGHT ACROSS ITS SCALE. AS SOON AS THE CURRENT FLOW STOPS, A SPRING RETURNS THE MOVEMENT TO ITS NORMAL POSITION SO THAT THE NEEDLE COINCIDES WITH THE ZERO MARK OF THE SCALE.

IT REQUIRES BUT LITTLE CURRENT TO OPERATE THIS MECHANISM AND FOR MEASURING HIGHER VOLTAGES IT IS THE PRACTICE TO INCLUDE A RESISTOR IN SERIES WITH THE METER WINDING IN ORDER TO LIMIT THE CURRENT FLOW.

A SMALL AND VERY LIGHT VANE IS ALSO ATTACHED TO THE MOVING PART OF THE INSTRUMENT. THIS VANE MOVES BACK AND FORTH IN A SEALED AIR CHAMBER WHENEVER THE INDICATOR MOVES AND IN THIS WAY OFFERS A CERTAIN AMOUNT OF

RESISTANCE OR DAMPING EFFECT TOWARDS THE MOVEMENT. THIS PERMITS THE NEEDLE TO COME TO A STATIONARY POSITION IMMEDIATELY AFTER ITS INITIAL DEFLECTION.

THIS MOVING-IRON PRINCIPLE CAN BE APPLIED TO EITHER AN AMMETER OR VOLTMETER OF THE A.C. TYPE.

STILL OTHER TYPES OF METERS ARE AVAILABLE TO THE ELECTRICAL INDUSTRY BUT THOSE SHOWN YOU WILL FAMILIARIZE YOU WITH THE OPERATING PRINCIPLES OF THE MOST POPULAR TYPES OF METERS, SUCH AS YOU ARE CALLED UPON TO USE IN YOUR RADIO WORK. THE NEXT STEP THEN, WILL BE TO SHOW YOU THE MANY DIFFERENT WAYS IN WHICH YOU CAN USE METERS. OF COURSE, YOU HAVE BEEN SHOWN TIME AFTER TIME HOW TO CONNECT AMMETERS IN SERIES WITH THE CIRCUIT UNDER TEST AND VOLTMETERS ACROSS THE CIRCUIT UNDER TEST. WE ARE THEREFORE TAKING IT FOR GRANTED THAT YOU HAVE A PERFECT UNDERSTANDING OF THIS SUBJECT AND FOR THIS REASON WILL NOT SPEND THE PRESENT TIME IN REVIEWING PREVIOUS SUBJECT MATTER. IF, HOWEVER, YOU HAVE FORGOTTEN SOME OF THESE IMPORTANT POINTS, IT IS MOST ADVISABLE THAT YOU GLANCE OVER THE EARLIER LESSONS REGARDING METER CONNECTIONS, BEFORE CONTINUING WITH THE STUDY TO FOLLOW.

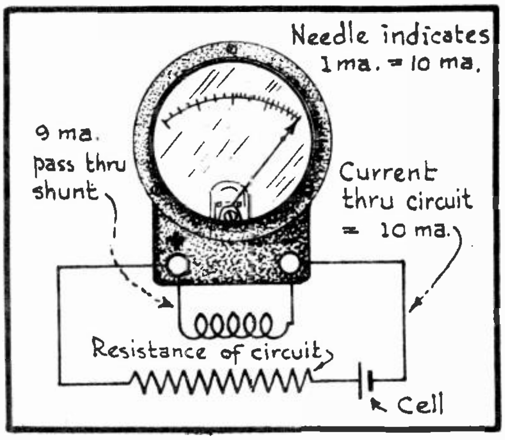

FIG. 14
Measuring 10 Ma. With a Meter of only 1 Ma. Range.

CONDITIONS FREQUENTLY ARISE WHERE THE RADIO EXPERT FINDS IT NECESSARY TO CHANGE THE SCALE OF HIS VOLTMETERS AND AMMETERS, THEREBY MAKING THEM SUITABLE FOR TESTS ON VARIOUS DIFFERENT CIRCUITS. BY PROPERLY ARRANGING THINGS, IT IS POSSIBLE TO USE A SINGLE METER AS A UNIVERSAL METER, THEREBY DOING AWAY WITH THE NEED FOR A WHOLE STRING OF EXPENSIVE METERS.

THE USE OF AMMETER SHUNTS

IN FIG. 13, FOR EXAMPLE, WE HAVE A MILLIAMMETER, WITH A FULL SCALE READING OF 1 MILLIAMPERE, CONNECTED IN A CIRCUIT IN WHICH JUST EXACTLY 1 MILLIAMPERE IS FLOWING. UNDER THESE CONDITIONS, IT IS OBVIOUS THAT 1 MILLIAMPERE WILL FLOW THROUGH THE METER WINDING BECAUSE IT IS CONNECTED IN SERIES WITH THE CIRCUIT AND SINCE THE METER HAS ORIGINALLY BEEN CALIBRATED BY THE MANUFACTURER TO READ 1 MILLIAMPERE WHEN 1 MILLIAMPERE IS FLOWING THROUGH ITS COIL, WE WILL FIND THE METER READING FULL SCALE AT THIS TIME. THAT IS, THE NEEDLE IS AT ITS MAXIMUM POSITION, READING 1 MILLIAMPERE.

SHOULD WE WISH TO USE THIS SAME METER TO MEASURE THE CURRENT FLOW THROUGH A CIRCUIT, WHICH WE KNOW BEFORE-HAND AS CARRYING MORE THAN 1 MILLIAMPERE, THEN WE MUST USE A SHUNT WITH THE METER. IN FIG. 14, FOR EXAMPLE WE HAVE A CIRCUIT, THROUGH WHICH 10 MA. ARE FLOWING, AND IF WE SHOULD SIMPLY CONNECT THE ORIGINAL METER IN SERIES WITH THIS CIRCUIT, THE METER WOULD BE INJURED BECAUSE ITS MAXIMUM RANGE IS ONLY ONE-TENTH OF THAT REQUIRED FOR THIS CIRCUIT.

IT IS, HOWEVER, POSSIBLE TO USE THIS SAME METER IN THE CIRCUIT OF

FIG. 14, PROVIDED THAT WE ONLY PERMIT 1 MILLIAMPERE TO FLOW THROUGH THE METER COIL AND BY-PASS THE BALANCE AROUND THE METER BY MEANS OF A SUITABLE SHUNT. IF 10 MA. ARE FLOWING THROUGH THE CIRCUIT OF FIG. 14 AND WE ARE ONLY ALLOWED TO PASS ONE MA. THROUGH THE METER COIL, THEN IT IS APPARENT THAT 9 MA. MUST BE PASSED BY THE METER SHUNT. THE QUESTION NOW ARISES AS TO THE RESISTANCE VALUE OF THE SHUNT, WHICH SHOULD BE USED IN THIS CASE.

LET US ASSUME THAT THIS METER HAS AN INTERNAL RESISTANCE OF 27 OHMS. SINCE THE SAME POTENTIAL EXISTS ACROSS THE METER AND SHUNT AND THE SHUNT HAS TO CARRY 9 TIMES AS MUCH CURRENT AS THE METER, THEN IT IS PERFECTLY LOGICAL THAT THE RESISTANCE VALUE OF THE SHUNT MUST BE JUST 1/9 OF THE METER'S INTERNAL RESISTANCE OR 3 OHMS (1/9 X 27 OHMS = 3 OHMS).

BY CONNECTING A SHUNT OF THIS SIZE ACROSS THE METER TERMINALS, THE RANGE OF THE METER HAS BEEN INCREASED TO 10 TIMES ITS FORMER VALUE AND THE NEEDLE WILL REGISTER 1 MILLIAMPERE WHEN THERE ARE ACTUALLY 10 MILLIAMPERES FLOWING THROUGH THE CIRCUIT. THIS MEANS THAT ALL THAT IS NECESSARY IS TO MULTIPLY THE METER READING BY 10, IN ORDER TO DETERMINE THE CORRECT VALUE. THAT IS, IF THE METER NOW READS .5 MILLIAMPERES, THERE ARE ACTUALLY 5 MILLIAMPERES FLOWING, A READING OF .25 MA. WOULD NOW BE INTERPRETED AS 2.5 MA. ETC.

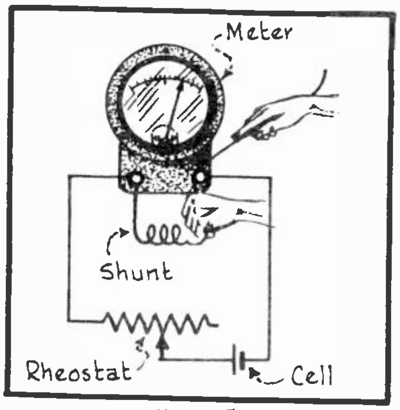

FIG. 15
Making the Shunt.

FOR THE SHUNT, YOU MAY USE ANY KIND OF WIRE, WHOSE RESISTANCE PER UNIT LENGTH IS KNOWN AND WHICH WILL CARRY THE REQUIRED CURRENT WITHOUT HEATING SUFFICIENTLY TO MATERIALLY INCREASE ITS RESISTANCE. MANGANIN AND GERMAN SILVER ARE FREQUENTLY USED FOR THIS PURPOSE AND IT IS ADVISABLE TO WIND THE WIRE SHUNT ON A PORCELAIN TUBE OR SOME OTHER SUITABLE SUBSTANCE.

THE EXPLANATION, AS JUST GIVEN, WILL ENABLE YOU TO CLEARLY SEE JUST EXACTLY HOW A SHUNT WORKS WITH THE METER, IN ORDER TO BRING ABOUT THE REQUIRED RESULTS BUT IN PRACTICE IT IS NOT EVEN NECESSARY TO DO ANY CALCULATING, IN ORDER TO CHANGE THE SCALE OF SUCH A MILLIAMMETER OR EVEN AN AMMETER FOR THAT MATTER.

DETERMINING THE SIZE OF SHUNT IN PRACTICE

THE EASIEST WAY TO CHANGE THE SCALE OF AN AMMETER OR MILLIAMMETER BY MEANS OF SHUNTS IS TO USE THE "CUT AND TRY" METHOD. TO CHANGE THE RANGE OF A MILLIAMMETER FROM 1 MA. TO 10 MA. BY THIS METHOD, YOU WOULD CONNECT THE METER IN SERIES WITH A CELL AND HIGH RESISTANCE RHEOSTAT AS SHOWN IN FIG. 15 AND THEN ADJUST THE RHEOSTAT SO THAT THE ORIGINAL METER READS FULL SCALE OR 1 MILLIAMPERE. THIS DONE, CONNECT A PIECE OF SHUNT WIRE ACROSS THE METER TERMINALS AND ADJUST ITS LENGTH UNTIL THE METER READING IS REDUCED TO .1 MA. THIS THEN IS THE SIZE SHUNT REQUIRED TO INCREASE THE RANGE OF THE METER TO TEN TIMES ITS ORIGINAL VALUE. TO DOUBLE THE RANGE, ADD ENOUGH SHUNT WIRE TO MAKE THE METER READ HALF OF THE FULL SCALE AND MULTIPLY THE READINGS BY TWO ETC.

YOU CAN TAKE ANY SIZE AMMETER YOU CHOOSE AND BY THIS MEANS INCREASE ITS RANGE TO ANY REASONABLE EXTENT. THE METER, WHICH WE HAVE USED AS THE

EXAMPLE IN OUR DISCUSSION, CAN HAVE ITS RANGE INCREASED EVEN TO 100 AND 500 MILLIAMPERES, SIMPLY BY REDUCING THE RESISTANCE OF THE SHUNT TO THE PROPER VALUE. WHEN USING THE 100 MILLIAMPERE SCALE, THE READINGS WILL HAVE TO BE MULTIPLIED BY 100 AND WHEN USING THE 500 MILLIAMPERE SCALE, THE READINGS WILL HAVE TO BE MULTIPLIED BY 500.

BUILDING A MILLIAMMETER WITH 4 RANGES

THE EASIEST WAY TO DETERMINE THE SHUNT FOR THE HIGHER SCALES IS BY MEANS OF THE SYSTEM ILLUSTRATED IN FIG. 16. FOR EXAMPLE, TO PROVIDE A 10-100 AND 500 MILLIAMPERE SCALE ON THE AMMETER, WHOSE MAXIMUM RANGE IS 1 MILLIAMPERE, YOU WOULD FIRST DETERMINE THE SIZE SHUNT TO USE FOR THE 10 MILLIAMPERE SCALE AS ALREADY DESCRIBED. THIS SAME SHUNT FOR THE 10 MILLIAMPERE SCALE CAN ALSO BE USED FOR THE 100 AND 500 MILLIAMPERE SCALES BY TAKING OFF TAPS AT THE PROPER POINTS.

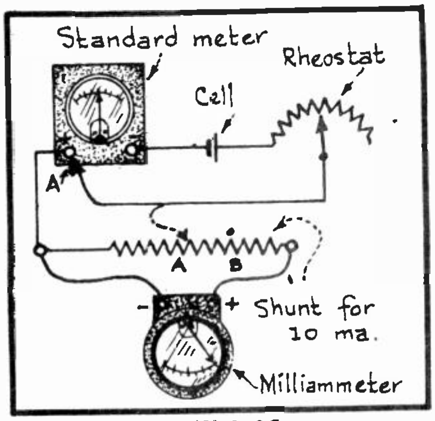

FIG. 16
Calibrating the higher Milliammeter Scales.

TO DETERMINE THE LOCATION OF THESE TAPS, CONNECT THE SHUNT FOR THE 10 MILLIAMPERE SCALE ACROSS THE 0 TO 1 MA. METER, AS SHOWN IN FIG. 16. THEN PROVIDE YOURSELF WITH A MILLIAMMETER, WHICH IS ALREADY CALIBRATED TO TAKE READINGS UP TO 500 MILLIAMPERES, AND USE THIS AS YOUR "STANDARD METER." TO LOCATE THE 500 MILLIAMPERE TAP ON THE 10 MA. SHUNT, CONNECT THE STANDARD METER IN SERIES WITH A CELL AND RHEOSTAT, WITH CONTACT POINT "A" TOUCHING THE (+) SIDE OF THE STANDARD METER.

NOW ADJUST THE RHEOSTAT UNTIL THE STANDARD METER READS JUST EXACTLY 500 MILLIAMPERES. THEN GRADUALLY MOVE CONTACT "A" TOWARDS THE RIGHT ALONG THE 10 MA. SHUNT UNTIL YOU LOCATE THE POINT AT WHICH THE METER TO BE CALIBRATED READS EXACTLY FULL SCALE OR 1 MILLIAMPERE. THE TAP ON THE SHUNT FOR THE 500 MILLIAMPERE SCALE IS TO BE MADE AT THE POINT NOW OCCUPIED BY CONTACT "A".

WITH THE TAP MADE AT THIS POINT, PUT CONTACT "A" BACK ON THE (+) TERMINAL OF YOUR STANDARD METER AND ADJUST THE RHEOSTAT UNTIL THE STANDARD METER READS 100 MILLIAMPERES. AGAIN MOVE YOUR CONTACT POINT ALONG THE 10 MA. SHUNT TOWARDS THE RIGHT UNTIL THE METER TO BE CALIBRATED READS JUST EXACTLY FULL SCALE. YOUR CONTACT POINT WILL NOW BE AT "B" AND THIS IS WHERE THE TAP MUST BE MADE SO THAT YOUR METER WILL READ PROPERLY UP TO 100 MILLIAMPERES. THE FINISHED METER WITH ITS CONNECTIONS FOR THE DIFFERENT SCALES THUS MADE IS SHOWN IN FIG. 17.

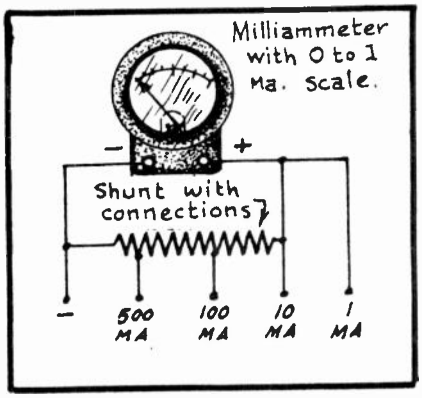

FIG. 17
A Milliammeter With Four Ranges.

BY USING THE (-) AND 1 MA. TERMINALS OF THE METER IN FIG. 17, THE METER WILL READ ON ITS OWN SCALE UP TO A MAXIMUM OF 1 MA. BY USING THE (-) AND 10 MA. TERMINAL, THE READINGS MUST BE MULTIPLIED BY 10 AND THE MAXIMUM READING IN THIS CASE WILL BE 10 MA. THE 100 MA. SCALE IS USED WHEN THE METER CONNECTIONS ARE MADE AT THE (-) AND 100 MA. TERMINALS AND THE READINGS WILL HAVE TO BE MULTIPLIED BY 100 ETC. THIS METER CAN BE MOUNTED ON A SMALL PANEL AND A BOX, WITH THE VARIOUS TERMINALS AND THUS BE MADE TO SERVE VARIOUS PURPOSES.

THE USE OF MULTIPLIERS

THE RANGE OF VOLTMETERS CAN ALSO BE INCREASED AND FOR THIS WE USE MULTIPLIERS. WHILE THE AMMETER SHUNT BY-PASSED THE BULK OF THE CURRENT SO AS TO PREVENT IT FROM FLOWING THROUGH THE METER, THE MULTIPLIER, ON THE OTHER HAND, SERVES AS AN ADDITIONAL RESISTANCE IN SERIES WITH THE CIRCUIT SO AS TO PREVENT TOO MUCH CURRENT FROM FLOWING THROUGH ITS WINDING.

IN FIG. 18, FOR EXAMPLE, WE HAVE DOUBLED THE RANGE OF A VOLTMETER, SO THAT THIS 0 TO 250 VOLT METER CAN READ VOLTAGES UP TO 500 VOLTS. TO DOUBLE THE RANGE OF A VOLTMETER, WE MUST USE A MULTIPLIER, WHOSE RESISTANCE IS THE SAME AS THAT OF THE RESISTANCE WITHIN THE METER. THAT IS, IF THE METER IS RATED AS HAVING AN INTERNAL RESISTANCE OF 1000 OHMS PER VOLT, THEN IF ITS MAXIMUM RANGE IS 250 VOLTS, ITS INTERNAL RESISTANCE WILL BE 250,000 OHMS.

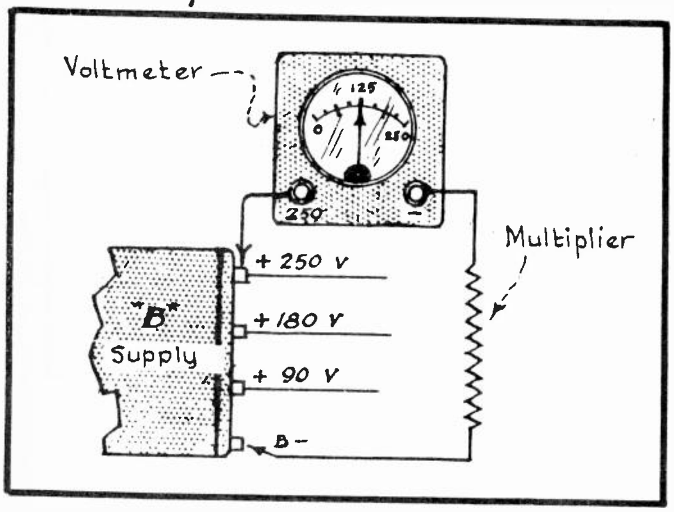

FIG. 18
Using a Multiplier.

BY DOUBLING THE RANGE OF THE VOLTMETER IN THIS WAY, THE NEEDLE WILL JUST READ EXACTLY ONE-HALF THE ACTUAL OR TRUE VALUE. TO PUT IT ANOTHER WAY - WHEN USING THE 250,000 OHM MULTIPLIER IN THIS CASE, WE MUST MULTIPLY THE INDICATED READING BY 2, IN ORDER TO DETERMINE THE ACTUAL OR TRUE VALUE.

SHOULD WE CARE TO INCREASE THE RANGE OF THE VOLTMETER IN FIG. 18 UP TO 750 VOLTS, THEN WE MUST USE A MULTIPLIER HAVING A RESISTANCE OF 500,000 OHMS AND TO INCREASE THE RANGE OF THIS SAME METER UP TO 1000 VOLTS, THE MULTIPLIER TO BE USED MUST HAVE A RESISTANCE OF 750,000 OHMS. THESE MULTIPLIER VALUES ARE FOUND IN THE FOLLOWING WAY: TO DOUBLE THE RANGE OF A VOLTMETER, THE METER RESISTANCE MUST BE DOUBLED. THAT IS, IF THE METER HAS AN INTERNAL RESISTANCE OF 250,000 OHMS, THIS MUST BE INCREASED TO 500,000 OHMS BUT SINCE 250,000 OHMS IS ALREADY PROVIDED INSIDE OF THE METER, AN ADDITIONAL RESISTANCE OF ONLY 250,000 OHMS MUST BE ADDED IN THE FORM OF A MULTIPLIER, SO AS TO BRING THE TOTAL METER RESISTANCE UP TO 500,000 OHMS.

TO TRIPLE THE RANGE OF A VOLTMETER, THE METER RESISTANCE MUST ALSO BE TRIPLED. MEANING THAT IF THE INTERNAL RESISTANCE OF THE METER IS 250,000 OHMS. THIS MUST BE INCREASED TO 3 TIMES THIS AMOUNT OR TO 750,000 OHMS. SINCE 250,000 OHMS OF THIS AMOUNT IS ALREADY INCLUDED WITHIN THE METER, THE MULTIPLIER MUST HAVE A RESISTANCE OF ONLY 750,000 OHMS MINUS 250,000 OR 500,000 OHMS. THE METER CAN NOW BE USED UP TO 750 VOLTS BUT THE READINGS INDICATED BY THE NEEDLE AT THIS TIME MUST ALL BE MULTIPLIED BY 3, IN ORDER TO DETERMINE THE TRUE VALUE.

YOU CAN FIGURE OUT ALL KINDS OF MULTIPLIER VALUES IN THIS WAY. MOST VOLT METERS HAVE THEIR "OHMS PER VOLT" RATING PRINTED ON THEIR DIAL OR ELSE THIS RATING IS SUPPLIED WITH THE LITERATURE FURNISHED BY THE MANUFACTURER AT THE TIME THE METER IS BOUGHT.

"LAYING-OUT" A 3 RANGE VOLTMETER

GENERALLY, IT IS CONVENIENT TO MOUNT A VOLTMETER IN A BOX, HAVING ITS FACE FLUSH WITH A NEAT PANEL. VARIOUS MULTIPLIERS CAN BE CONNECTED UP INSIDE THE BOX AND THEN ATTACHED TO DIFFERENT TERMINALS ON THE METER BOX. IN THIS WAY, A SINGLE-SCALE VOLT METER CAN BE TRANSFORMED INTO ONE HAVING TWO, THREE OR FOUR RANGES ETC. FIG. 19 SHOWS YOU HOW THIS CAN BE DONE.

IN FIG. 19, WE HAVE A VOLTMETER, WHOSE MAXIMUM RANGE IS 50 VOLTS BUT WE HAVE MOUNTED IT IN A BOX AND INCREASED ITS RANGE UP TO 250 AND 500 VOLTS THROUGH THE USE OF MULTIPLIERS, THUS CONVERTING IT INTO A THREE-RANGE INSTRUMENT. TO DO THIS, WE MOUNT FOUR TERMINALS IN A ROW ALONG THE PANEL, MARKING THEM AS (-), (500), (250) AND (50).

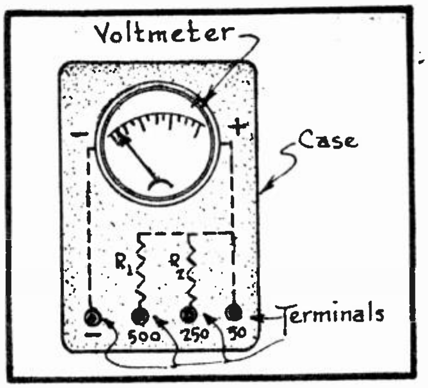

FIG. 19
A Multi-range Voltmeter.

THEN INSIDE OF THE BOX, WE CONNECT ONE (-) TERMINAL DIRECTLY TO THE (-) TERMINAL OF THE METER BY MEANS OF A PIECE OF INSULATED COPPER WIRE. THE "50" TERMINAL IS CONNECTED DIRECTLY TO THE (+) TERMINAL OF THE METER INSIDE THE BOX AND BY USING THE (-) AND "50" TERMINALS FOR OUR CIRCUIT TESTS, WE WILL BE USING THE METER IN ITS ORIGINAL FORM. THAT IS, ITS RANGE WILL NOW BE 50 VOLTS AND WE READ THE SCALE JUST AS IT IS.

THE 250 VOLT RANGE IS PROVIDED BY CONNECTING THE RESISTOR (MULTIPLIER) R_2 IN SERIES WITH THE "250" TERMINAL AND THE (+) METER TERMINAL AND THE 500 VOLT RANGE IS PROVIDED BY CONNECTING THE MULTIPLIER R_1 IN SERIES WITH THE "500" TERMINAL AND THE (+) METER TERMINAL. THE VALUES FOR THESE MULTIPLIERS ARE CALCULATED IN EXACTLY THE SAME WAY AS ALREADY DESCRIBED. YOU NOW HAVE A NEAT MULTI-RANGE VOLTMETER, WITH ALL WIRING, MULTIPLIERS ETC. CONCEALED WITHIN THE BOX.

TO USE THE 250 VOLT SCALE IN FIG. 19, THE INDICATED READINGS WILL HAVE TO BE MULTIPLIED BY 5 AND WHEN THE 500 VOLT RANGE IS USED, THEY WILL HAVE TO BE MULTIPLIED BY 10, IN ORDER TO DETERMINE THE TRUE VALUE.

CONVERTING A MILLIAMMETER TO A VOLTMETER

ANOTHER FAVORITE TRICK OF THE RADIO INDUSTRY IS TO CONVERT A MILLIAMMETER INTO A VOLTMETER, SO THAT IT CAN BE USED FOR BOTH PURPOSES. THIS IS ALSO DONE QUITE EASILY AND WE ACCOMPLISH THIS BY CONNECTING A RESISTOR IN SERIES WITH THE MILLIAMMETER.

THE VALUE FOR THIS SERIES RESISTOR IS DETERMINED IN THE FOLLOWING WAY: DIVIDE THE NUMBER REPRESENTING THE DESIRED VOLTAGE RANGE BY THE CURRENT RATING OF THE METER EXPRESSED IN AMPERES AND THE RESULT WILL BE THE OHM-RATING OF THE SERIES RESISTOR REQUIRED FOR THIS VOLTAGE RANGE. FOR EXAMPLE, LET US SUPPOSE THAT YOU HAVE A MILLIAMMETER WITH A SCALE READING OF 0 TO 1 MILLIAMPERES. IN ORDER TO CONVERT THIS INSTRUMENT INTO A VOLTMETER, HAVING A RANGE OF 0 TO 10 VOLTS, WE DIVIDE 10 BY .001 AMPERE (1 MILLIAMPERE), WHICH GIVES US AN ANSWER OF 10,000 OHMS ($R = \frac{E}{I}$) AS THE VALUE FOR

THE REQUIRED RESISTOR.

SO BY CONNECTING A 10,000 OHM RESISTOR IN SERIES WITH THIS MILLIAMMETER, WE CAN USE IT AS A VOLTMETER WITH A RANGE OF 0 TO 10 VOLTS AND EACH MILLIAMPERE DIVISION ON THE SCALE WILL BE READ AS 1 VOLT.

TO CONVERT THIS SAME MILLIAMMETER INTO A VOLTMETER WITH A RANGE OF 0 TO 100 VOLTS, WE DIVIDE 100 VOLTS BY .001 AMPERE, WHICH GIVES US 100,000 OHMS AS THE VALUE FOR THE SERIES RESISTOR AND EACH MILLIAMPERE DIVISION ON THE SCALE WOULD NOW BE INTERPRETED AS 10 VOLTS. TO INCREASE THE RANGE UP TO 200 VOLTS, A 200,000 OHM RESISTOR SHOULD BE USED ($R = \frac{E}{I} = \frac{200}{.001} = 200,000$ OHMS) AND EACH DIVISION ON THE SCALE WILL BE INTERPRETED AS 20 VOLTS.

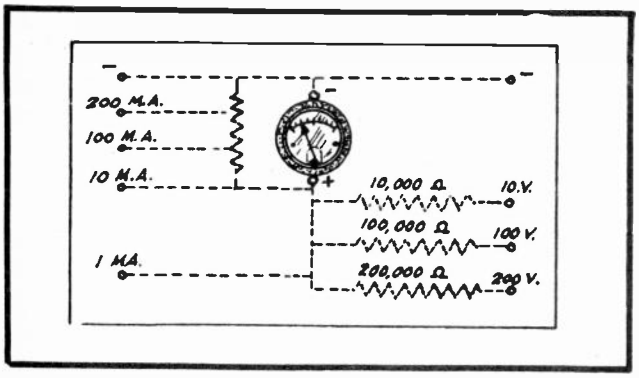

FIG. 20

Combination Milliammeter-Voltmeter.

AS YOU WILL NO DOUBT HAVE NOTICED FROM THIS EXPLANATION, WE ARE NOT TAKING INTO ACCOUNT THE INTERNAL RESISTANCE OF THE MILLIAMMETER'S MOVING COIL WHEN CALCULATING THE VALUE OF THE SERIES RESISTOR WHICH IS USED WHEN CONVERTING IT TO A VOLTMETER. FOR THE HIGHER VOLTMETER RANGES, THIS WILL NOT AFFECT THE ACCURACY OF THE INSTRUMENT TO ANY MARKED DEGREE BECAUSE THE SERIES RESISTOR VALUE IS SO VERY GREAT COMPARED TO THE METER'S INTERNAL RESISTANCE.

SHOULD THE INTENDED VOLTMETER RANGE BE LESS THAN 10 VOLTS, THEN THE RESISTOR VALUE THUS CALCULATED SHOULD BE CONSIDERED AS BEING THE INTERNAL RESISTANCE OF THE MILLIAMMETER ITSELF PLUS THE "VOLTAGE" SERIES RESISTOR VALUE. THE TRUE VALUE FOR THE "VOLTAGE" SERIES RESISTOR WILL THEN BE THE RESISTANCE VALUE THUS OBTAINED MINUS THE METER'S INTERNAL RESISTANCE.

A COMBINATION MILLIAMMETER-VOLTMETER

IN FIG. 20, YOU WILL SEE HOW A MILLIAMMETER WITH A RANGE OF 0 TO 1 MA. CAN BE MOUNTED IN A NEAT BOX AND USED BOTH AS A VOLTMETER AND A MILLIAMMETER, IN ADDITION TO HAVING A MILLIAMMETER RANGE OF 1-10-100, AND 200 MILLIAMPERES AND A VOLTMETER RANGE OF 10-100 AND 200 VOLTS. THE VOLTMETER TERMINALS ARE PLACED ALONG THE RIGHT EDGE OF THE BOX AND THE MILLIAMMETER TERMINALS ALONG THE LEFT EDGE.

VARIOUS SIMILAR ARRANGEMENTS CAN BE WORKED OUT AND THE RESISTANCES CALCULATED FOR THE PARTICULAR METER USED IN THE MANNER ALREADY SHOWN YOU IN THIS LESSON.

RESISTANCE RATING OF VOLTMETERS

AS YOU ALREADY KNOW, VOLTMETERS IN ADDITION TO BEING RATED ACCORDING TO THEIR VOLTAGE RANGE, ARE ALSO RATED AS TO THEIR INTERNAL RESISTANCE. THIS INTERNAL RESISTANCE IS EXPRESSED AS BEING A CERTAIN NUMBER OF OHMS FOR EACH VOLT REPRESENTED ON ITS DIAL SCALE. FOR INSTANCE, YOU WILL FIND VOLTMETERS HAVING A RESISTANCE RATING OF 300 OHMS PER VOLT, 500 OHMS PER

VOLT, 1000 OHMS PER VOLT ETC. FURTHERMORE, THE HIGHER THE OHMS PER VOLT RATING OF THE METER, THE GREATER WILL BE ITS DEGREE OF ACCURRACY BECAUSE IT WILL DRAW LESS CURRENT FROM THE CIRCUIT ACROSS WHICH A MEASUREMENT IS BEING TAKEN.

NOW THEN, SINCE A VOLTMETER HAVING A HIGH INTERNAL RESISTANCE TAKES VERY LITTLE CURRENT FROM THE LINE, IT STANDS TO REASON THAT THE METER ITSELF MUST BE VERY SENSITIVE, THAT IS, IT MUST REQUIRE VERY LITTLE CURRENT IN ORDER TO MOVE ITS COIL AND INDICATING NEEDLE OVER ITS DIAL FOR A FULL-SCALE DEFLECTION. THIS MEANS THAT EITHER THE PERMANENT MAGNET MUST BE STRONGER THAN IN THE USUAL METER OR ELSE MORE TURNS OF WIRE MUST BE WOUND ON THE MOVING COIL IN ORDER TO OBTAIN THE SAME AMPERE-TURN EFFECT AT A SMALLER VALUE OF AMPERES. THE LATTER METHOD IS USED IN THE CONSTRUCTION OF HIGH RESISTANCE VOLTMETERS AS EMPLOYED IN RADIO WORK. IN THIS CASE, THE MOVING COIL CONSISTS OF SEVERAL LAYERS OF VERY THIN COPPER WIRE IN ORDER TO PRODUCE THE NECESSARY FIELD STRENGTH.

THIS LEADS US UP TO ANOTHER POINT AND THAT IS THAT IT IS NOT POSSIBLE TO MAKE A HIGH RESISTANCE VOLTMETER OF THE SAME RANGE FROM AN ORDINARY OR CHEAP LOW RESISTANCE VOLTMETER BY SIMPLY CONNECTING ADDITIONAL RESISTANCE IN SERIES WITH ITS COIL. THE REASON FOR THIS IS OBVIOUS WHEN WE CONSIDER THE FACT THAT A LOW RESISTANCE METER REQUIRES CONSIDERABLE CURRENT IN ORDER TO OBTAIN A FULL SCALE DEFLECTION AND THIS MEANS THAT IF ADDITIONAL RESISTANCE IS USED, THE CURRENT THROUGH THE METER WILL BE REDUCED AND THIS IN TURN WILL REDUCE THE SCALE DEFLECTION. SO REMEMBER NOW THAT HIGH RESISTANCE VOLTMETERS ARE BUILT ESPECIALLY FOR THE PURPOSE, MORE SENSITIVE THAN THE LOW RESISTANCE TYPE AND THAT IT ISN'T PRACTICAL TO BUY CHEAP LOW RESISTANCE VOLTMETERS WITH THE EXPECTATION OF "RE-VAMPING" THEM INTO ACCURATE HIGH RESISTANCE UNITS BY MEANS OF SERIES RESISTORS.

IN THE FOLLOWING LESSON, YOU ARE GOING TO CONTINUE YOUR STUDY OF RADIO TESTING EQUIPMENT BY LEARNING ABOUT THERMO-COUPLE METERS, COPPER-OXIDE METERS AND OHMMETERS. ALL OF THESE INSTRUMENTS ARE EXTENSIVELY USED IN RADIO PRACTICE AND SO IT IS IMPORTANT THAT YOU BECOME THOROUGHLY FAMILIAR WITH THEM.

Examination Questions

LESSON NO.49

Success hinges on loyalty. Be true to your art, your business, your employer, your "house." Loyalty is for the one who is loyal. It is a quality woven through the very fabric of one's being, and never a thing apart.

1. - DESCRIBE THE MOVING COIL TYPE METER MOVEMENT.

2. - DESCRIBE THE "HOT-WIRE" METER.

3. - DESCRIBE THE MOVABLE-IRON TYPE A.C. METER.

4. - WHAT ARE THE ESSENTIAL DIFFERENCES BETWEEN A D.C. AMMETER AND A D.C. VOLTMETER?

5. - EXPLAIN WHY SHUNTS ARE SOMETIMES USED IN CONJUNCTION WITH AMMETERS OR MILLIAMMETERS.

6. - IF YOU SHOULD HAVE A VOLTMETER WITH A MAXIMUM RANGE OF 300 VOLTS AND AN INTERNAL RESISTANCE OF 1000 OHMS PER VOLT, WHAT VALUE OF MULTIPLIER RESISTOR WOULD YOU USE TO INCREASE THE RANGE OF THIS METER UP TO 900 VOLTS? HOW WOULD YOU READ THIS METER AFTER INCREASING ITS RANGE IN THIS WAY?

7. - IF YOU SHOULD HAVE A D.C. MILLIAMMETER WITH AN INTERNAL RESISTANCE OF 27 OHMS, AND WISHED TO CONVERT THIS INSTRUMENT INTO A D.C. VOLTMETER WITH A MAXIMUM RANGE OF 500 VOLTS, HOW WOULD YOU GO ABOUT THIS TASK?

8. - HOW WOULD YOU INCREASE THE RANGE OF A MILLIAMMETER HAVING A FULL SCALE READING OF 1 MA. SO THAT READINGS UP TO 10 MA. MAY BE TAKEN?

9. - EXPLAIN HOW YOU COULD INCREASE THE RANGE OF A MILLIAMMETER WITHOUT RESORTING TO CALCULATION.

10. - DRAW A COMPLETE CIRCUIT DIAGRAM OF A COMBINATION MULTI-RANGE D.C. MILLIAMMETER AND D.C. VOLTMETER.

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LESSON NO. 50

Thermocouple Meters - Copper Oxide Meters - Ohmmeters

In this lesson, you are going to continue your study of radio service equipment by learning about thermo-couple instruments, rectifier type meters, and ohmmeters.

Upon completing this series of lessons, you will find yourself in the possession of a thorough understanding of all types of testing equipment used in the modern radio laboratory and service shop. Furthermore, you can if you wish, use the information supplied in this group of lessons to assist in constructing equipment of this type for your own use.

THERMOCOUPLE INSTRUMENTS

Thermocouple instruments, as their name indicates, also use the effects of heat to actuate their movement, only that this is accomplished in a different manner than in the so-called "hot-wire" instruments.

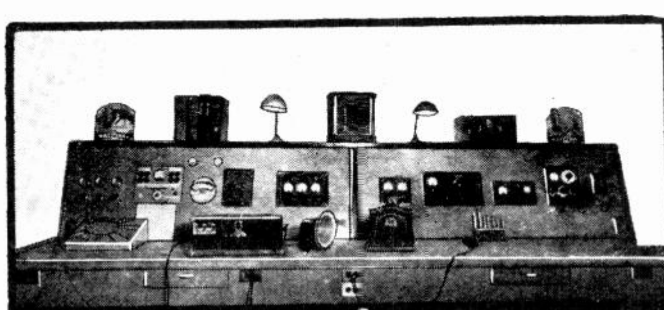

FIG. 1
A Well-Equipped Service Bench.

The constructional features of the thermocouple instrument are illustrated for you in Fig. 2. Here you will observe that the meter mechanism itself is of the moving coil type with which you are already familiar. The essential difference, however, lies in the thermocouple unit, which consists of two wires of dissimilar metals electrically welded together at their center.

Now then, the basic principle upon which this thermo-couple operates is that whenever the junction point of two dissimilar metals is heated, a voltage is generated. This voltage is proportional to the difference in temperature between the heated junction and the other ends of the two

PIECES OF DISSIMILAR METALS.

LET US ASSUME THAT A MEASUREMENT OF THE CURRENT FLOW IS TO BETAKEN WITH THE INSTRUMENT OF FIG.2 IN A CIRCUIT CARRYING RADIO FREQUENCY CURRENT. THE TERMINALS OF THE METER WILL THEN BE CONNECTED IN THE CIRCUIT AS SHOWN IN FIG. 2 AND THE R.F. CURRENT AT ANY ONE INSTANT WILL FLOW IN AT ONE TERMINAL,PASSING INTO ONE WIRE OF THE THERMO-COUPLE,THROUGH THE WELDED JOINT AT THE JUNCTION POINT AND BY WAY OF THE OTHER THERMO-COUPLEWIRE TO THE OTHER METER TERMINAL AND BACK TO THE CIRCUIT.

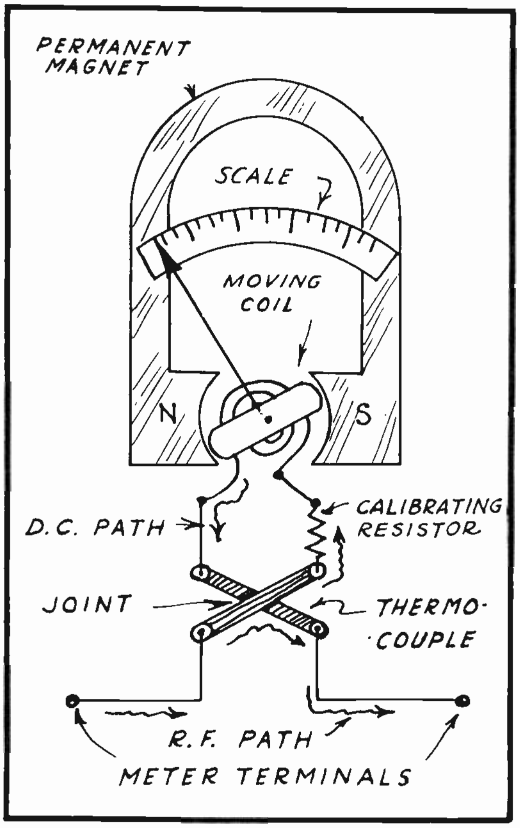

FIG. 2
The Thermocouple Meter.

THIS FLOW OF RADIO FREQUENCY CURRENT WILL HEAT THE JUNCTION POINT, AS WELL AS THE WIRES OF THE THERMO-COUPLE.

THIS HEATING EFFECT OF THE RADIO FREQUENCY CURRENT PASSING THROUGH THE JUNCTION POINT OF THE TWO DISSIMILAR METALS CAUSES A DIRECT CURRENT E.M.F. TO BE GENERATED WHICH IN TURN RESULTS IN A FLOW OF DIRECT CURRENT THROUGH THE METER'S CALIBRATING RESISTOR AND MOVING COIL WHICH ARE TOGETHER CONNECTED ACROSS THE ENDS OF THE THERMO-COUPLE WIRES. THIS RESULTING FLOW OF DIRECT CURRENT THROUGH THE MOVING COIL OF THE METER CAUSES THE MOVING COIL TO ROTATE ABOUT ITS AXIS AND THEREBY SWING THE INDICATING NEEDLE ACROSS ITS SCALE.

THE HEATING EFFECT IS PROPORTIONAL TO THE SQUARE OF THE RADIO FREQUENCY CURRENT BEING MEASURED,WHEREAS THE VOLTAGE WHICH IS GENERATED ACROSS THE JUNCTION,IS PROPORTIONAL TO THE TEMPERATURE. FOR THIS REASON,THE MOVEMENT OF THE INDICATING NEEDLE ACROSS ITS SCALE WILL INCREASE APPROXIMATELY PROPORTIONALLY TO THE SQUARE OF THE RADIO FREQUENCY CURRENT WHICH PASSES THRU THE THERMO-COUPLE. IT IS DUE TO THIS CONDITION THAT THE MARKINGS ON THE SCALE OF SUCH INSTRUMENTS ARE CROWDED TOGETHER AT THE LOWER END AND MORE WIDELY SPACED AT THE HIGHER END OF THE SCALE.

SINCE THE ACTION OF THE THERMOCOUPLE INSTRUMENT DEPENDS UPON A HEATING EFFECT AND IS NOT INFLUENCED BY THE FREQUENCY OF THE CURRENT BEING MEASURED,THIS TYPE OF INSTRUMENT IS SUITABLE FOR TAKING MEASUREMENTS IN RADIO FREQUENCY CIRCUITS,AS WELL AS IN CIRCUITS CARRYING ALTERNATING CURRENTS OF ANY FREQUENCY OR EVEN IN D.C. CIRCUITS. IT IS MOST EXTENSIVELY USED, HOWEVER, FOR TAKING MEASUREMENTS IN R.F. CIRCUITS.

THE TWO DISSIMILAR METALS WHICH ARE FREQUENTLY USED IN THE CONSTRUCTION OF THE THERMOCOUPLE ARE COPPER AND CONSTANTAN. THE MOST GENERAL TROUBLE WHICH DEVELOPES IN THIS TYPE OF INSTRUMENT IS THE BURNING UP OF THE THERMOCOUPLE CAUSED BY A CURRENT OVERLOAD. AS A RULE, THIS DOES NO

HARM TO THE MOVEMENT OF THE INSTRUMENT SINCE THE CURRENT FROM THE CIRCUIT DOES NOT FLOW THROUGH ITS WINDINGS, CONSEQUENTLY TO REMEDY THE CONDITION, IT IS ONLY NECESSARY TO REPLACE THE THERMOCOUPLE UNIT WITH A NEW ONE AND TO ADJUST THE CALIBRATING RESISTOR TO SUIT THE THERMOCOUPLE.

THE MAJORITY OF THE THERMOCOUPLE INSTRUMENTS ARE DESIGNED SO THAT THE D.C. VOLTAGE ACROSS THE MOVING COIL FOR FULL-SCALE DEFLECTION IS FROM ABOUT 15 TO 25 MILLIVOLTS. THE SMALL CALIBRATING RESISTOR WHICH IS CONNECTED IN SERIES WITH THE MOVING COIL OF THE INSTRUMENT AND THE THERMO COUPLE BEING SO ADJUSTED AS TO AFFECT THE DESIRED CALIBRATION OF THE INSTRUMENT.

THE PRINCIPLE OF CONSTRUCTION AS ILLUSTRATED IN FIG.2 IS ONLY USED IN SUCH CASES WHERE THE CURRENT TO BE MEASURED DOES NOT EXCEED ONE-HALF AMPERE.

INSTRUMENTS WHICH ARE CAPABLE OF HANDLING GREATER LOAD CURRENTS THAN THIS ARE CONSTRUCTED SOMEWHAT AS ILLUSTRATED IN FIG. 3. HERE YOU WILL SEE THAT THE TWO DISSIMILAR METALS OF THE THERMOCOUPLE ARE CONNECTED IN PARALLEL WITH RESPECT TO THE R.F. PATH OR EXTERNAL CIRCUIT BUT IN SERIES WITH RESPECT TO THE D.C. CURRENT WHICH IS GENERATED BY THE THERMAL-ELECTRIC EFFECT AT THE THERMO-COUPLE.

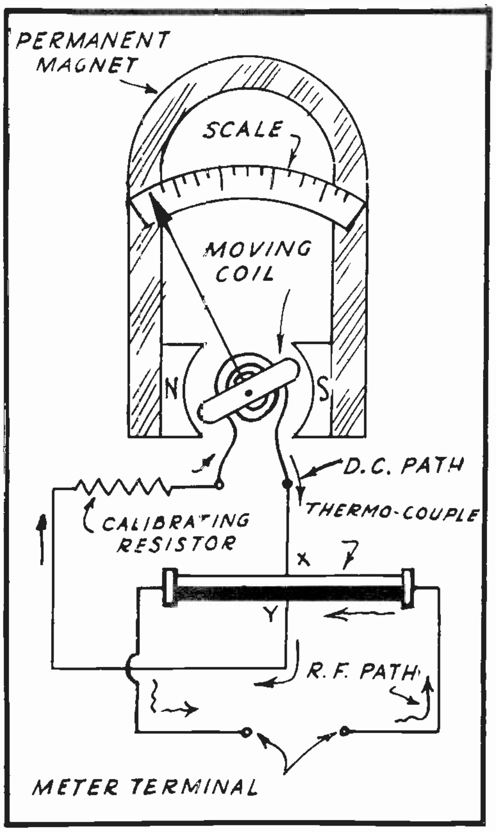

FIG.3
Compound Thermocouple Instrument.

BY LOOKING AT FIG.3 A LITTLE CLOSER YOU WILL SEE ONE OF THE METALS OF THE THERMO-COUPLE METALS DRAWN IN BOLD BLACK WHILE THE OTHER IS NOT SHADED. THE METALS FREQUENTLY USED IN THIS CASE ARE MANGANIN AND "ADVANCE" WIRE. ALSO NOTICE IN FIG. 3 THAT WITH RESPECT TO THE D.C. PATH, THE VOLTAGE AS PRODUCED AT THE JUNCTION X OF THE THERMO-COUPLE IS IN THE SAME DIRECTION AS THE VOLTAGE PRODUCED AT JUNCTION Y AND THAT THESE VOLTAGES WILL ADD TOGETHER SO THAT THE OVERALL THERMAL- ELECTRIC VOLTAGE WILL BE HIGHER. AT THE SAME TIME, THE LOAD CARRYING CAPACITY ALSO BEING GREATER.

RECTIFIER-TYPE METERS

A.C. METERS IN GENERAL ARE MORE SLUGGISH THAN D.C. METERS AND "ABSORB" A GREAT DEAL MORE POWER FROM THE CIRCUIT IN WHICH THE MEASUREMENT IS BEING MADE IN ORDER TO ENERGIZE THE INSTRUMENT. WHEN MAKING RADIO MEASUREMENTS, THIS IS A SERIOUS CONDITION BECAUSE QUITE OFTEN, MORE POWER IS REQUIRED TO SWING THE METER'S NEEDLE THAN IS AVAILABLE IN THE CIRCUIT UNDER TEST.

THE ADVANTAGES OF THE LOW CURRENT DRAIN OF SENSITIVE D.C. INSTRUMENTS CAN BE RETAINED FOR MEASURING LOW A.C. VOLTAGES AND CURRENTS BY USING A SUITABLE SENSITIVE D'ARSONVAL (MOVING COIL) TYPE D.C. INSTRUMENT IN CONJUNCTION WITH A RECTIFIER. IN OTHER WORDS, THE A.C. VOLTAGE TO BE MEAS-

URED, WOULD UNDER THESE CONDITIONS BE RECTIFIED AND THEN APPLIED TO THE D.C. INSTRUMENT.

THERE ARE SEVERAL METHODS WHEREBY WE CAN RECTIFY THE ALTERNATING CURRENT TO BE MEASURED. THE FIRST IS BY USE OF A CRYSTAL RECTIFIER AS ILLUSTRATED IN FIG. 4. THE CRYSTAL, HOWEVER, IS GENERALLY TOO UNSTABLE IN OPERATION AND NEEDS TO BE ADJUSTED QUITE OFTEN IN ADDITION TO BEING SUBJECT TO BURNOUTS AT COMPARATIVELY LOW CURRENT VALUES.

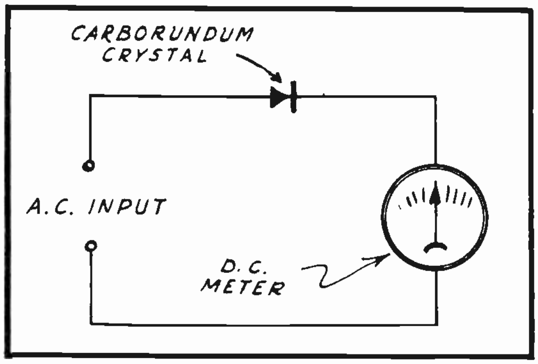

FIG. 4
The Crystal Rectifier.

THE SECOND METHOD TO OBTAIN RECTIFICATION FOR THE USE OF THIS INSTRUMENT IS TO EMPLOY A VACUUM TUBE RECTIFIER AS SHOWN IN FIG.5. THE ORDINARY DESIGN OF SUCH A DEVICE GENERALLY LIMITS ITS APPLICATION BECAUSE IT IS SUBJECT TO TUBE FAILURE, AND EVERYTIME THE TUBE NEEDS TO BE REPLACED, THE INSTRUMENT MUST BE RECALIBRATED. THE SAME INSTRUMENT IS SOMETIMES USED AS AN OUTPUT METER WHEN THE INDICATIONS ARE FOR COMPARISON ONLY.

THE THIRD AND MOST DESIRABLE METHOD OF RECTIFICATION FOR THIS PURPOSE IS TO USE A COPPER OXIDE RECTIFIER AS ILLUSTRATED IN FIG.6. THIS TYPE IS SATISFACTORY FROM THE STANDPOINT OF RUGGEDNESS, SENSITIVITY AND CONSTANCY AND AT THE PRESENT TIME IS BEING MOST EXTENSIVELY USED FOR THIS PURPOSE.

ITS MAIN DISADVANTAGE IS THAT THE METER INDICATES "AVERAGE" VALUES INSTEAD OF EFFECTIVE VALUES. THIS INTRODUCES AN INACCURACY IN READINGS WHICH BECOMES APPARENT WHEN THE VOLTAGE TO BE MEASURED HAS A DISTORTED WAVE FORM. HOWEVER, SINCE THE WAVE FORM OF MOST VOLTAGES ENCOUNTERED IN A RADIO RECEIVER CLOSELY APPROXIMATE SINE WAVES, WE FIND THAT FOR PRACTICAL PURPOSES, THE DISTORTION AND ITS CONSEQUENT ERROR DUE TO THE RECTIFIER WILL BE NEGLIGIBLE.

RECTIFIER TYPE INSTRUMENTS HAVE A LARGE CAPACITANCE DUE TO THE RECTIFIER, WHICH CAUSES A CHANGE IN SCALE DEFLECTION AS THE FREQUENCY OF THE APPLIED VOLTAGE TO BE MEASURED IS VARIED. THE EFFECT OF THIS CAPACITY IS NOT GREAT AT LOW FREQUENCIES BUT ABOVE ABOUT THREE THOUSAND CYCLES, THE ERROR IS MORE PRONOUNCED BY THE INCREASE IN FREQUENCY. THIS IS NOT AS SERIOUS AN OBJECTION AS IT APPEARS AT FIRST GLANCE BECAUSE THE SERVICE MAN SELDOM REQUIRES ABSOLUTE ACCURACY ABOVE THE STANDARD COMMERCIAL FREQUENCIES.

MOMENTARY OVERLOADS OF THREE TO TEN TIMES THE NORMAL VOLTAGE RATING DO NOT DAMAGE THE RECTIFIER, THUS REDUCING TO A MINIMUM THE DANGER OF DESTRUCTION OF THE UNIT DUE TO OVERLOAD.

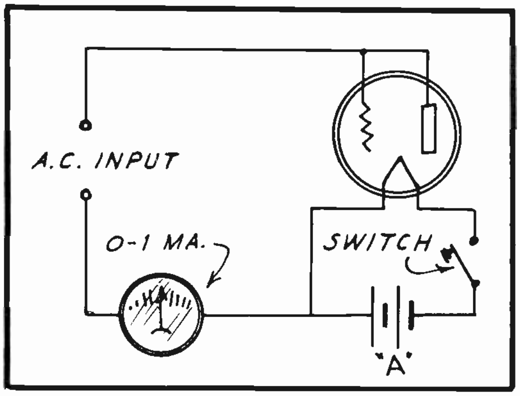

FIG. 5
The Vacuum Tube Rectifier.

A UNIVERSAL METER

METERS ARE NOW BEING MANUFACTURED WITH A SELF-CONTAINED COPPER-OXIDE RECTIFIER SO THAT THEY CAN BE USED TO TAKE MEASUREMENTS IN BOTH A.C. AND D.C. CIRCUITS. INSTRUMENTS OF THIS TYPE ARE GENERALLY CLASSIFIED AS UNIVERSAL METERS.

THE WESTON MODEL 301 UNIVERSAL METER, FOR INSTANCE, IS DESIGNED FOR USE WITH EXTERNAL SHUNTS AND EXTERNAL RESISTANCES FOR MEASURING D.C. VOLTAGES AND CURRENTS AND A.C. VOLTAGES. THIS INSTRUMENT IS OF THE PERMANENT MAGNET MOVING COIL TYPE WITH A SELF-CONTAINED COPPER OXIDE RECTIFIER FOR THE A.C. MEASUREMENTS. IT IS SELF-CONTAINED FOR 5 VOLTS AND 1 MILLIAMPERE A.C. AND 50 MILLIVOLTS AND 1 MILLIAMPERE D.C. IT IS PROVIDED WITH TWO SCALES, ONE FOR THE A.C. MEASUREMENTS AND ONE FOR THE D.C. MEASUREMENTS.

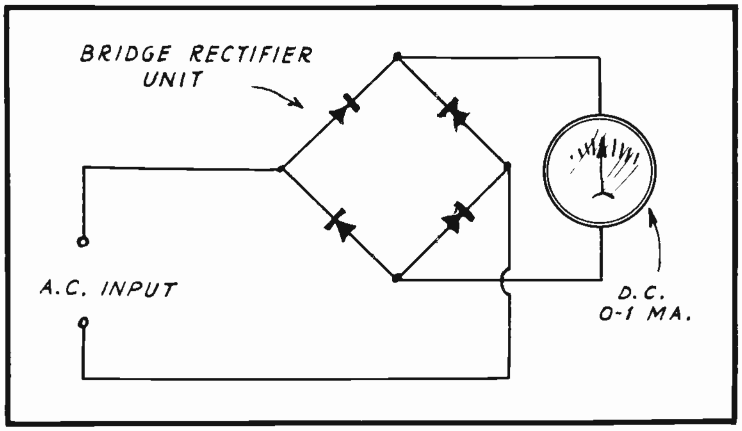

FIG. 6
The Copperoxide Rectifier.

FIG. 7 SHOWS YOU HOW THIS WESTON MODEL 301 UNIVERSAL METER CAN BE USED IN CONJUNCTION WITH A GROUP OF SHUNTS AND MULTIPLIERS SO THAT IT CAN BE USED FOR MEASURING EITHER A.C. OR D.C. VOLTAGES FROM 5 UP TO 1000 VOLTS AND D.C. MILLIAMMETER RANGES EXTENDING FROM 1 MILLIAMPERE TO 100 MILLIAMPERES.

TO READ VOLTAGES WITH THIS INSTRUMENT, SET SWITCH "S" TO THE 1 MA. POSITION. THEN CLOSE THE DOUBLE-POLE SWITCH UPWARD TO THE "D.C. POSITION" IF D.C. VOLTAGES ARE TO BE READ AND DOWNWARD TO THE "A.C. POSITION" IF A.C. VOLTAGES ARE TO BE READ.

FOR D.C. READINGS, CONNECT THE -D.C. TERMINAL TO THE NEGATIVE SIDE OF THE CIRCUIT AND CONNECT THE +D.C. VOLTAGE TERMINAL FOR THE DESIRED RANGE TO THE POSITIVE SIDE OF THE CIRCUIT BEING TESTED.

WHEN TAKING A.C. VOLTAGE READINGS, THE ±A.C. TERMINAL CAN BE CONNECTED TO EITHER SIDE OF THE CIRCUIT UNDER TEST AND THE OTHER VOLTMETER TERMINAL OF THE DESIRED RANGE IS TO BE CONNECTED TO THE OTHER SIDE OF THE A.C. CIRCUIT UNDER TEST.

A SET OF THREE SHUNTS IS PROVIDED TO INCREASE THE D.C. MILLIAMMETER RANGE, THE POLARITY OF THE "MILLIAMPERE TERMINALS" BEING AS DESIGNATED IN FIG. 7.

IF THE MAXIMUM RANGE DESIRED IS 1 MA., THEN TURN SWITCH "S" TO THE 1 MA. POSITION. TO INCREASE THE RANGE TO 2.5 MA., TURN SWITCH "S" TO THE "2.5 MA. POSITION" ETC. — THE D.C. MILLIAMMETER RANGES THUS OFFERED ARE 0-1 ; 0-2.5 ; 0-25 AND 0-100 MA.

THE VOLTMETER-AMMETER METHOD OF MEASURING RESISTANCE

YOU WERE ALREADY SHOWN HOW RESISTANCE CAN BE MEASURED BY MEANS OF

THE WHEATSTONE BRIDGE BUT NOW LET US SEE HOW METERS CAN BE USED FOR THIS PURPOSE.

THE SIMPLEST WAY TO MEASURE A RESISTANCE VALUE IS ILLUSTRATED FOR YOU IN FIG. 8. HERE YOU WILL OBSERVE THAT THE RESISTANCE TO BE MEASURED IS

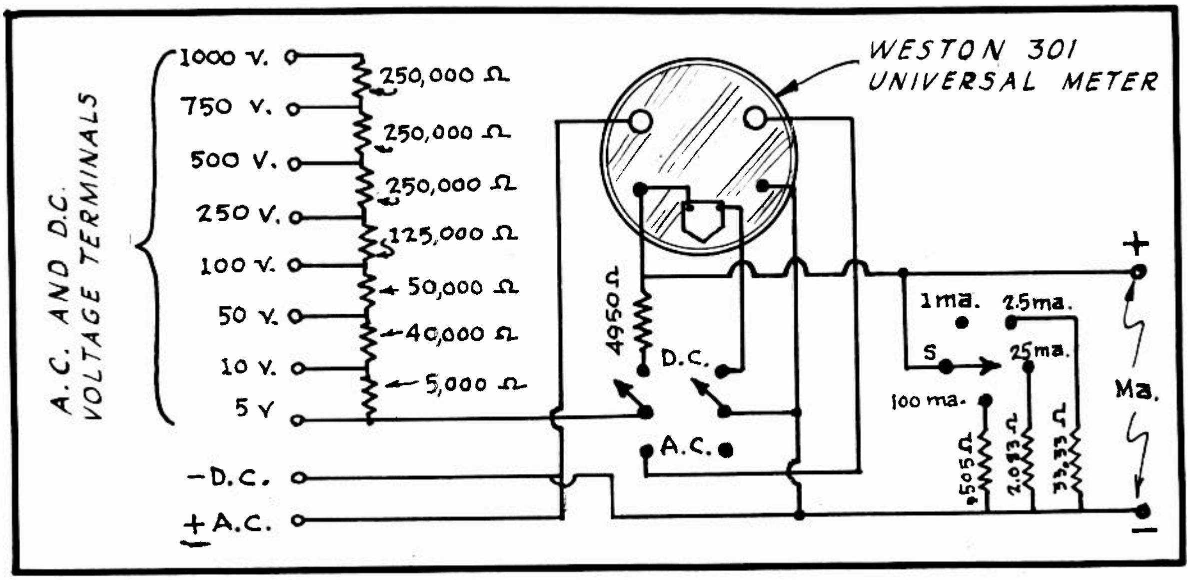

FIG. 7
A Single Meter Serving as a Multi-Range D.C.– A.C. Voltmeter and D.C. Milliammeter.

CONNECTED IN SERIES WITH A SWITCH, BATTERY AND AN AMMETER OR MILLIAMMETER.

UPON CLOSING THE SWITCH, BATTERY CURRENT WILL FLOW THROUGH THE CIRCUIT AND ITS VALUE WILL BE INDICATED BY THE AMMETER. THEN IF A D.C. VOLTMETER IS CONNECTED ACROSS THE ENDS OF THIS RESISTANCE, IT WILL INDICATE THE VOLTAGE DROP ACROSS THE RESISTOR. WE CAN THEREFORE APPLY OHM'S LAW IN THE FORM $R = \frac{E}{I}$ WHERE R = THE RESISTANCE VALUE TO BE DETERMINED; I = THE CURRENT FLOWING THROUGH IT AND E = THE VOLTAGE DROP ACROSS IT. FOR EXAMPLE, IF THE AMMETER READS .5 AMPERE AND THE VOLTMETER 100 VOLTS, THEN THE VALUE OF THE RESISTANCE BEING MEASURED BECOMES 200 OHMS ($R = \frac{E}{I} = \frac{100}{.5} = 200$ OHMS).

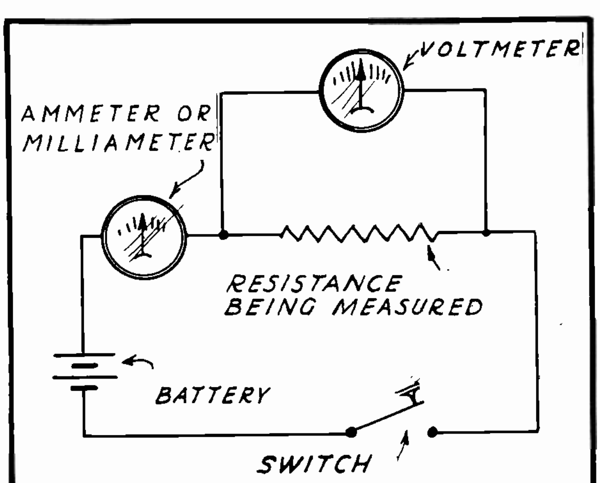

FIG. 8
The Ammeter-Voltmeter Method.

THE VALUE OF THE APPLIED E.M.F. (BATTERY VOLTAGE OR ANY OTHER CONSTANT D.C. VOLTAGE SOURCE) SHOULD BE CHOSEN SO THAT THE RESISTANCE DOES NOT BECOME HOT AS THE CURRENT FLOWS THROUGH IT.

SINCE THE VOLTMETER ITSELF WILL DRAW A CERTAIN AMOUNT OF CURRENT WITH WHICH TO ENERGIZE ITS MOVEMENT, THIS WILL INTRODUCE AN ERROR INTO THE COMPUTATION OF THE

RESISTANCE VALUE. HOWEVER, FOR MEASURING COMPARATIVELY LOW RESISTANCE VALUES, THIS METHOD IS FAIRLY SATISFACTORY FOR UNDER THESE CONDITIONS, THE CURRENT FLOW THROUGH THE RESISTANCE WILL BE RELATIVELY LARGE SO THAT EVEN IF A FEW MILLIAMPERES OF VOLTMETER CURRENT ARE ADDED TO THE AMMETER READING, THIS WILL NOT CAUSE AN APPRECIABLE ERROR.

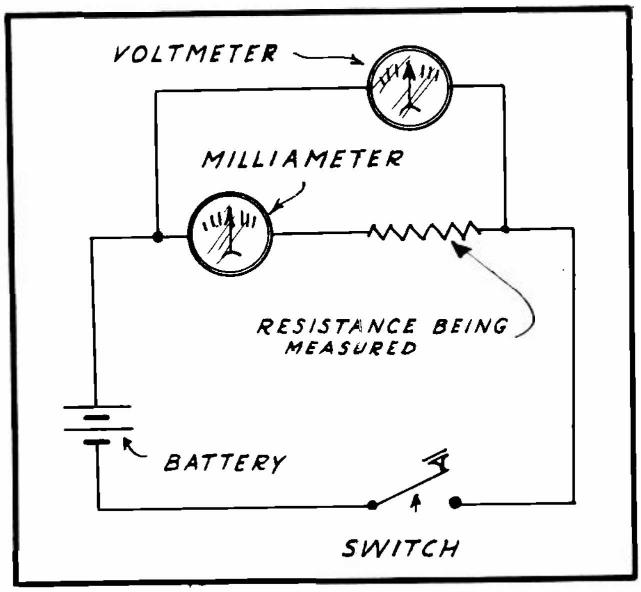

FIG. 9
Measuring High Resistance Values.

TO MEASURE A HIGH RESISTANCE VALUE, THIS METHOD WOULD NOT BE SUITABLE, FOR IN THIS CASE, THE CURRENT FLOW THROUGH THE RESISTANCE WOULD BE VERY SMALL SO THAT THE VOLTMETER CURRENT MAY BE JUST AS GREAT AS THAT FLOWING THROUGH THE RESISTOR. THEN SINCE THE MILLIAMMETER READS THE COMBINED CURRENT OF THAT FLOWING THRU THE RESISTANCE AND THE VOLTMETER, WE WOULD BE INFLUENCED BY AN APPRECIABLE ERROR. IN OTHER WORDS, THE SMALLER THE PROPORTION OF THE TOTAL CURRENT FLOWING THRU THE VOLTMETER TO THAT FLOWING THROUGH THE RESISTANCE, THE HIGHER WILL BE THE DEGREE OF ACCURACY.

FOR MEASURING HIGH RESISTANCE VALUES WHERE THE CURRENT VALUE IS VERY SMALL, IT IS PREFERABLE TO MEASURE THE VOLTAGE DROP ACROSS BOTH THE AMMETER OR MILLIAMMETER AND THE RESISTANCE BEING MEASURED, AS ILLUSTRATED IN FIG. 9. ALTHOUGH IT IS TRUE THAT THE VOLTMETER NOW ACTUALLY MEASURES THE VOLTAGE DROP ACROSS BOTH THE AMMETER AND THE RESISTANCE, YET THE RESISTANCE OF THE AMMETER WINDING IS SO VERY SMALL AS COMPARED TO THE RESISTANCE BEING MEASURED THAT THE PERCENTAGE OF ERROR WILL BE APPRECIABLY SMALL.

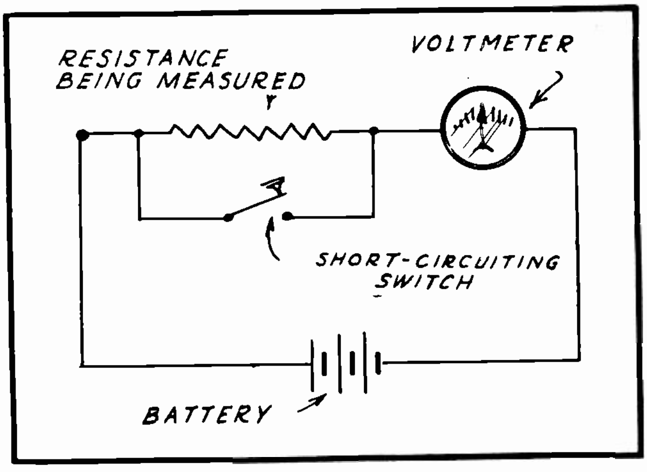

FIG. 10
Voltmeter Method of Measuring Resistance.

THE VOLTMETER METHOD OF MEASURING RESISTANCE

FIG. 10 SHOWS YOU HOW IT IS POSSIBLE TO MEASURE RESISTANCE WITH A VOLTMETER ALONE. TO DO THIS, CONNECT THE RESISTANCE TO BE MEASURED IN SERIES WITH THE VOLTMETER AND THE D.C. VOLTAGE SOURCE AND CONNECT A SHORT-CIRCUITING SWITCH ACROSS THE ENDS OF THE RESISTANCE.

THE FIRST STEP IS TO CLOSE THE SHORT-CIRCUITING SWITCH. THIS WILL CONNECT THE VOLTMETER DIRECTLY ACROSS THE

BATTERY OR OTHER D.C. VOLTAGE SOURCE SO THAT THE SOURCE OF E.M.F. CAN BE ACCURATELY MEASURED BY THE VOLTMETER. THIS IS GENERALLY CALLED THE "LINE READING".

AFTER THIS READING HAS BEEN CAREFULLY NOTED, OPEN THE SHORT CIRCUITING SWITCH. THE RESISTANCE WILL NOW BE CONNECTED IN SERIES WITH THE VOLTMETER AND THE VOLTAGE SOURCE. THE VOLTMETER READING WILL NOW BE LESS THAN FORMERLY AND WE CALL THIS THE "DROP READING". TO DETERMINE THE VALUE OF THE RESISTANCE IN QUESTION USE THE FOLLOWING FORMULA:

$$\text{UNKNOWN RESISTANCE} = \frac{\text{LINE READING} - \text{DROP READING}}{\text{DROP READING}} \times \text{RESISTANCE OF THE VOLTMETER}$$

TO ILLUSTRATE THE USE OF THIS FORMULA, LET US WORK OUT A PRACTICAL PROBLEM. WE SHALL ASSUME THAT UPON CLOSING THE SHORT-CIRCUITING SWITCH, THE VOLTMETER READS 180 VOLTS. THIS IS THE "LINE READING".

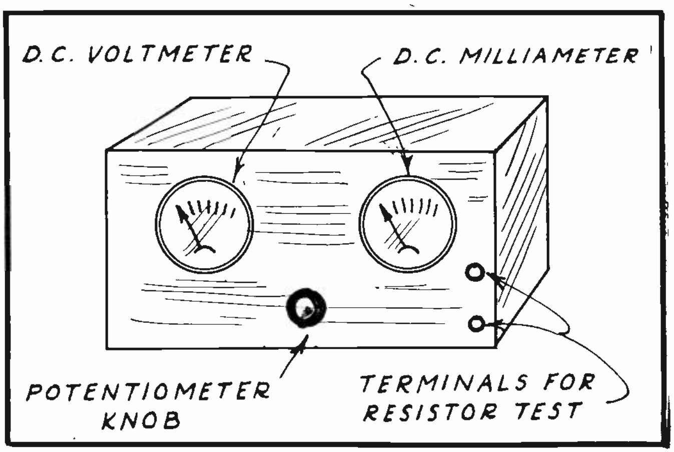

FIG. 11
The Resistor Tester.

NOW LET US SUPPOSE THAT THE VOLTMETER READS 40 VOLTS WHEN THE SWITCH IS OPENED. THIS CORRESPONDS TO THE "DROP READING".

THE VOLTMETER BEING USED HAS A FULL SCALE RANGE OF 250 VOLTS AND AN INTERNAL RESISTANCE OF 1000 OHMS PER VOLT. ITS TOTAL RESISTANCE WILL THEREFORE BE 250 TIMES 1000 OR 250,000 OHMS. SO SUBSTITUTING INTO THE FORMULA, THE DATA WHICH WE HAVE SO FAR ACQUIRED WE HAVE:

$$\text{UNKNOWN RESISTANCE} = \frac{180 - 40}{40} \times 250{,}000 = \frac{140}{40} \times 250{,}000 = 3.5 \times 250{,}000 = 875{,}000 \text{ OHMS.}$$

THIS METHOD IS ONLY SUITABLE FOR MEASURING RESISTANCES OF HIGH VALUE FOR IF THE RESISTANCE IN QUESTION IS OF LOW VALUE, THERE WILL BE SO LITTLE DIFFERENCE IN THE VOLTMETER READING WHEN THE VOLTMETER IS CONNECTED DIRECTLY ACROSS THE SOURCE OF E.M.F. OR IN SERIES WITH THE UNKNOWN RESISTANCE.

A SELF-CONTAINED RESISTOR TESTER

IN FIG. 11 YOU ARE SHOWN A MORE ELABORATE TESTING OUTFIT WHICH WILL ENABLE ONE TO MEASURE RESISTANCE VALUES UP TO 100,000 OHMS. HERE ALL OF THE NECESSARY EQUIPMENT IS HOUSED IN A COMPACT CASE WHICH MAY BE MADE OF SHEET ALUMINUM, WOOD WITH A BAKELITE PANEL OR ANY OTHER DESIRABLE MATERIALS.

THE CIRCUIT DIAGRAM FOR THIS SAME TESTER APPEARS IN FIG. 12.

BY REFERRING TO FIG. 12, YOU WILL OBSERVE THAT A MILLIAMMETER WITH A RANGE OF 0 TO 1 MA, A 0 TO 10 VOLTMETER, A 400 OHM POTENTIOMETER, A 10 MILLIAMPERE SHUNT, 2 SWITCHES AND THREE $4\frac{1}{2}$V. "C" BATTERIES ARE USED IN THIS CIR

CUIT.

TO MEASURE ANY RESISTANCE UP TO 10,000 OHMS, THE UNKNOWN RESISTOR IS CONNECTED ACROSS THE TERMINALS "X" AND "Y" WITH THE MILLIAMMETER SHUNT SWITCH OPEN AND THE MASTER SWITCH CLOSED. THE POTENTIOMETER IS THEN ADJUSTED UNTIL THE MILLIAMMETER READS FULL SCALE, THAT IS, 1 MA. OR .001 AMPERE. WITH THIS SETTING, THE VOLTMETER READING IS NOTED. ACCORDING TO OHM'S LAW, THE RESISTANCE VALUE OF THE UNKNOWN RESISTOR ACROSS X AND Y IS EQUAL TO THE VOLTAGE AS GIVEN BY THE VOLTMETER DIVIDED BY THE CURRENT IN AMPERES AS READ ON THE MILLIAMMETER. FOR EXAMPLE, SHOULD THE VOLTMETER READ 2 VOLTS, THEN THE VALUE OF THE UNKNOWN RESISTOR IS 2 DIVIDED BY .001 AMPERE OR 2000 OHMS. THE VALUE IN OHMS CAN BE DETERMINED AT A GLANCE BECAUSE DIVIDING A NUMBER BY .001 IS THE SAME AS MULTIPLYING IT BY 1000 AND FOR THIS REASON IT IS ONLY NECESSARY TO POINT OFF THREE DECIMAL PLACES TO THE RIGHT OF THE VOLTMETER READING, IN ORDER TO CONVERT THIS READING TO OHMS. THAT IS, A READING OF 3.5 VOLTS IN THIS CASE WOULD BE INTERPRETED AS 3500 OHMS ETC.

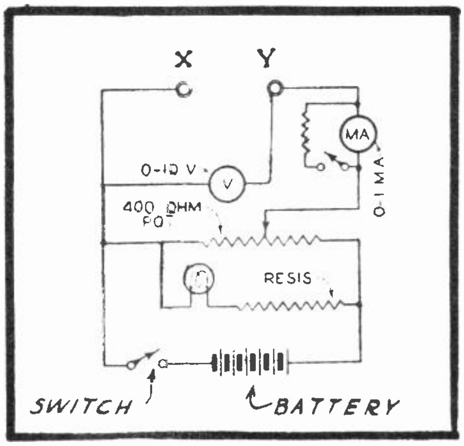

FIG. 12
Circuit Connections for the Resistor Tester.

IN ORDER TO MEASURE RESISTANCES UP TO 100,000 OHMS, THE UNKNOWN RESISTOR IS CONNECTED TO THE TESTER IN THE SAME MANNER BUT NOW INSTEAD OF ADJUSTING THE POTENTIOMETER UNTIL A MILLIAMMETER READING OF 1 M.A. IS OBTAINED, IT IS SET TO THE POSITION AT WHICH THIS METER READS .1 M.A. OR .0001 AMP. THE VOLTMETER READING IS THEN MULTIPLIED BY 10,000 INSTEAD OF 1000 AND THE RESULT IS THE VALUE OF THE UNKNOWN RESISTOR IN OHMS.

THE SWITCH FOR THE 10 M.A. SHUNT IS ONLY USED WHEN MEASURING RESISTANCES BETWEEN 0 AND 1000 OHMS. IN THIS CASE, THE SHUNT SWITCH IS CLOSED AND THIS WILL INCREASE THE RANGE OF THE MILLIAMMETER UP TO 10 MA. OR .01 AMPERE. THE POTENTIOMETER IS NOW ADJUSTED UNTIL THE METER READS FULL SCALE, WHICH NOW WILL BE .01 AMPERE AND THE RESULTING VOLTMETER READING WILL THEN BE MULTIPLIED BY 100. THIS WILL BE THE VALUE OF THE UNKNOWN RESISTOR IN OHMS AND THIS LAST METHOD MAKES THE METER SCALE MORE READABLE FOR RESISTANCES BETWEEN 50 AND 1000 OHMS.

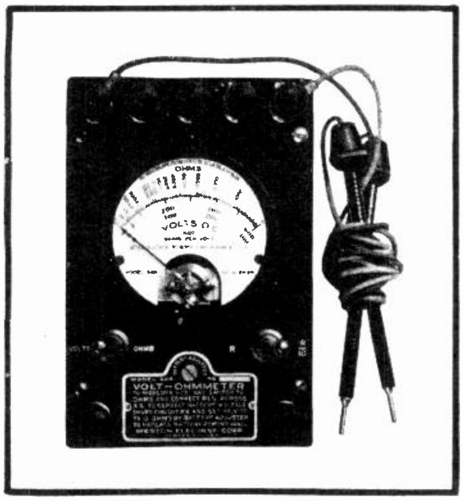

FIG. 13
A Volt-Ohmmeter.

IT IS ALSO ADVISABLE TO REMIND YOU AT THIS TIME, THAT THE RESISTORS, WHICH ARE USED IN CONJUNCTION WITH ANY KIND OF TESTING DEVICES AT ALL, MUST BE OF THE PRECISION TYPE WHICH ARE GUARANTEED TO BE ACCURATE WITHIN 1% OF THEIR RATED VALUE. CHEAP RESISTORS MEAN INACURRATE RESULTS AND THIS HOLDS GOOD FOR ALL MULTIPLIERS ETC. THEN TOO, OF COURSE, THE HIGHER THE QUALITY OF METERS USED, THE MORE ACCURATE WILL BE THE RESULTS.

OHMMETERS

INSTRUMENTS ARE NOW AVAILABLE WHICH

ENABLE ONE TO READ THE RESISTANCE VALUE OF ANY RESISTOR UPON A METER SCALE WHICH IS CALIBRATED DIRECTLY IN OHMS. WE CALL THESE INSTRUMENTS OHMMETERS AND IT IS A COMMON PRACTICE AMONG METER MANUFACTURERS TO INCORPORATE THESE UNITS INTO A SINGLE CASE IN SUCH A MANNER THAT THE DEVICE SERVES BOTH AS A D.C. VOLTMETER AND AN OHMMETER. YOU ARE SHOWN ONE OF THESE VOLT- OHMMETERS, AS THEY ARE CALLED, IN FIG. 13.

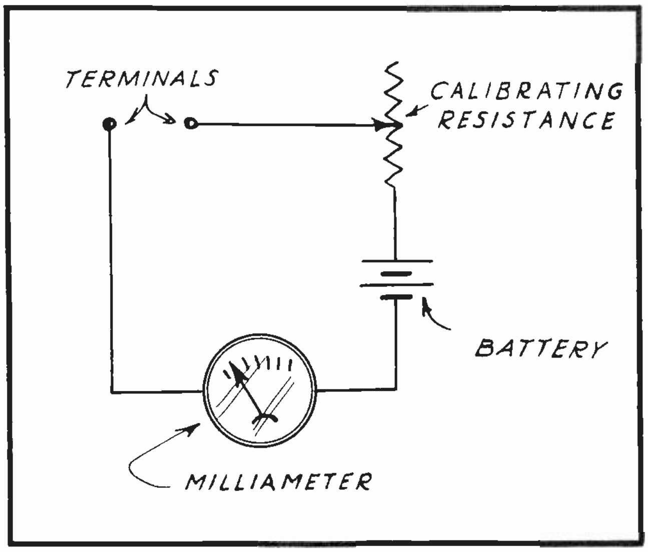

FIG. 14
The Ohmmeter Principle.

THE OHMMETER PRINCIPLE IS ILLUSTRATED FOR YOU IN FIG. 14. AS YOU WILL OBSERVE, THE INSTRUMENT CONSISTS OF A MOVING COIL TYPE MILLIAMMETER WHOSE SCALE IS CALIBRATED IN OHMS. THIS METER IS CONNECTED IN SERIES WITH A SMALL $4\frac{1}{2}$ VOLT DRY BATTERY, CALIBRATING RESISTANCE AND A PAIR OF TERMINALS.

TO USE THIS OHMMETER, THE RESISTANCE TO BE MEASURED IS CONNECTED ACROSS THE TWO TERMINALS WHICH ARE POINTED OUT IN FIG. 14 AND THE METER WILL THEN INDICATE THE RESISTANCE VALUE DIRECTLY IN OHMS. NO CALCULATIONS ARE THEREFORE REQUIRED.

WHAT REALLY TAKES PLACE IN THIS CASE IS THAT WHEN CONNECTING AN UNKNOWN RESISTOR ACROSS THE TERMINALS, THE METER DEFLECTION WILL BE PROPORTIONAL TO THE CURRENT FLOW AND SINCE THE SCALE IS ALREADY CALIBRATED IN OHMS, THE RESISTANCE VALUE IS QUICKLY AND EASILY DETERMINED.

TO COMPENSATE FOR THE REDUCTION IN BATTERY VOLTAGE AS THE BATTERY BECOMES AGED, THE EFFECTIVE VALUE OF THE CALIBRATING RESISTANCE WILL HAVE TO BE CHANGED. TO ACCOMPLISH THIS, IT IS ONLY NECESSARY TO TEMPORARILY SHORT CIRCUIT THE OHMMETER TERMINALS AND BY MEANS OF A SCREW-DRIVER ADJUST THE POTENTIOMETER ADJUSTING SCREW SO THAT THE METER NEEDLE COMES TO REST AT THE ZERO MARK.

WHEN THE BATTERY IS NO LONGER FITTED FOR USE, IT CAN BE REMOVED FROM THE CASE OF THE INSTRUMENT AND REPLACED WITH A NEW ONE. THE INSTRUMENT SHOULD THEN BE RE-CALIBRATED FOR ITS ZERO SETTING AS JUST DESCRIBED.

THE PARTICULAR METER ILLUSTRATED IN FIG. 13 HAS VOLTAGE RANGES OF 3-30-300 AND 600 VOLTS — THE ROW OF TERMINALS ALONG IS UPPER EDGED BEING USED AS THE VOLTMETER TERMINALS IN THE CUSTOMARY MANNER. THE READING IS OBTAINED FROM THE VOLTAGE SCALE.

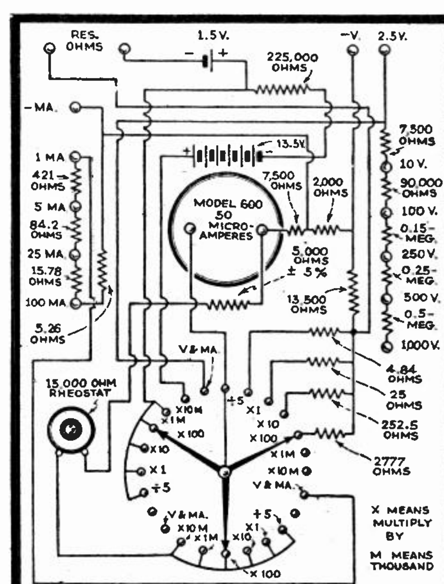

FIG. 15
Combination Voltmeter-Ammeter-Ohmmeter.

To use this instrument as in ohmmeter, the toggle switch at the left is snapped to the "ohms" position and for measuring resistance values up to 100,000 ohms, the right toggle switch is snapped to the "R" position and for measuring resistance values up to 10,000 ohms, this same switch is snapped to the "$\frac{R}{10}$" position.

The resistance to be measured is then connected across the two lower terminals and its resistance in ohms read directly on the ohm scale.

COMBINATION METERS

From your studies so far, you have seen how flexible that a good milliammeter really is in that it can be used in conjunction with shunts, multipliers etc. so as to serve as a milliammeter of various ranges, a multi-range voltmeter, ohmmeter etc.

In Fig. 15 you are shown a circuit diagram of the Weston 663 which is a compact instrument offering resistance measuring ranges of 0-200; 0-1000; 0-10,000; 0-100,000; 0-1,000,000; and 0-10,000,000 ohms in addition to voltage ranges of 0-2.5; 0-10; 0-100; 0-250; 0-500 and 0-1000 volts with a sensitivity of 1000 ohms per volt and milliammeter ranges of 0-1; 0-5; 0-25 and 0-100.

In this instrument, a model 600 Weston microammeter having a full-scale sensitivity of 50 microamperes is used as the heart of the tester. The entire tester is housed in a compact portable carrying case and weighs but six pounds.

A switching device which operates through eight positions offers seven ohmmeter ranges and one position for both Volts and Milliamperes.

No doubt, you are finding these lessons on testing equipment of special interest in that they contain a great deal of valuable information which you can apply to the actual construction for equipment of this type. It is instruction of this nature which makes National Training PRACTICAL and yet SCIENTIFIC in all branches of the radio industry.

In your next lesson, you are going to find a great deal more information concerning wavemeter and service oscillators.

EXAMINATION QUESTIONS

LESSON NO. 50

1. - DESCRIBE THE THERMOCOUPLE TYPE METER.

2. - WHAT ARE SOME OF THE DISADVANTAGES OF THE ORDINARY TYPE A.C. METERS?

3. - DESCRIBE IN DETAIL THE CONSTRUCTIONAL FEATURES OF THE COPPER-OXIDE METER.

4. - DESCRIBE THE VOLTMETER-AMMETER METHOD OF MEASURING RESISTANCE.

5. - HOW MAY RESISTANCE BE MEASURED BY MEANS OF THE VOLTMETER METHOD?

6. - DESCRIBE AN OHMMETER AND EXPLAIN HOW IT IS USED.

7. - DRAW A CIRCUIT DIAGRAM OF A METER WHICH CAN BE USED TO MEASURE BOTH A.C. AND D.C. VOLTAGES, AS WELL AS D.C. CURRENTS. INDICATE THE TYPE OF INSTRUMENT BEING USED, THE MULTIPLIERS, SHUNTS ETC.

8. - WE SHALL ASSUME THAT YOU ARE MEASURING A RESISTOR BY THE VOLTMETER METHOD. THE VOLTMETER BEING USED HAS A RANGE OF 500 VOLTS AND THE INTERNAL RESISTANCE OF THE METER AMOUNTS TO 1000 OHMS PER VOLT. WHILE TAKING THE MEASUREMENT, THE "LINE READING" IS FOUND TO BE 200 VOLTS AND THE "DROP READING "50 VOLTS. WHAT IS THE OHMIC VALUE OF THE RESISTANCE BEING MEASURED?

9. - CAN THE ORDINARY TYPE OF RADIO RECEIVER RESISTORS BE USED WITH GOOD RESULTS AS MULTIPLIERS FOR A D.C. VOLTMETER?

10. - EXPLAIN HOW THE VOLT-OHMMETER, ILLUSTRATED IN FIG. 13 OF THIS LESSON, IS USED IN PRACTICE.