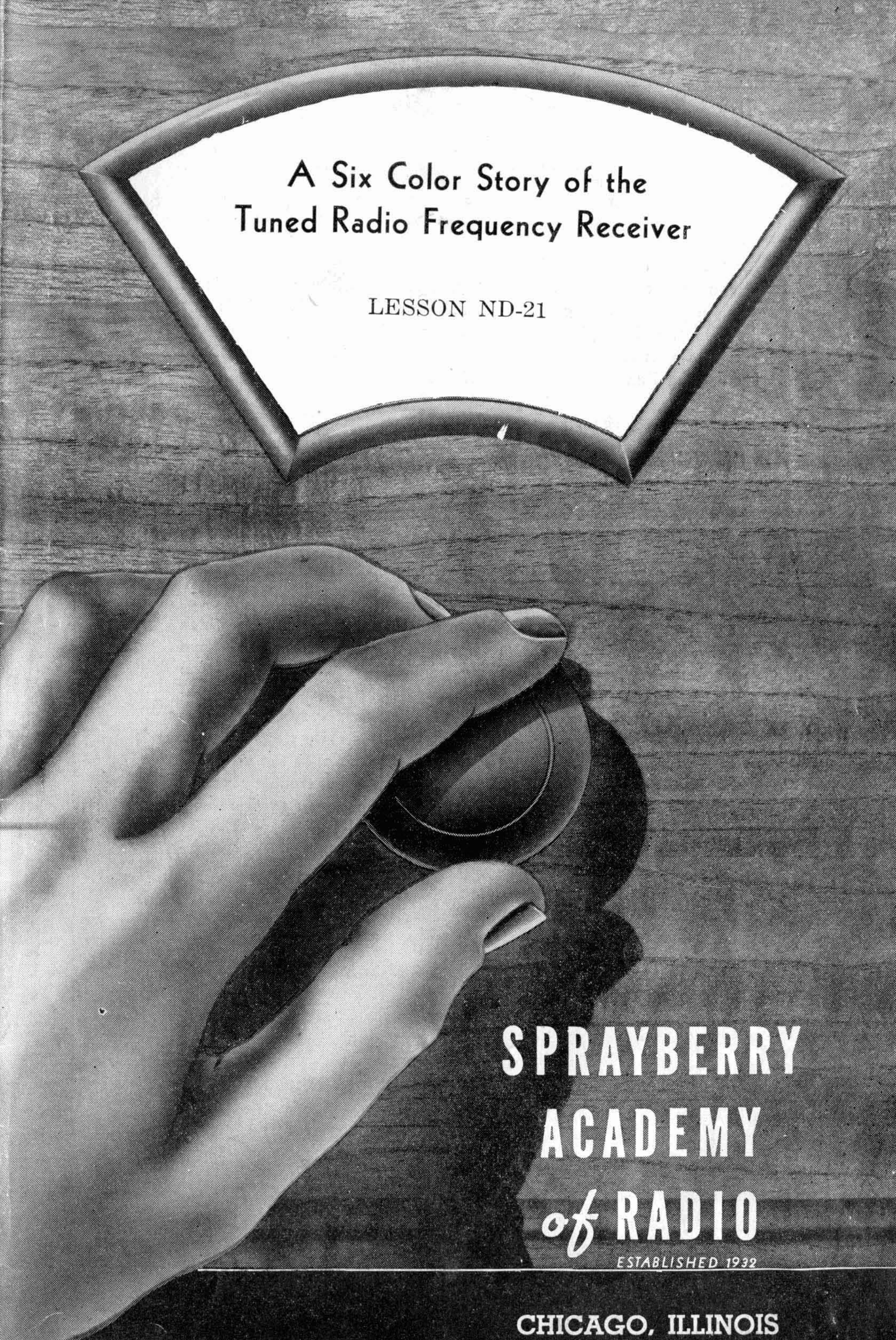


A Six Color Story of the Tuned Radio Frequency Receiver

LESSON ND-21

SPRAYBERRY ACADEMY of RADIO

ESTABLISHED 1932

CHICAGO, ILLINOIS

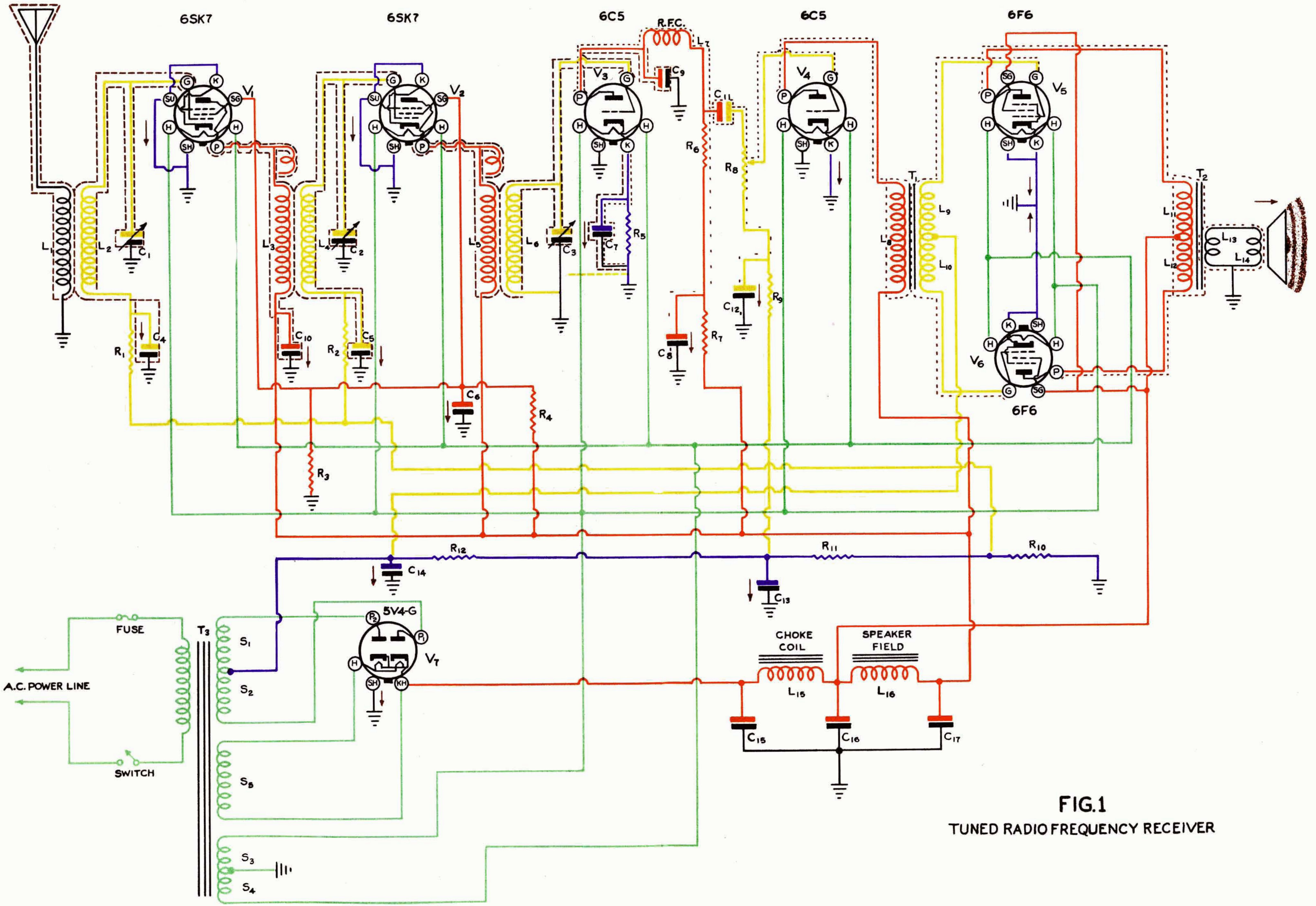


FIG.1

TUNED RADIO FREQUENCY RECEIVER

BRAINWORK VS. GUESSWORK

You have reached the stage in your studies where most students begin to feel the urge to begin doing servicing work. This is just about the right place for it, since you have studied all of the basic stages of a receiver and are in a position to test these various stages and analyze the results of such tests.

At this time, then, it is important to emphasize the use of your knowledge and your imagination. Any person, given enough time, can tinker a receiver back into operation, even if he winds up with every part and every length of wire replaced. This is not professional radio servicing procedure. The basic premise in servicing is that one fault exists. The object of the technician is to locate that fault and repair it. This is where brainwork comes in and where guess work must go out.

The trained service man will make a series of tests, each of which will lead him closer to the fault, and he will think his way through these tests so that not a single unnecessary test is made. You will find yourself making guesses as to what is wrong, then making tests to prove these guesses. This is a time-wasting procedure and you must constantly train yourself at this early stage to avoid this common pitfall. Always work from the known to the unknown and you will soon develop an automatic, fool-proof trouble shooting system that will save you much time and allow you to perform a greater number of repair jobs each day.

O'B 9-56 2M

A Six Color Story of the Tuned Radio Frequency Receiver

LESSON ND-21

In twenty lessons you have covered most of the basic underlying principles on which all of radio, television, frequency modulation, radar and much of the broad field of electronics are based. These basic principles are simply expanded and applied in different ways to accomplish all of the known applications in use today. Of course, there are many more details to be covered in the remaining lessons of your SAR course, but they will all be based on the preceding twenty lessons. So do not hesitate to refer to them whenever you feel the need of a review on basic principles.

The purpose of this lesson is to correlate these basic principles and show how they may all be brought together and made to perform the marvelous function of reproducing a signal thousands of miles from where it originates. Various circuits may be employed for this purpose. The tuned radio frequency type of circuit has been chosen because it is simple and embodies most of the principles which you have studied in previous lessons. The name *tuned radio frequency* (TRF) comes from the fact that this type of circuit employs several stages of tuned radio frequency amplification before the signal is applied to the detector tube. Several such tuned stages are necessary to give the receiver ability to *select* one signal out of all others and reproduce it in the form of sound waves. Such a receiver will give a fair and passable degree of *selectivity* but not enough for modern broadcast conditions. The superheterodyne type of circuit is the accepted standard today and will give a high degree of selectivity. However, it employs many of the TRF principles, and it is much easier to understand the superheterodyne type of circuit if you first have a good understanding of the TRF circuit. So this lesson will describe the basic TRF principle. If you follow the discussion carefully you will be well repaid for your efforts when you come to the study of the superheterodyne type of circuit.

In any selective receiving circuit six elements are necessary. These are (1) an energy collector or antenna, (2) selective amplification of the R.F. carrier provided by the R.F. amplifier, (3) a detector to remove the R.F. carrier, (4) an audio frequency amplifier to build up the signal energy to operate a speaker, (5) a speaker to reproduce the sound and (6) a power supply to operate the various tubes of the system. All of these elements are included in the basic circuit shown in Fig. 1 in this lesson, and these are illustrated by use of a six color circuit.

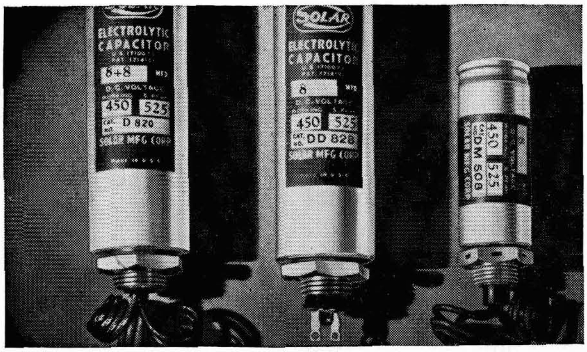
The Sprayberry Academy of Radio has pioneered in the use of colors in its course of instruction in radio. So far as we know no other school has gone to the trouble and expense to provide this type of instruction for its students. The full and complete circuit is shown in Fig. 1 of this lesson which you will find in the center of the book, it being necessary to place it there because of the need for employing two full pages for its reproduction.

This circuit merits your careful study because it tells much about a radio receiver *in a small space*. You will note it consists of 7 tubes. The first two tubes, V_1 and V_2, reading from left to right are R.F. amplifiers of the 6SK7 type. Tube V_3 is the detector employing a 6C5 tube. Tube V_4 is an A.F. amplifier also of the 6C5 type. Tubes V_5 and V_6 are of the 6F6 type and together form a push-pull stage. Tube V_7 is a full wave rectifier of the 5V4-G type *employing a heater-cathode circuit*. Note in this case the heater of the rectifier is connected to the cathode within the tube.

Colored wiring and symbols are used to aid in the study of the separate circuits and to show how these are related to other circuit parts. Green indicates all 60 cycle wiring. Blue indicates what is commonly known as negative voltage circuits although this is not strictly true as will be pointed out later. Red indicates all positive voltage circuits and again this is not strictly true as will be explained later. Yellow is used to indicate the grid return circuits to which is applied the negative or grid bias voltages. Brown is used to indicate the electromagnetic and electrostatic lines of force about the various parts as a result of the AC form of the signal voltages. Black indicates the receiver metal chassis (ground), the antenna coil L_1, the secondary coil L_{13} of T_2, the voice coil L_{14} of the speaker, the iron cores of the transformers, the tube sockets and the letter and number designations of the various parts. The reason for this separation of the various parts will be made clear as progress is made with the lesson.

THE GREEN CIRCUIT

Since a multiple tube receiver must have a power supply the logical place to begin the study of the circuit of Fig. 1 is with the raw AC just as it is obtained from the power line. The power transformer T_3, in Fig. 1, has a plug attached to its primary ends. This plug may be inserted into any 60 cycle power outlet such as is found in the usual home. In this way all operating voltages for the entire receiver are obtained. The leads of the primary include a switch and a fuse. The switch is operated by the control knob of the volume control R_8. Thus, this control operates both switch and volume and this, incidentally, is more or less standard practice in the modern receiver of today. The fuse is included for the purpose of protecting the receiver from overloads and breakdowns of various receiver parts—it being much cheaper to replace a fuse than other more expensive parts in the receiver. For instance, condenser C_{15} may breakdown. This will form a short circuit across the output of the rectifier tube and may so overload it that the power transformer is, in turn, overloaded, and it may burn out due to this overload. When a fuse is included, however,



In the modern radio circuit, large capacity but small size electrolytic condensers are used for filtering the power unit circuit. The above view shows three such condensers which might well be used for C_{15}, C_{16} and C_{17} of Fig. 1. These are the nut and screw mounting type. Courtesy of Solar.

the first heavy surge of current in the primary due to the overload will burn out the fuse and thus the primary of the transformer is interrupted or opened. Current to the set is thus stopped, and it ceases to operate. This action, therefore, prevents a possible replacement of the rectifier tube and power transformer. More details along this line are included in your Master Service Course lessons.

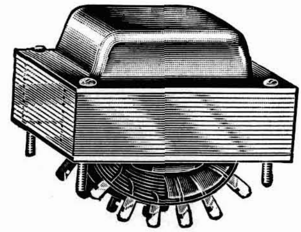
To continue with the green circuit action, the primary, iron core and secondaries are in such magnetic relation (as explained in a previous lesson) that proper voltages are induced in the secondaries.

There are three secondaries—*a high voltage secondary,* a low voltage 5 volt *rectifier filament secondary* and a *low voltage secondary* of 6.3 volts for the filaments of the remaining six tubes. The high voltage secondary and the 6.3 volt secondary consists of two windings which essentially means a *single winding with the proper electrical centertap.* Thus, S_1 and S_2 form the high voltage winding, while S_3 and S_4 form the 6.3 volt winding. The 6.3 volt winding is required to provide heater current for 6 tubes. Tubes V_1, V_2, V_3 and V_4 require .3 ampere and V_5 and V_6 require .7 ampere. This is a total of 2.6 amperes as the minimum which the 6.3 volt secondary must supply.

The high voltage secondary connects to the two plates of the 5V4-G rectifier tube. For maximum conditions this winding must supply 300 volts R.M.S. of AC each side of the centertap. This makes a total of 600 volts AC from plate to plate. This is the rating by the manufacturer for the type of rectifier tube being used. Actually, as is the case in many receivers, the maximum rated amount of current is not always drawn by the rectifier tube unless the load demands it. The rectifier filament winding in Fig. 1 should be rated at 5 volts and 2 amperes. Note it is a separate circuit from the other filament circuits. This is necessary because the filament and cathode are common or connected together within the tube. Since the cathode must be kept isolated from all other circuits except the input to the filter, the filament of the rectifier must not be grounded or be connected to other parts of the receiver.

Little technical knowledge is needed by the radio man in ordering a replacement power transformer for this or a similar receiver. If it was necessary to order one for the circuit of Fig. 1 all you would have to specify to your radio parts jobber would be a power transformer for a 5V4-G rectifier tube with a low voltage 6.3 volt secondary capable of supplying at least 2.6 amperes and a 5 volt rectifier filament winding rated at 2 amperes.

The 6.3 volt secondary circuit of transformer T_3 is simple and conventional in every way. It operates the filaments of six tubes. You will note these tube filaments are in parallel which means that each tube *forms a separate load* on the secondary circuit. The centertap to the low voltage secondary of 6.3 volts is grounded which means that it is connected to *the metal chassis of the receiver.* Such a ground or chassis connection is highly desirable for it enables the *entire filament circuit* to discharge to ground any static charges to which it might be susceptible. While the cathode of each tube is the actual electron emitter, it must be remembered the filament itself is the real heating source and, as a consequence, *some few electrons are radiated by it.* Some of these may get over into the regular plate-cathode stream and thus leave the filament entirely. This would have a tendency to cause the filament to assume a positive charge on account of having lost electrons—thus, it would soon be trying to attract other electrons. As a con-



The above view shows a half-shell type of power transformer such as T_3 of Fig. 1. It is mounted from the top side of the chassis with the terminals extending through a hole in the chassis for convenient wiring underneath.

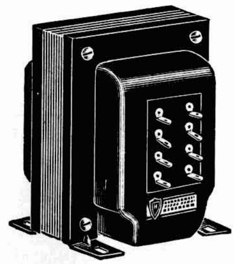
sequence it would develop small alternate positive and negative charges which might be reproduced as a hum in the receiver. In addition, the filament is within the tube envelope and, therefore, is in or very near to the strong electrostatic fields around the other tube elements. Under these conditions it is readily seen that the filament could have induced into it electrical charges which could not leak away except through very high insulation resistances. However, if a ground connection is provided any charge which may accumulate on the filament can instantly leave it by way of the ground connection and so equalize itself throughout the entire circuit. An *electrical* centertap connection is usually provided on the secondary because this is the point in the wire winding where the AC cycle goes through zero and it, therefore, remains at zero potential. Thus, any equalizing charge either entering the secondary winding or leaving it cannot add to nor subtract from the AC voltage already present to create other unequal charges. With this centertap connection held at zero potential all of the time, no hum can result from the filaments of the various tubes accumulating transient charges because they can all discharge to ground through the centertap connection.

The use of color brings out the details of all the circuits in a radio schematic diagram. Study Fig. 1 carefully and note the green circuit is only a small portion of the entire circuit wiring. While this is true note also that the green or AC circuit is the basis for the entire operation of the receiver, and, if a defect occurs in it, the entire receiver will cease to operate.

THE RED CIRCUIT

The red circuit in Fig. 1 deserves careful study because it shows distribution of all *positive* DC voltages from the rectifier cathode up to the various tube elements and through the bleeder resistor R_3 to ground. The cathode circuits are also a part of the DC voltage circuit, but they are considered negative with respect to the plates and screen grids and are, therefore, indicated in another color (blue) and will be taken up later.

At this time you are probably wondering about the direction of current flow. Is it from negative to positive or from positive to negative? Both conceptions are in vogue in the electrical and radio industry, and there is a basis for argument on both sides of the question. There can be no real basis for argument, however, if there is a distinction made between *electron flow and current flow.* It has been definitely established that electrons drift from an atom with excess electrons to one which is positively charged or to one with a deficiency of electrons. This is fundamentally true regardless of whether or not the voltage pressure



This view shows a power transformer with all wire windings fully protected with a metal shell. The wire leads of the windings are soldered to the back side of the terminals shown above. Circuit connections are soldered to the external terminals.

is AC or DC. There are some, however, who contend that the flow of current and the flow of electrons are two different things entirely, and it is here that there begins to be room for argument.

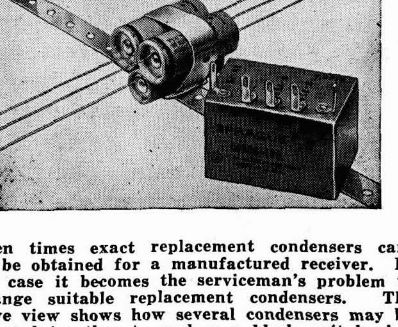
In the early days of electricity, current was assumed to flow from positive to negative or from a high to a low level, just as water will. Thus, much of our radio and electrical literature follows this conception. All of this was before the days of the electron tube. Later investigations show that electron flow is from negative to positive and that theory is used throughout the SAR course. We, therefore, make no distinction between current flow and electron flow and simply refer to it as current flow and its direction of movement as being from negative to positive. Actually it is unimportant whether you consider the direction of current movement as being from negative to positive or from positive to negative *as long as you maintain the same consideration for the solution of a given circuit.*

To return to the red circuit, note it begins at the cathode of the rectifier tube—this polarity being established by the tube by virtue of the fact that it changes AC to DC—this is the first point in the circuit where the DC positive charge can be said to come into being. All of this, as you know from your previous study of rectification is due to the principle that current can only flow through the rectifier tube in one direction. The 5V4-G tube in this circuit is a full wave rectifier and, therefore, both halves of an AC wave form are rectified. The cathode accepts or accumulates these rectified pulses and, therefore, is ready and prepared at all times to feed them to the rest of the circuit according to the load demand.

The no signal DC load demand on this set is 127.4 milliamperes distributed as follows: 6F6 tube plate circuit, 34 ma., screen current 6.5 ma and for two tubes the total will be 81 ma.; for the 6C5 (V_4) 8 ma.; for the other 6C5 (V_3) .2 ma.; and for each of the R.F. 6SK7 tubes 9.2 ma. for the plates and 2.4 ma. for the screen grids and for these two tubes a total of 23.2 ma. In addition the bleeder resistor R_3 is allotted 15 ma. Thus, the total current load is equal to 40.5+40.5+8+.2+11.6+11.6+15 or 127.4 milliamperes. This neglects any leakage current through C_{15}, C_{16} and C_{17}. On the average, this will equal from 1 to 2 ma. per 8 mfd. of capacity so for three condensers this should not exceed 6 ma. These values also neglect peak plate current values which are sure to occur on strong signals. However, due to the maximum rating of the 5V4-G rectifier tube this factor will automatically take care of itself as peak pulses rise to high values. So for practical design purposes a maximum plate current value of 127.4 ma. is sufficient assumption for this receiver.

The manufacturer's characteristic curve for the 5V4-G tube shows that with a current drain of 127.4 ma. (approximately) the DC output for the tube with an 8 mfd. input condenser for the filter should be 330 DC volts with 300 AC input volts *per plate.* Thus, from the cathode of the 5V4-G tube to the centertap of the high voltage secondary 330 DC volts exist. The remaining problem is to get this voltage properly distributed so as to operate the various tube circuits. A beginning can be made by starting at the centertap of the high voltage secondary or at the cathode of the 5V4-G tube. The reason for this is the entire circuit of the receiver is a *series load* on the rectifier tube, and it does not make any difference where calculation is started on a series circuit as long as two factors of Ohm's law are known. In this case, E and I are known so values of R must be found to distribute E and I to fit the requirements of the circuit.

Suppose a start is made at the cathode of the 5V4-G tube. Trac-



Often times exact replacement condensers cannot be obtained for a manufactured receiver. In this case it becomes the serviceman's problem to arrange suitable replacement condensers. The above view shows how several condensers may be strapped together to replace a block unit having one or more defective condensers. Courtesy of **Sprague.**

ing along this red circuit from the cathode, you will note the first resistor element from a DC viewpoint is the choke coil L_{15}. All current for the receiver must pass throught this choke coil. A practical value for it is 15 henries and 375 ohms. The voltage drop across it is equal to $.1274 \times 375 = 47.7$ or approximately 47 volts. Thus, the DC voltage at its negative end is $330 - 47$ or 283 volts. This is applied to the centertap of output transformer T_2. Operating values for the 6F6 call for 250 volts for the plate and a negative bias of 16.5 volts, making a total of $250 + 16.5 = 266.5$ volts. This is for medium operation and does not work the tubes to their maximum limit. Thus each half of the output transformer primary winding should have enough resistance to drop the voltage $283 - 266.5$ or 16.5 volts. In each plate circuit there will flow 34 ma. Thus the resistance of windings L_{11} and L_{12} should equal

$$\frac{16.5}{.034} \text{ or 485 ohms.}$$

Actually a push-pull output transformer will have unequal halves in the primary winding from a DC viewpoint. This is because some of the layers of wire are wound over other layers with their insulation and, therefore, more turns of wire will be on one half winding than the other. Rather than place the centertap at the DC midpoint of the winding, it is placed at the AC impedance midpoint so that each tube will have the proper AC load. Thus, in a well designed transformer, the primary half windings *will usually have unequal DC resistance.*

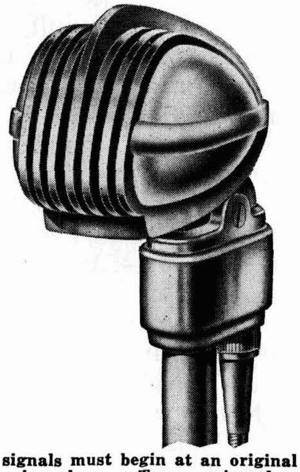
In adjusting the tuned circuits of a TRF or Superheterodyne type receiver, a dependable signal source such as a signal generator or test oscillator is needed. The above view shows a Hickok signal generator for use in adjusting tuned circuits. Your Service course lessons give full details on how to use this and other similar instruments.

Calculations show that each half winding of the primary should have a DC resistance of 485 ohms. Note this is an exact calculated value. For practical conditions in an actual output transformer, one half of the primary winding will have slightly more resistance than the other half. For instance for one manufactured receiver using 6F6 push-pull tubes, the specifications show that one half of the winding should be 520 ohms and the other half 490 ohms. This is a difference of 30 ohms between half windings. Remember this represents practical conditions. For the purpose of this lesson and to simplify calculations, it is assumed that the primary winding of the output transformer T_2 in Fig. 1 has equal half windings of 500 ohms each (instead of the calculated value of 485 ohms as mentioned in the foregoing). Thus, if 500 ohms is accepted, there will be an approximate voltage drop across each half of the output transformer primary equal to .034 $\times$500 or 17 volts. This subtracted from 283 volts gives 266 volts, and this, in turn, is to be distributed as approximately 250 volts for the plate and 16.5 volts for the control grid as measured from plate and control grid to ground. The voltage drop across R_{10}, R_{11} and R_{12} provides grid voltage as will be explained later.

Note the screen grids of the 6F6 tubes also connect to the same positive point as the centertap of the output transformer. This means they operate at approximately 266 volts as measured from screen grid to ground. This places them at a higher potential than the plates. While this does not follow the tube manufacturer's exact specifications, it is an accepted practice by radio manufacturers and is followed generally in the industry.

The next step in the voltage distribution circuit is the second choke or speaker field winding. Not all current from the power unit flows through this winding. The plate and screens of the 6F6 tubes draw approximately 81 milliamperes so this leaves 127.4−81 or 46.4 milliamperes to flow through the speaker field winding. Voltage in a receiver is usually measured from the tube elements to ground or to the cathode. In this case most of the cathodes are directly grounded so the chassis (or ground) will be used as a reference. It was stated previously that 283 volts existed at the mid point of L_{15} and L_{16}. Note, however, this is in reference to the centertap of the high voltage winding. To get the net voltage on the tube elements (with reference to ground), 16.5 volts must be subtracted from 283 volts to give 266.5 volts. The 16.5 volts is the voltage drop across R_{10}, R_{11} and R_{12} which will be taken up later. To avoid using the fraction in 266.5 volts, let it equal 266 volts. At the left end of L_{16} 266 volts exist and at the right end 250 volts are wanted to operate the other tubes. Thus, a voltage of 266−250 or 16 volts must be lost across this winding. Since the current through the winding is 46.4 ma. and the voltage across it is 16 volts, its resistance is equal to $\frac{16}{.0464} = 344.8$ or, approximately 345 ohms. From this it should be clear that the output of the entire filter is approximately 250 volts and this is normal plate voltage for the tubes in the receiver.

The 6C5 audio tube (V_4) is the next one to which voltage is applied. It will draw between 7 and 8 milliamperes of current if the applied plate voltage is in the neighborhood of 250 volts with a control grid voltage of 8 volts. If



All radio signals must begin at an original source. The above view shows a Turner microphone which is one instrument by which original AF signals are produced. Most radio stations and large public address systems employ a "mike" similar to this one.

7 milliamperes is taken as an average value with a normal resistance of 1500 ohms for the primary of T_1, the voltage drop across the primary will be $.007 \times 1500 = 10.5$ or 10 volts. Thus the actual voltage for this tube will be $250-10$ or 240 volts.

The next tube is the detector 6C5 (V_3) which includes in its plate circuit R_7 of 10,000 ohms, R_6 of 250,000 ohms, an RF choke coil of 80 ohms and a cathode resistor R_5 of 85,000 ohms. With no signal plate current of .0002 ampere the voltage drop across R_7 is $10{,}000 \times .0002$ or 2 volts, across R_6 it is $250{,}000 \times .0002$ or 50 volts, across the RFC it is $80 \times .0002$ or .016 volts, across R_5 it is $85{,}000 \times .0002$ or 17 volts. These various voltage drops for the detector circuit total 69.016 or approximately 69 volts, leaving $250-69$ or 181 volts from plate to cathode to operate the tube. From plate to ground the voltage is $181+17$ or 198 volts.

The remaining two 6SK7 tubes are exactly alike, and what is true for one is true for the other. These tubes have a low DC resistance winding in their plate circuits so almost the full DC voltage from the output of the filter is applied to them. The resistance of coils L_3 and L_5 is 18.5 ohms and the plate current through them is .0092 ampere. Therefore, the voltage drop across each coil is $18.5 \times .0092$ or .17 volt—a value which can be neglected entirely. Thus tubes V_1 and V_2 with their cathodes at ground potential will have a plate voltage of 250. Since plate voltage conditions are the same for tubes V_1 and V_2, this completes the explanation of all the plate circuits.

The remaining part of the red circuit is the screen grids of the two 6SK7 tubes and the bleeder resistor R_3. This circuit is controlled by resistor R_4 which reduces the plate voltage from approximately 250 to 100 volts for the screen grids. The screen grids draw 2.6 ma. each and resistor R_3 draws 15 ma. This gives a total of 20.2 ma. The voltage must be reduced 150 volts so $R_4 = \dfrac{150}{.0202}$ or 7,425 ohms.

Resistor R_3 provides a path to ground for the positive screen grid voltage and is called the bleeder resistor. The current through it is 15 ma. and the voltage across it is 100 volts. Therefore, its value is equal to $\dfrac{100}{.015}$ or 6,666 ohms. The power rating for R_3 as well as all other resistors in this circuit is equal to $E \times I$ —that is the voltage drop across each resistance times the current through it will give the minimum watt rating for each resistor. There are several condensers across the B+ circuits in Fig. 1, and their function will be described further on in this lesson.

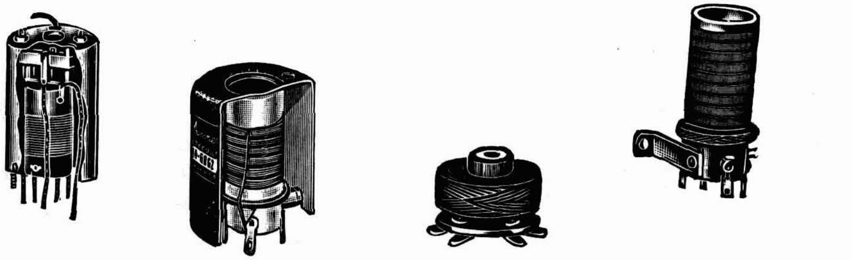
THE BLUE OR CATHODE CIRCUITS

It was previously explained that the blue or cathode circuits were technically a part of the red or plate circuits because the cathode terminals at the tube sockets are usually at a positive potential with reference to ground or the chassis of the receiver. This would be the case if a bias resistor were connected in series with each cathode as is often done. However, there are two ways in which bias voltage for control grids is usually obtained in AC operated receivers. Where the resistor is in series with the cathode of a given tube, it is called a *self bias* system. Where most or all of the cathodes in a given receiver are directly grounded, as in the case of Fig. 1, resistors are connected in series with the B negative lead to provide bias voltage. In this case the cathode current of all tubes in the receiver are caused to flow through the resistors and this system is called a *fixed bias*. Fixed bias is essential for Class B or C amplifiers and is often used in Class A amplifier systems, as in Fig. 1. Tube V_3, the detector, obtains its bias from the voltage drop across R_5, and this is an example of the self bias system. Tubes V_1, V_2, V_4, V_5 and V_6 employ the fixed bias system and obtain their bias voltages from across R_{12}, R_{11} and R_{10}, as will be explained. It has already been explained that the value of R_5 is 85,000 ohms and that a 17 volt drop occurs across it as a result of the .2 ma. plate current through the tube. Just how this voltage is applied to the control grid of the detector tube will be explained when the yellow circuit is described.

The fixed bias system is illustrated by R_{10}, R_{11} and R_{12} in Fig. 1. As in any full wave rectifier circuit, current must flow over the path of the centertap of the high voltage secondary. In flowing over this path, it must flow through resistors R_{10}, R_{11} and R_{12}. Therefore, if the values of these resistors are proportioned properly, correct voltage drops will occur across them for the control grids of the tubes. The grid returns of the various tubes must, of course, be connected to the proper points in the circuits for this to occur.

In a fixed bias circuit of this type, the resistor values must be so proportioned that the lower bias voltage values will occur nearest the grounded end of the string of resistors because the voltage drops across all the resistors are additive. Thus, you will note three resistors are in series between ground and the centertap to the high voltage winding. There will be a certain voltage drop across R_{10}, R_{11} and R_{12}. If a voltmeter is connected from ground (positive terminal) to the junction of R_{10} and R_{11} it will read the voltage drop across R_{10}. If the positive terminal of the meter is left connected to ground and the negative terminal is moved from the junction of R_{10} and R_{11} to the left end of R_{11}, the meter will read the voltage drop across R_{10} *plus* that of R_{11}. Likewise, if the negative terminal of the meter is moved to the left end of R_{12} it will read the voltage drop across R_{10} *plus* that of R_{11} *plus* that of R_{12}. From this it should be clear that the voltage drop across these and other similarly connected resistors is additive.

The requirements of the tubes are such that the 6SK7 tubes require a control grid voltage of 3 volts, the 6C5 audio tube (V_4) 8 volts, and the 6F6 tubes 16.5 volts. Since the lowest value of grid voltage must appear nearest the grounded end of the series string of resistors, it is clear that R_{10} must provide 3 volts, R_{11} plus R_{10}, 8 volts and R_{12} plus R_{10} and R_{11}, 16.5 volts. It has already been shown that the total current for this receiver is 127.4 milliamperes



The average radio set employs several wire wound coils. In the above four typical examples are shown. At the left is a typical IF transformer used in the superheterodyne type receiver. Next is a typical RF antenna coil such as L_1 and L_2 of Fig. 1. The third coil is an unshielded RF choke coil such as L_7 in Fig. 1. The coil to the right is another RF coil of the unshielded type. It is usually mounted within a metal container before being used. Courtesy of Meissner.

or .1274 ampere. Therefore if R_{10} is to provide 3 volts, its value is found from $\frac{3}{.1274}$ or 23 ohms. R_{11} is to provide 8 volts, but 3 volts is already provided by R_{10}. So actually R_{11} must provide 5 volts because $8-3=5$. Therefore, the value of R_{11} is equal to $\frac{5}{.1274}$ or 39 ohms. Resistor R_{12} is to provide 16.5 volts but R_{10} and R_{11} provide 8 volts. Therefore, R_{12} need provide only $16.5-8$ or 8.5 volts. Thus, R_{12} is equal to $\frac{8.5}{.1274}$ or 66 ohms. Thus, the value of all three resistors is R_{10}, 23 ohms; R_{11}, 39 ohms; and R_{12}, 66 ohms. Each of these must be capable of carrying the required current and must have the proper power rating. The power formula is $E \times I = W$ so the power rating for R_{10} is $3 \times .1274$ or .3822 watts, for R_{11} $5 \times .1274$ or .637 watts and for R_{12} $8.5 \times .1274$ or 1.0829 watts. All of these are odd power values and standard practice would employ 2 watt resistors for each of them.

THE YELLOW CIRCUIT

This circuit is extremely interesting. You should remember, however, this description treats it from a *DC viewpoint* with respect to how the various grids are operated. Later the AC or signal operation will be described. One cardinal point to remember when tracing the circuits of any radio tube is that the DC grid voltage for the tube is always equal to *whatever voltage exists between the control grid and cathode of the tube*. Likewise, that voltage existing between the plate and cathode is equal to the applied plate voltage. Thus, the cathode of the tube is always the reference point when measuring voltage applied to any other element of the tube. With this basic principle in mind, you are ready to consider the control grid circuits of Fig. 1. First consider the two 6SK7 tubes. A simplified circuit of the control grids is shown in Fig. 2. In this the RF coil windings and the two resist-

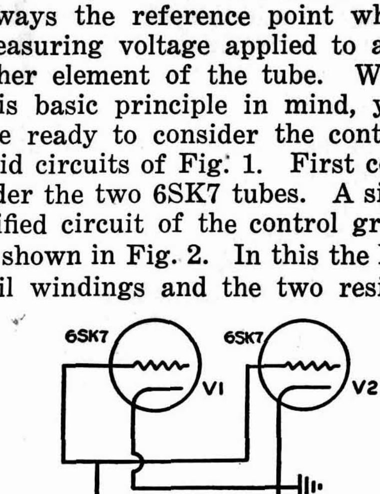


FIG. 2

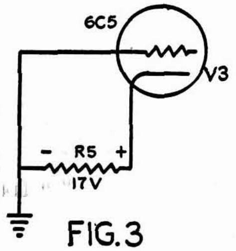


FIG. 3

ors R_1 and R_2 have been *omitted*, it being assumed that they are conductive. This clearly shows how 3 volts are applied to the two control grids. Note the two control grids form one common circuit and the cathodes form another. Remembering that the voltage existing between control grid and cathode is the value of the applied control grid voltage, it is easy to see in Fig. 2 how the control grid voltage is applied. The left end of R_{10} is negative and the right end is positive. This makes the cathode positive and the control grid negative because the two tube elements connect to these polarities as established by the resistor R_{10}. Thus, it may be said the control grid is 3 volts negative and the cathode is 3 volts positive but with respect to each other only.

The next tube in the line up is the detector 6C5 and note it employs its own bias resistor in series with its cathode. A simplified circuit of it is shown in Fig. 3. Note in this case the cathode is still positive which makes the control grid negative just as in Fig. 2. Note, also, the ground connection has moved from the positive, as in Fig. 2, to the negative, as in Fig. 3. This is necessary because the V_3 tube employs its own cathode resistor, and if the cathode of this tube is to remain positive in relation to the control grid (the return of which is grounded) the ground connection must be made in such a way as to permit this polarity. If the cathode of the tube V_3 were directly grounded, as is the case with the other tubes, then a fixed bias system similar to R_{10}, R_{11} and R_{12} would be required.

From a study of Figs. 1, 2 and 3, it should be clear to you that the metal chassis of the receiver is acting as a conducting path for a portion of all the grid circuits in this receiver. This, incidentally, is standard practice in the radio industry for most receivers. This is made possible by the fact that all circuits in a receiver at a zero or common *potential* can be made one common circuit. Take note here that zero or ground potential means that this part of the circuit does not have polarity *except with reference to some other definite point in the receiver*. Also, you should understand that no one part of the receiver circuit *need be grounded.* It can be grounded at any intermediate point between extreme positive and extreme negative. Once the ground point is established, however, proper polarity of all other parts in the receiver must be maintained especially if the receiver employs an actual ground connection as, for instance, to a cold water pipe. The reason for this is one side of the AC power line is grounded, and thus if an improper point in the receiving circuit is grounded it will short circuit the power supply of the receiver. For instance, if the cathode of the tube V_7 in Fig. 1 (or any other highly positive circuit) should become grounded to the chassis of the receiver, the entire power transformer and rectifier tube would be sure to cause trouble. Thus, in Fig. 1 all DC voltages are either positive or negative in relation to ground or the metal chassis of the receiver.

Just how the chassis may be employed to act as a conductor for a portion of the grid circuits may be seen by referring to the Yellow Circuit of Fig. 1. Note for tube V_1 the DC control grid circuit begins at the tube socket and continues through the secondary of coil L_2, through R_1 and R_{10} to ground. The cathode of the tube is directly grounded at the tube socket. Thus, one end of R_{10} is grounded and so is the cathode of the tube—but note these ground connections occur at two different points. Designers try to have these connecting points to the chassis occur as close together as possible. Actually, they may be from 2 or 3 to 12 or more inches apart. Regardless of how much distance is involved, the *metal chassis* of the receiver becomes the conducting medium to complete the circuit. In Fig. 1 the metal chassis completes the circuit between the cathode of tube V_1 and the grounded end of R_{10}. For tube V_2 a similar condition exists where the chassis completes the circuit between the cathode of this tube and the grounded end of R_{10}. For tube V_3 note coil L_6 is grounded and so is one end of R_5. Thus, the chassis completes the circuit between these two points. For tube V_4 the circuit may be traced from the cathode of the tube via the chassis to R_{10}, through R_{10} to R_{11} and from this point through R_9 and R_8 to the grid of the tube. The resistors in the grid returns

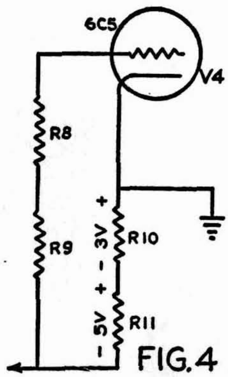


FIG. 4

such as R_9, R_2 and R_1 *do not involve the flow of DC,* and their purpose will be explained later. From the foregoing explanation you should understand *that the metal chassis of the receiver can act as a common conductor for several circuits* just as one conducting wire can be made a portion of several other circuits.

To consider the complete grid circuit of tube V_4 in Fig. 1 refer to Fig. 4 where it is shown in a simplified manner. As in the other circuits, all elements not having to do with the DC distribution are not shown for simplicity. Thus, in Fig. 4 there is a complete circuit from the grid of the tube through R_8, R_9, R_{11} and R_{10} to ground. With 3 volts across R_{10} and 5 volts

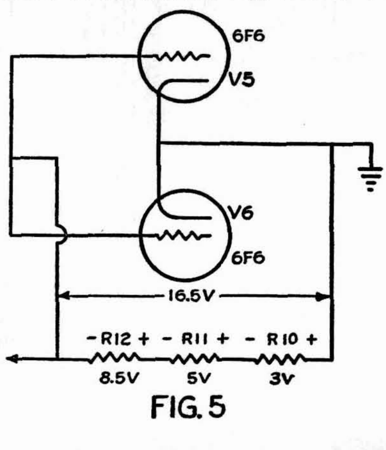


FIG. 5

across R_{11}, a total of 8 volts is applied between grid and cathode of the tube. As already explained, the chassis completes the circuit from R_{10} to the cathode of the tube.

Figure 5 shows how the control grid circuit is completed for the two push-pull 6F6 tubes. Note the cathodes are joined together and grounded. The grids of the tubes also join together and connect to the negative end of R_{12}. These tubes require 16.5 volts for their grids and this is provided by a 3 volt drop across R_{10}, 5 volts across R_{11} and 8.5 volts across R_{12} for a total of 16.5 volts. The ground connection in Fig. 5 merely symbolizes that the positive end of R_{10} and the cathodes of the tubes are at ground potential. Actually, of course, the cathodes are grounded at one point and the positive end of R_{10} at another point with the chassis acting as the medium to complete the circuit.

By now you have, no doubt, come to the conclusion that resistors R_{10}, R_{11} and R_{12} are nothing more than a series voltage divider. However, you may not clearly understand how the additive voltages across these resistors can be made to act on several tubes at different values. This is explained by the fact that the various grids do not draw current from the DC divider. It is the *voltage pressure* only that is utilized. This is comparable to three coil springs being placed end to end and then being compressed at their extreme ends. While in this condition they will maintain a steady pressure as long as they are not required to do work or expend energy. It is the same way with the three resistors R_{10}, R_{11} and R_{12}. No DC energy is expended in the grid circuits proper. The grid circuits, therefore, do not consume DC power and require voltage pressure only to maintain them in operating condition. This goes back, you will recall, to your fundamental tube studies where it was explained that no DC current flow could be tolerated in the grid circuit else distortion would creep in. The exceptions to this are class B and C amplifiers, and, in this case, special circuits and tubes take care of the difficulties as explained in your tube lessons. Also, because of the fact that no DC flows in the grid circuit no voltage drop occurs across such resistors as R_8, R_9, R_2 and R_1. These are filter and *de-coupling* resistors, and their exact function will be better appreciated by you when you come to the study of AVC or automatic volume control.

THE BLACK CIRCUIT

The black circuit of Fig. 1 represents the metal chassis and all parts which are at a zero or neutral potential. It is common practice in the radio industry to refer to voltages as being below or above ground or zero potential. Thus, the screen grid and plate voltages in Fig. 1 are above (or more positive) ground potential while the grid voltages are below (more negative) ground potential. You should keep this in mind when studying the black circuit of Fig. 1. The antenna coil L_1 is black because no DC voltage is applied to it. That end of the coil connecting to the antenna is called the high potential end of the coil while the end connecting to ground is called the low potential end. This is in

A matched antenna kit is highly desirable for best conditions of sensitivity and selectivity. The above view shows such a kit as made by Taco. It includes matching transformers, overhead antenna, twisted lead-in, insulators, etc.

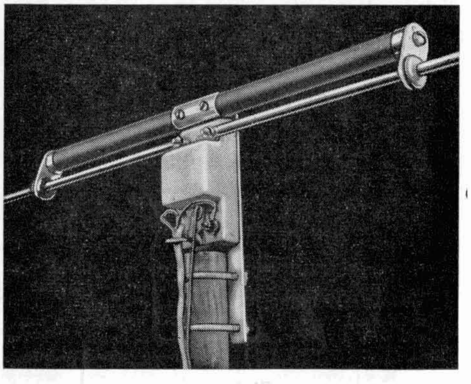
reference to the AC signal and does not refer to the DC voltages. The AC signal voltage distributes itself across this coil from top to bottom and is induced into L_2 which will be explained later.

You will note one side of each of the by-pass or filter condensers is black. This signifies that all AC pulses, variations or signals which pass through these condensers go to ground or to a point of neutral potential where they cannot interfere with the operation of the rest of the circuit. Also, you should understand that the passage of these AC pulses is permitted through the condensers only because the various condensers offer a path of less *reactance* in ohms than other parts of the circuit with respect to the DC resistance in ohms. Current is always seeking the path of least resistance. When in the form of AC it will always flow through a condenser in preference to a DC wire or resistance circuit if the reactance of the condenser in ohms is less than the DC circuit resistance in ohms (through which it might flow if the condenser were not present). Thus, where one side of a condenser in Fig. 1 is black, remember it indicates the condenser is used to by-pass AC out and away from a DC circuit. The action of the condensers of Fig. 1 will be described more in detail later on. The secondary circuit of T_2 and the voice coil of the speaker are indicated in black because DC is not applied to them. The same thing holds true with respect to the transformer and choke coil cores in Fig. 1. No DC is applied to them. They are in actual contact with the metal chassis of the receiver so that any transient charges built up on them can be immediately discharged to ground.

Other black designations in Fig. 1 indicate tube symbols and a grounded tube shield or metal envelope. The black numbers and letters in Fig. 1 have no special electrical significance other than to indicate values and certain parts.

FILTER CONDENSERS AND RESISTORS

The various filter resistors and by-pass condensers of Fig. 1 have been mentioned before. A discus-



High frequency reception such as FM and television requires a dipole type of antenna in two sections. In addition, matched coupling transformers and a matched transmission line or lead-in is required. The above view shows such an antenna as made by Taco.

sion of them has been omitted up to now to avoid the study of too many subjects at one time. A description of these circuit elements is now in order. The first of these units to be studied is R_1 and C_4.

If the grid bias is secured by bringing the grid return to the ungrounded side of the biasing resistance *without* providing a filter circuit, the variations in plate current caused by the signal may cause a corresponding variation in grid voltage. This variation will be *out of phase* with the signal thus tending to neutralize the signal. This action is called *degeneration* and must be avoided. If there is a ripple in the plate supply voltage, this ripple will be impressed on the grid because of the biasing resistance. In order to avoid these undesirable conditions, a condenser is placed across the biasing resistance to ground. Experimental work by engineers has developed a rule of thumb which has been found practical in choosing the correct value of such a condenser. *Its size should be about 1/10 the impedance of the by-passed part.* In certain cases this value may reach unwieldy proportions, however, by placing a resistance in the grid return (R_1), the value of the by-pass condenser may be kept within a reasonable limit. R_1 in these cases, may be from 3000 to 100,000 ohms. It is desirable to keep R_1 as low as possible because if its value is too high the entire grid circuit will become unstable and extremely sensitive to stray fields. This *portion* of the circuit is shown in Fig. 6. You may see that any variation in bias voltage, such as ripple will be developed across R_{10} and therefore across C_4. The cut-off value of this filter condenser can be assumed to be 50 cycles (for 60 cycle operation). The time constant for an RC filter is T=RC. T=time in seconds, R=resistance in ohms and C=the capacity in farads. R_1= 100,000 ohms and C_4 = .00000002 farad (.02 mfd.). Therefore T = .00000002×100,000 or .002 seconds. This result is satisfactory from the ripple frequency standpoint. The other proof necessary is to determine if the condenser C_4 offers a path from grid to cathode, of less impedance than the resistors R_1 and R_{10}, to the *lowest frequency* to which L_2 and C_1 resonate. Here the lowest frequency is used as the capacitive reactance will *decrease* as the frequency is increased. As this frequency is assumed to be 540 KC, and, as the condenser is known to be .02 mfd. its reactance may be calculated as follows: $X_C = \frac{1}{2\pi FC}$

$$X_C = \frac{1}{6.28\times540\times10^3\times2\times10^{-8}}$$
$$= \frac{1}{6.28\times540\times2\times10^{-5}}$$
$$= \frac{1}{6.28\times1080\times10^{-5}}$$
$$= \frac{100,000}{6.28\times1080}$$
$$= \frac{100,000}{6782.4}$$
$$= \mathbf{14.7\ ohms.}$$

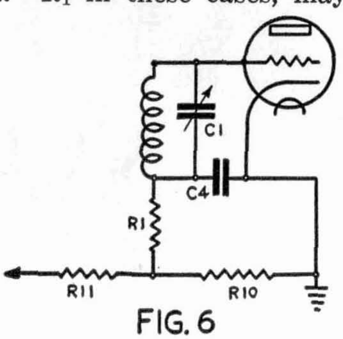


FIG. 6

As C_4 is in parallel with R_1 and R_{10} which total 100,023 ohms, you may readily see that both conditions will be fulfilled with a capacity of .02 mfd. for C_4 and a value of 100,000 ohms for R_1.

In this case (Fig. 1) R_1 and R_2 are also termed de-coupling resistors. This means that the two grids are *isolated* insofar as one disturbing the other is concerned. In cases where these de-coupling resistors are not used, *motorboating* or undesirable oscillation can take place due to the interaction between the two RF stages. Resistor R_2 and condenser C_5 function in the same manner as just described.

The by-pass condenser C_6 serves two purposes. The first is to provide a short path to ground for any *stray* RF on the screens of the first two tubes. The second is to aid in removing any small percentage of ripple which could be present in the supply. Working, as it is, in combination with resistors R_4 and R_3 it serves to level the voltage at this point. The usual capacity of .5 to 1 mfd. is sufficient.

At V_3 (Fig. 1) the yellow dotted line from the ground connection of L_6C_3 to the ground of C_7R_5 indicates that there *is* a chassis connection between the two. By-pass condenser C_7 across R_5 is of .05 mfd. capacity. Due to the extreme sensitivity of the detector, this size has been chosen. As far as RF is concerned, this condenser is in *series* with the tube capacity. As its capacity is several *million times* greater than the grid to cathode capacity, the largest RF voltage drop will be across the tube and a low resistance path will exist for the RF grid return. R_5 will produce the bias for this tube as has been mentioned.

The RF choke (RFC-L_7) and condenser C_9 serve as the *plate filter* for the detector as you have studied in your lesson on detection. The choke is designed to offer a high reactance to RF and, in conjunction with the condenser C_9, forces any RF remaining in the output of the detector to ground. The value for C_9 must not be too large as it will act as a cut-off filter for AF in conjunction with R_6 and C_8 if improperly chosen. In other words, if their capacity is high they will by-pass the high audio frequencies just as a tone control would do. These will be discussed later in this lesson.

Resistor R_7 and condenser C_8 function as a plate filter and decouples the detector stage from the other stages in a manner similar to that described for R_1 and C_4 and R_9 and C_{12}.

Coupling condenser C_{11} must be of high quality with a very minimum of leakage. Its value is determined by the *time constant* in conjunction with R_8 and R_9. This will largely govern the frequency response fed to the tube V_4. For good low audio frequency response this time constant should be large.

Volume control is provided by the moving contact on R_8, which is a three terminal potentiometer. The grid of V_4 being connected to the center or variable terminal of the control it will receive an AC signal which will depend on the position of the moving element along R_8, this latter being a voltage divider in this case. Its value or resistance is chosen in accordance with the tube manufacturer's recommendations. If too high a resistance is used in this input position to a tube, the grid will become exceedingly sensitive and pick up hum and transient surges too easily.

Condenser C_{13} is of the low voltage electrolytic type. It is rated at 25 volts and 50 mfd. Condenser C_{14} is of the same value. Note that only R_{12} separates these two condensers, and its value (66 ohms) is so small that the two condensers are virtually in parallel. Their purpose is to aid in smoothing any ripple present in the bias circuit of R_{10}, R_{11} and R_{12}.

In arriving at the size of the filter condensers C_{15} and C_{16} the resistance of the load must first be ascertained. Since the voltage and current at the output of this first untuned filter is known the problem is simple. Since $R = \frac{E}{I}$ then the load resistance $R_L = \frac{283}{.1274}$ or 2221+ ohms. The formula for determining the capacity value of condensers in a filter as given in a previous lesson is $C = \frac{318{,}300}{F_C \times R_L}$ As the cut-off frequency is to be 50 cycles the solution is as follows:

$$C = \frac{318{,}300}{50 \times 2221},\ C = \frac{318{,}300}{111{,}050}$$

or 2.8 mfd.

As this is an odd value and as a high capacity is desirable at the input for maintenance of high voltage an 8 mfd. condenser is used for C_{15}.

The formula for determining the value in henries of the choke is $L = \frac{.3183 R_L}{F_C}$. This then becomes

$$L = \frac{.3183 \times 2221}{50},\ L = \frac{706.9443}{50}$$

or 14.13 henries. As this is an odd value, the 15 henry choke is used.

Being at the output of the filter just described, C_{16} will act as a tank or voltage regulator and, therefore, is chosen as 8 mfd.

Because the speaker field (L_{16}) handles less current and because its inductance (L) is approximately the same as L_{15}, a third 8 mfd. condenser is used as C_{17}. The working voltage rating of these three condensers is safely chosen at 450 volts DC.

The combination of L_{15}, L_{16}, C_{15}, C_{16} and C_{17} affords what is commonly known as a brute force untuned filter, as explained in a previous lesson.

THE RF TRANSFORMERS

The RF transformers shown in Fig. 1 are somewhat different than those you have studied up to now. You will note at the top of each primary winding, an extra coil is shown *with an open end.* The purpose of this is to give a more even overall gain for the broadcast band from 540 to 1600 KC. This extra coil is referred to as a coupling loop or coupling link. It usually consists of heavy wire, about size 14. One end of it is connected to the high potential end of the primary winding, and the other end, consisting of one or two turns, is held in place on the secondary winding by proper forming of the wire and the use of cement. You will remember it is a principle of tuned circuits that the gain varies for different frequencies where a wide band of frequencies is to be covered. Thus in the broadcast band, there is a natural tendency for the gain to increase as tuning advances toward the higher frequencies. Also, another factor prevalent in the early days of radio was to include just a few turns on the primary with a large number of turns on the secondary. Due to the few turns in the primary, it would resonate at some frequency in the tuning range of the circuit of its own accord. By this is meant the distributed capacity between the primary turns was enough to tune the inductance of the winding to resonance at some frequency in the band. Later practice, and that followed today, is to include a very large inductance in the primary winding of tuned circuits so as to form a maximum load for the plate circuit of the tube. This, in turn, employs relatively little coupling to the secondary circuit so as to get maximum selectivity. The large inductance together with the distributed capacity between the turns of wire tunes such a coil to a low frequency in the broadcast band somewhat near 540 KC. Thus, resonance of the primary circuit is established at this low frequency. As a result, there is greater amplification at the lower frequencies as tuning approaches 540 KC because of the resonant condition of the primary. This, in effect, reverses the natural characteristics of the tuned circuit wherein more gain is provided at the low frequencies than at the high frequencies. To off-set this lack of gain at the higher frequencies, the coupling link, or open end winding, is used for the RF transformers as shown in Fig. 1. This coupling link provides just enough extra coupling at the higher frequencies to give the desired gain. It is not so effective at the lower frequencies for the reason that the frequency is lower, meaning there is a smaller number of changes of magnetic lines of force taking place.

This system is used today in many TRF circuits as well as in the preselector stages of superheterodyne type receivers which you will study later on.

L_3L_4 and L_5L_6 are exactly the same. L_1 and L_2 comprise the antenna coupling transformer. All of the RF transformers are mounted in individual shield cans. The shield cans are 1⅞″ outside diameter and 2¼″ high and made of pressed zinc.

The exact specifications for L_1 are as follows: it is wound in what is called a *universal* fashion. This means that as the form on which it is wound is turned, the wire is moved from side to side so as to build up a *pie* shaped coil .093 inches long and consisting of 161 turns of number 36 single silk enameled (SSE) covered wire. The form upon which the coil is wound is an impregnated fibre tube ⅞″ in diameter and 2 1/16″ long. The form carries four solder lugs and L_1 is wound on the lug end about ½″ from the end. Coil L_1 is 1,000 microhenries (5% tolerance). L_2 is wound on this same form and consists of 10 pie sections (similar to L_1) which occupy a space of about 1½ inches on the form. The first section of L_2 is spaced 3/32 of an inch from L_1. L_2 consists of 147 turns of Litz wire. This wire is made of 7 strands of number 41 SSE wires braided together. Litz wire is often used in RF coils due to the maximum wire *surface* it offers over an equivalent solid wire —more about Litz wire in a following lesson. The inductance of this secondary (L_2) is 274.8 microhenries with *1% tolerance*. This small tolerance is necessary because of the fact that the three *tuning condensers* are on the same shaft therefore requiring exact and similar characteristics for L_2, L_4 and L_6. The two coils (L_1 and L_2) possess a *mutual inductance* of 120 microhenries ± 10%.

The coil turns are held in place with collodion, and after winding is completed and all terminals soldered, the coils are impregnated in wax.

The design of the RF transformers comprising L_3L_4 and L_5L_6 are similar to the antenna coil, but the primaries are designed for proper loading of the plates of the tubes at the frequencies to be covered. The primary (L_3) is wound on a ¼″ wax impregnated dowel rod ¾″ long. The coil consists of 831 turns of No. 38 SSE wire wound universally on the dowel and is approximately ¼″ long by ¼″ deep. The inductance of the primary is 5000 microhenries ± 5%. The short dowel with its winding is mounted *crosswise* at the lug end of the ⅞″ fibre coil form. The center of the dowel is spaced about ⅝ of an inch from the end of the form. The secondary (L_4) is wound in the same manner as described for L_2 and consists of 10 sections and 145 turns ± 1%. Note here that these two secondaries (L_4L_5) have *2 less* turns than the secondary L_2. This is because the compensating loop is wound close to the grid end of the secondary thus adding enough capacity in parallel to the tuning condenser to make up for the difference between 145 turns (L_4L_6) and 147 turns (L_2). The inductance of this secondary is 266.5 microhenries with 1% tolerance.

The three tuning condensers $C_1C_2C_3$ are each 365 mmfd. capacity (maximum). Using the resonant frequency formula given in a previous lesson, the lower frequency limit of the tuning coils and condensers may be calculated by substituting in the formula with the proper values.

THE DETECTOR PLATE FILTER

You will remember from your studies of detection that in both grid and plate circuit detection, an RF filter is required in the plate circuit. In Fig. 1 a filter of this type is included in the plate circuit of tube V_3. It consists of the RF choke L_7 and the condenser C_9. The purpose of the filter is to remove any RF which may remain in the plate circuit of tube V_3 after detection. The impedance of the choke to RF should be very high in relation to the impedance of condenser C_9. The purpose of the circuit is to practically present a short circuit to the RF so it will enter C_9, leaving the AF to go through the RFC and so be fed to the AF amplifier. To accomplish this, the impedance of C_9 must be low to RF and high to AF. For the same reason the impedance of L_7 must be low to AF and high to RF. If these impedances are arranged properly, proper detector filter action will be obtained. To bring about all of this, the ratio of the impedance of L_7 to C_9 should be very high with respect to RF. This ratio may be stated as $\frac{Z_L}{X_C}$ where Z_L equals the impedance of L_7 and X_C equals the reactance of C_9.

The lowest RF frequency to be handled by the circuit is approximately 540 KC—the lower limit of the broadcast band. A standard value for the RF choke coil is 20 millihenries and 80 ohms of DC. You will remember impedance, or Z, is equal to:

$$Z=\sqrt{R^2+X^2}$$

Before the value of Z can be found X_L (X) in the preceding formula must be found. You will remember that inductive reactance is equal to: $X_L=6.28\times F\times L$.

The frequency is equal to 540,000 or 54×10^4 cycles. The inductance is equal to .02 or 2×10^{-2} henries. Thus the problem becomes:

$$\begin{aligned} X_L &= 6.28\times54\times10^4\times2\times10^{-2} \\ &= 6.28\times54\times2\times10^2 \\ &= 6.28\times108\times100 \\ &= 628\times108 \\ &= 67{,}824 \text{ ohms.} \end{aligned}$$

The DC resistance of the choke is only 80 ohms. To get the impedance value, the usual formula should be used as follows:

$$Z=\sqrt{80^2+67{,}824^2}$$

The reactance value of 67,824 ohms is so much greater than 80 ohms it can be seen from inspection that the total impedance value is going to be practically the same as the reactance value. Actually, with R included the impedance equals 67,824.04 ohms which is just .04 ohm difference from the reactance. Thus it is seen that the impedance of the choke is very high at the lowest frequency in the broadcast band. It will of course be higher at the upper end of the band at 1600 KC. Since the RF will have extreme difficulty entering the choke, it may be shunted away from it by use of condenser C_9 if it, in turn, has a low impedance at the frequencies involved.

It is standard practice to use as a detector plate circuit by-pass condenser a value between .001 and .006 mfd. This has been proven true by experience and calculation will bear this out. A value of .003 mfd. would be average for this type of circuit. Its reactance will be equal to: $X_C = \frac{1}{6.28\times F\times C}$

The frequency is 540,000 or 54×10^4 cycles. The condenser in farads will be equal to .000,000,003 or 3×10^{-9}. Thus, the problem becomes:

$$\begin{aligned} X_C &= \frac{1}{6.28\times54\times10^4\times3\times10^{-9}} \\ &= \frac{1}{6.28\times54\times3\times10^{-5}} \\ &= \frac{1}{1017\times10^{-5}} \\ &= \frac{100{,}000}{1017} \\ &= 98.3 \text{ ohms.} \end{aligned}$$

The ratio of Z_L to X_C may now be obtained. It is equal to $\frac{67{,}824}{98.3}$ $=689.95$ or about 700 to 1. Thus, it is seen that all the RF which gets into the detector plate circuit is going to seek the path offered by C_9 rather than attempt to go through L_7.

From an AF viewpoint, L_7 should have minimum impedance and C_9 should have maximum impedance. In other words, the AF signal will seek the path of L_7 rather than C_9 which is what is wanted. Many AF calculations are based on a standard frequency of 400 cycles. This value will be used to show how L_7 and C_9 react to audio frequencies—the same principles will, of course, apply for any AF frequency from a few cycles on up to the upper limit of the band.

For C_9 at 400 cycles, X_C will equal:

$$X_C = \frac{1}{6.28 \times 4 \times 10^2 \times 3 \times 10^{-9}}$$

$$= \frac{1}{6.28 \times 12 \times 10^{-7}}$$

$$= \frac{10,000,000}{75.36}$$

$$= 132,696.3 \text{ ohms.}$$

For L_7 at 400 cycles, X_L will equal:

$$X_L = 6.28 \times 4 \times 10^2 \times 2 \times 10^{-2}$$

$$= 6.28 \times 8$$

$$= 50.24 \text{ ohms.}$$

Since the reactance of 50.24 ohms is more nearly like the DC resistance of 80 ohms for L_7, in this case, it is necessary to combine X_C and R to get Z which will be:

$$Z = \sqrt{50^2 + 80^2}$$

$$= \sqrt{2500 + 6400}$$

$$= \sqrt{8900}$$

$$= 94+ \text{ ohms.}$$

Thus, for AF, the ratio of X_C to Z_L is $\frac{132,696}{94} = 1411$. It is clear from this that AF will seek the path through L_7 rather than that offered by C_9.

THE AUDIO TRANSFORMERS

The primary of T_1 is rated at 1500 ohms DC with an AC impedance of approximately 10,000 ohms. The secondary is center tapped so as to properly feed the AF signal to the two 6F6 tubes. The ratio of the primary turns to the secondary turns is chosen so as to provide a signal voltage of not over 16.5 volts per tube.

The output transformer T_2 is chosen to provide the correct load for the 6F6 tubes. The *total* primary AC impedance from plate to plate is 10,000 ohms. The secondary of T_2 furnishes the current to operate the voice coil and, as the AC impedance of the voice coil is 6 ohms, the secondary is wound to match this value. The turns ratio of the output transformer is equal to the square root of the impedance ratio. The plate to plate impedance of the two 6F6 tubes is 10,000 ohms, making 5,000 ohms each side of the centertap. The secondary impedance is 6 ohms so the impedance ratio is $\frac{5,000}{6} = 833$. The turns ratio is therefore equal to $\sqrt{833} = 28.86$. Thus for every turn on the secondary there is 28.86 turns on the primary.

TRACING THE SIGNAL

Starting at the antenna, the signal voltage flows through the coil L_1 to ground. L_1 consists of 161 turns and L_2, 147 turns; thus, a slight stepdown in voltage is evident in transferring the energy from L_1 to L_2, this being done to aid in the selectivity. Notice that C_1 tunes L_2 (forming a parallel resonant circuit), and the voltage across C_1 is fed to the grid and cathode of V_1. The signal is amplified by the action of V_1 and this increased voltage is placed across L_3.

The signal path to the tube V_1 for the RF developed across C_1 is directly to the grid from one side of C_1, and *through* C_4 to the cathode of V_1 from the other side of C_1. As mentioned before, decoupling resistor R_1 prevents the RF from traveling into the bias supply system. The tuned circuit consisting of L_2C_1 here provides the first selection of the desired signal.

The RF circuit of the *plate* of V_1 is completed through by-pass condenser C_{10}; thus the AC signal path exists from the plate of V_1 through L_3 to by-pass condenser C_{10} and thence to ground or to the cathode of the tube. The by-pass condenser C_{10} is .5 mfd. and provides a path of *less* reactance to the cathode for the RF than through the power supply and back to the cathode. The winding of L_3 is 5,000 microhenries and provides a suitable load for the plate of V_1. The RF voltage in L_3 *induces* a voltage in L_4 which is tuned by C_2. Notice that the signal is again tuned here thus adding to the selectivity.

This second tuned circuit consists of L_4C_2. The RF voltage across C_2 is fed to the cathode of V_2 through C_5. The signal voltage is thus supplied to the cathode and grid of V_2. The signal is again amplified by V_2 and this increased RF voltage is thus fed to the plate coil L_5. The AC signal path to the cathode is through by-pass condenser C_{10}. The amplified RF in L_5 induces a voltage in L_6 which is a *third* tuned coil. It is tuned by C_3. This tuned circuit again aids in the selection of the desired signal and the rejection of other signals. The RF present at C_3 is fed to the grid and cathode of V_3. The grid to cathode circuit is through condenser C_7. This tube (V_3) is the detector and here the RF is rectified and filtered. The received and amplified RF *carrier* is here stripped of its AF component. Any RF remaining in the plate circuit of V_3 is by-passed to ground by C_9. The RF choke L_7 prevents the flow of RF into the audio coupling system. The audio frequency variations in the plate circuit of V_3 are applied to R_6 which is the load resistor for the detector. The AC signal path to the cathode for the AF is provided by condenser C_8. The audio frequency variations thus produced across R_6 are transferred to R_8 through C_{11}. Condenser C_{12} completes the signal circuit to the cathode of the tube. As R_8 is a volume control and has a variable contact the desired volume level of the signal is regulated by the position of the movable contact. This is possible because the grid of V_4 (the first audio stage) is fed from the volume control movable contact. The signal now in the form of an audio frequency is amplified by V_4 and this amplified AF is supplied to L_8 of T_1. The AF is next transferred to the secondaries L_9 and L_{10} through the core of T_1.

The audio frequency transformer (T_1) is a push-pull input transformer and the voltage of its secondary supplies the signal to V_5 and V_6. These two tubes comprise the power output push-pull stage.

The audio frequency voltage at the grids of V_5 and V_6 is further amplified by their action and is supplied to the output transformer primaries L_{11} and L_{12}. The signal voltage of these primaries is *stepped down* by T_2 to the proper value necessary to operate the voice coil of the speaker.

Note that throughout the receiver circuit use is made of the metal chassis as a path for the signal as well as for a ground connection of zero potential.

THE BROWN CIRCUIT

The brown circuit of Fig. 1 shows the distribution of the signal voltages as they pass through the receiver. No attempt is made to indicate the amount of amplification. The brown dash lines simply indicate the path of the signal voltages. Long dash lines are used in the RF part of the circuit to indicate high frequency while shorter dash lines from the detector to the speaker indicate AF energy.

Beginning at the antenna, high frequency energy is collected by it and, consequently, enters the coil L_1. The same voltage is induced into L_2 by mutual induction. It is then impressed across the grid and cathode of tube V_1. Note there is a short wire connection from the top end of L_2 to the grid of V_1. Note the cathode, the rotor of C_1 and one side of C_4 all connect to ground or chassis. Therefore, from an RF viewpoint, they are all at the same potential because they all form a common circuit. The metalic or conductor circuit from the lower terminal of coil L_2 is through resistors R_1 and R_{10} to ground. Remember the RF energy will be seeking the path of least resistance to ground. The path offered by R_1+R_{10} will equal 100,023 ohms while that offered by C_4 is .147 ohms at 540 KC. Thus, the RF energy will go through C_4 in preference to the path offered by R_1 and R_{10} to ground. The brown dash lines around C_4 indicate that the path of the signal is through this unit. It is in this way that the AC signal is applied across grid and cathode of the tube.

Referring to condenser C_1, do not infer from its length that there is an unduly long lead from the grid of the tube to the stator of the tuning condenser. Actually, this lead may be very short. However, it is shown long in the drawing to indicate the condenser is connected across coil L_2 and serves to tune it. The brown dash lines around the condenser indicates there is a strong electrostatic field around it and its wire lead due to the AC signal.

When the signal gets to the plate circuit of tube V_1, the same general action takes place as described for coils for L_1 and L_2. In the plate circuit the signal distributes itself across L_3 and the open end coupling coil. The signal path to the cathode is through condenser C_{10} at ground potential and with the cathode at ground potential, the signal voltage is effectively placed across plate and cathode of the tube. Next the signal is induced into coil L_4 where it is applied across the grid and cathode of tube V_2. Condenser C_5 in this case provides the short signal path to the cathode of the tube. When the signal gets to the plate of tube V_2, the same process is repeated all over again. The signal occurs across coil L_5 with condenser C_{10} acting as the return path to the cathode. Note condenser C_{10} is common to the plate circuits of both tubes V_1 and V_2.

Next consider the screen grid circuits of tubes V_1 and V_2. The screens are located directly in the signal path within the tubes between the plates and cathodes. They are also at a positive potential with relation to the cathode and could, therefore, act as plate elements. The reason they do not act as plate elements is because of condenser C_6. This condenser is common to both the screen grid circuits. Thus, if any RF energy attempts to flow along either screen grid circuit, it will be immediately by-passed to ground by way of condenser C_6. If this condenser were not included, the brown dash lines would appear along the screen circuit to indicate the presence of RF energy. With this present there would be severe oscillation of the RF stages. For this reason it is essential that all RF screen grid circuits be by-passed with a suitable condenser.

When the signal reaches coil L_6 it is applied directly across the grid and cathode of the 6C5 tube. The dashed yellow line indicates the connection from coil L_6 to the cathode of the tube is by way of the metal chassis and resistor R_5 and condenser C_7—the latter will present the least opposition to the flow of RF. It is in the detector tube where separation of RF and AF takes place. As a consequence both RF and AF occur across R_5 and C_7. Almost all of the RF and AF will go through C_7. The reactance of C_7 will be rather high for AF of low frequencies, but it will still be less in ohms than will be the resistance of R_5. Thus, the longer brown dash lines to the left of C_7 indicate RF, and the shorter dashed lines to the right of it indicate the presence of AF. In the plate circuit of tube V_3, the brown lines around C_9 indicate it is passing all of the RF through it. The AF continues on through the RFC (L_7) wherein a large AF signal voltage is developed across R_6. This AF signal voltage is transferred to the following grid circuit by way of condenser C_{11} as indicated by the brown short dash lines around it. While condenser C_{11} will transfer most of the signal voltage on to the next stage, some of it will appear across R_6 and will be by-passed to ground through condenser C_8. The relatively few brown dash lines indicate this distribution. Condenser C_8, of course, provides the short return path back to the cathode of tube V_3.

When the signal gets over into the grid circuit of tube V_4 it is applied across the grid and cathode of the tube by way of R_8, R_9 and C_{12}. Condenser C_{12} completes the AF grid circuit to the cathode of tube V_4 by way of the metal chassis of the receiver. Note the distribution of the brown dash lines in the grid circuit of tube V_4. By visualizing the metal chassis connection between K of the tube and the black side of C_{12} you can see that a complete AF circuit exists between G and K of the tube.

When the signal gets to the plate circuit of tube V_4 note by the brown dash lines it is transferred through T_1 by way of the black metal core to the secondary circuit. There is no by-pass condenser at the B+ end of winding L_8 of T_1. The return AF signal path back to the cathode of tube V_4 is by way of condenser C_{17} and C_{10} as these two condensers effectively by-pass the plate circuit of tube V_4.

When the signal gets to the secondary circuit of T_1, it is divided and made to act on the grids of push-pull tubes V_5 and V_6. The brown dash lines indicate that both grids are being acted upon at the same time. However, you should understand that they are of opposite polarity. If the grid of tube V_5 is assumed to have a peak of positive polarity (positive half cycle) the grid of tube V_6 will be driven to the same voltage value as tube V_5 but of opposite or negative polarity. This, of course, is made possible by using a split or center tapped secondary for T_1. This qualification should be kept in mind when tracing the brown circuit of tubes V_5 and V_6. Condenser C_{14} provides the path for the AF signal back to the cathodes of the push-pull tubes.

In the plate circuits of the two push-pull tubes much the same action takes place as in the grid circuit with the exception that the signal is considerably amplified. There will be little or no AF signal on the screen grids of the 6F6 tubes because condenser C_{16} holds the voltage practically constant on these elements. That is the reason no brown dash lines occur along side the screen grid circuits of these two tubes. Thus, practically all of the AF energy is applied across L_{11} and L_{12} of T_2. Here again transformer action takes place through T_2. The power in the primary winding is changed from high voltage and low current to low voltage and high current to operate the speaker. The brown dash lines at T_2 indicate signal power is changed from primary to secondary—L_{13} is the secondary winding and L_{14} the voice coil winding on the speaker cone. The secondary circuit of transformer T_2 is grounded so it will not pick up stray magnetic and electrostatic fields. The brown dots just to the right of the speaker indicate air sound waves and is the last operation of the radio set to reproduce a signal.

Throughout the diagram of Fig. 1 you will note several brown arrows. The significance of these is that they indicate AC (RF or AF) signal paths. They do not indicate the direction of current flow as it is always considered to be from negative to positive. For instance, the brown arrows at the tube sockets indicate a return signal path to the grounded cathodes. Likewise, at the various by-pass condensers, brown arrows indicate a signal path through them instead of along a wire circuit. Thus, by proper use of condensers, DC voltages may be blocked from one or more circuits, yet AC can effectively flow through these condensers.

These questions are designed to test your knowledge of this lesson. Read them over first to see if you can answer them. If you feel confident that you can, then write out your answers, numbering them to correspond to the questions. If you are not confident that you can answer the questions, re-study the lesson one or more times before writing out your answers. Be sure to answer every question, for if you fail to answer a question, it will reduce your grade on this lesson. When all questions have been answered, mail them to us for grading.

QUESTIONS

No. 1. How many watts of AC power are dissipated by the 6.3 volt filament winding in Fig. 1?

No. 2. What part of the circuit in Fig. 1 is most positive and what part is most negative?

No. 3. If the required grid voltage for the detector tube in Fig. 1 was 25 volts and the plate current was .1 milliampere, what would be the value of R_5?

No. 4. Of all the amplifying tube elements shown in Fig. 1, which of them have the highest applied value of DC voltage?

No. 5. A push-pull output transformer has primary impedance of 15,000 ohms and 15 ohms on the secondary side. What is the turns ratio of the two windings?

No. 6. When a tuned coil employs a decoupling resistor, what method is employed to provide a short RF path to the cathode of the tube?

No. 7. If the speaker field winding (L_{16}) in Fig. 1 had a voltage drop of 50 volts across it and its resistance was 1000 ohms, what would be the value of current through it?

No. 8. What is the difference between a fixed and self-bias?

No. 9. What completes the circuit between the grid return of tube V_4 in Fig. 1 and its cathode?

No. 10. What is the value of the DC current through resistor R_9 in Fig. 1?