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PRACTICAL RADIO

AND

ELECTRONICS COURSE

VOLUME TWO

Receivers, Transmitters, and Test Equipment

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LESSON 14

Receiver Circuits

PURPOSE OF THE RECEIVER. The electro-magnetic waves from all radio stations induce voltages in the receiving antenna. Of course, the amount of voltage depends on the power of the transmitting station, the distance to the station, and the type of antenna. It is the function of the radio receiver to select the signal of the desired station, amplify this signal, detect the original audio signal, and deliver these audio electrical variations to the loudspeaker. All this is accomplished with the aid of the circuits we have already studied.

The majority of radio occupations deal with the building and repairing of radio receivers. This fact makes this lesson especially important.

SELECTIVITY. A radio receiver must separate the signals of any station wanted from the signals of all remaining operating stations. The degree of selectivity is the ability of the receiver to perform this function. Since the broadcast band stations are separated by 10 K.C., selectivity that is sufficient to separate stations 10 K.C. apart is employed in broadcast receivers.

Radio receivers are successful in performing this function of selecting the wanted station because radio stations are *separated* in the frequency spectrum.

SENSITIVITY. The receiving set must also amplify the incoming signal voltage to a sufficient degree to operate the loud-speaker. The sensitivity of a receiver is the measurement of overall amplification from the antenna input to the loud-speaker connections. Sensitivity should be as large as practical; it is possible to over do this in modern high gain sets.

The amplification may take place at radio or audio frequencies and is of voltage amplification type until the last stage where power amplification takes place.

All noise picked up by the receiver, collectively is known as the *noise level*. If a station's signal has less strength than the stray impulses forming the noise level, that station cannot be received successfully. Therefore, a radio set that can "go down" to the noise level is as sensitive as is required.

FIDELITY. The exactness with which the receiver reproduces speech and music is an indication of its fidelity. The radio receiver should not distort, add, change, or alter the original broadcasted sound in any way.

This is the requirement for a perfect receiver. Small discrepancies exist and are permissible.

The required qualities of a radio receiver, which we discussed, are inter-related. The tuning arrangement permits the selection of the wanted radio station and, therefore, serves to give selectivity. But the inductance-capacity, used for tuning, also gives a voltage gain which makes the receiver more sensitive. In most R.F. circuits, as you can see, selectivity and sensitivity go hand in hand. A very selective radio will be very discriminating against all frequencies except the frequency to which it is adjusted. But a broadcast station transmitting music must have a channel of about 5 kilocycles on each side of its carrier frequency. The idea of the channel width implies that the frequency transmitted, and which must be received for good quality reproduction, shifts around in the channel. If the radio receiver is sharp (has extremely good selectivity), it will not amplify all the frequencies in the channel with equal intensity. But you understand that the amplification of all frequencies in the channel of a station with almost equal intensity is the requirement for high fidelity. In designing equipment, a compromise is made between sharp selectivity and fidelity, since these factors have limiting effects on each other.

We already mentioned these requirements in talking about the selectivity curve of an R. F. amplifier.

DISADVANTAGE OF TRF SETS

The coil coupling the last R. F. stage to the detector is also called an R. F. coil.

This trimmer adjustment (alignment) in TRF receivers is made at the high frequency end of the band (1,400 KC. for broadcast band). Since at high frequencies the tuning condenser has minimum capacity, the shunting stray capacities have the most effect under such conditions. This is the reason why these stray capacities are equalized at a frequency where they have the most effect. Once adjusted at the high frequency end of the band, the TRF receiver will tune properly at other points of the dial.

This one paragraph suggests the reason for the popularity of the superhet circuit. You better read it once again.

Field Strength. The transmitted radio energy is spread out in all directions and is quickly reduced to a very low comparative value. In order to have a method of comparison between the signals received from various stations and as well as between the sensitivity of different receivers, it is practical to call the voltage induced in the receiving antenna, the field strength of the transmitter at a particular point on the earth's surface. The voltage induced in a higher antenna will be greater than that set up in a lower one. Since the voltage in the average antenna is a few thousandths of a volt (millivolts), the field strength is rated as so many millivolts or microvolts per meter of the effective antenna height. An antenna having an effective height of 3 meters and receiving a signal 15 microvolts, will have 5 (15/3) microvolts per meter field strength.

TRF Receivers. A tuned radio frequency (TRF) amplification stage essentially consists of an input tuned transformer and an output tuned transformer; the latter also serves as the means of input for the next R.F. stage. These transformers are familiar to us as coils. If the coil is used to couple together two R.F. stages, it is called an R.F. coil; if the coil is used to connect the antenna to the first R.F. stage, it is called the antenna coil.

It is possible to use a number of such TRF stages before the detector to obtain the needed sensitivity and selectivity. The variable condensers used to tune the coils are ganged together for single dial control. Each condenser section is identical and is of about .000365 mfd. capacity. Since the condenser sections rotate together and because the distributed capacity of each R.F. stage is not necesarily the same, small trimmer condensers shunt each section and are adjusted to make up for this difference in distributed capacity.

Some of the older receivers, before 1927, used triodes in the R.F. sections. These tubes give but little gain, therefore, it was common to employ four such stages. These stages were followed by the detector. Since five coils were needed, one *between* each of the stages and one between the first stage and antenna, the tuning condenser was of the five gang type. Tetrodes and pentodes used after this period gave much greater gain per stage. Only two R.F. stages were used in many TRF sets.

The TRF receiver is made up of several R.F. stages, detector, and an audio amplifier which usually consists of one voltage amplifier stage and the power stage connected to the loudspeaker. Since TRF circuits have not been very popular since the real development of the superhetrodyne circuit around 1930, we will not give tuned radio frequency receivers any more space.

Single Frequency Amplifiers. An R.F. amplifier can be designed to give exceptionally good results, from the tone quality point of view, if it is to be operated with the *channel* frequencies of a single, pre-fixed carrier frequency. In a regular TRF receiver, the R.F. stages must be adjusted to many different frequencies for the purpose of receiving various stations. If a way could be found to change the frequency of any desired station, to a fixed frequency of the pre-arranged amplifier, but at the same time change the stations not wanted to some other frequencies, we could obtain much better results from our equipment. And this is exactly what is done in the superhet circuit.

Mixing in a Non-Linear Impedance. Let us assume that we have two generators producing two different frequencies. These generators may be connected to a resistor, and both frequencies will be present in the circuit. The resistor is considered a *linear* impedance because its graph of voltage against current is a straight line. The two frequencies superimposed on the resistor will be present, but no new frequencies will be produced.

RESULTS OF FREQUENCY MIXING

A very interesting thing happens when two different frequencies are superimposed upon a non-linear impedance. A non-linear impedance is associated with a circuit which causes the current-against-voltage graph to appear as a curve. Some sections of all tube characteristic curves are of this type. Suppose we arrange a circuit using a vacuum tube so that two different frequencies are superimposed and the tube is operated over the curved (non-linear) portion, what frequencies will be present? Here we have a surprise. Extensive practical experiments as well as mathematical development have shown that besides the two original frequencies imposed on the circuit, two new frequencies will also be present. These two new frequencies (created in the circuit) will be equal to the sum and difference of the original frequencies. For example, if the original frquencies were 7 and 12 cycles, the new frequencies are 12—7=5 cycles, and 12+7=19 cycles. Or if the original frequencies are 550 KC. and 1010 KC., the resulting frequencies will be the original two frequencies and also 460 KC. and 1560 KC.

Here the word curve is used to suggest curvature. In the mathematical sense, even a straight line is a curve.

Let us assume that such a mixer tube is connected to a tuned circuit. The frequency of the station we want is received and is one of the original frequencies. Now we have a little transmitter (oscillator) built in the radio which can be adjusted to give any required frequency. We also follow this mixer tube with several stages of amplifiers designed for a single frequency reception. Let these amplifiers be made for 460 KC. and, since this frequency lies between audio and radio frequencies, we call it intermediate frequency, or abbreviated I.F.

Your future ability to service superhet receivers will depend to a very large extent on your understanding of the basic principles explained on this page. Be certain you understand the action described. The explanation is simple and is carefully covered.

If we wish to receive the program of a radio station which is operating on 670 KC. (WMAQ in Chicago for example), we adjust our tuning arrangement for this frequency. At the same time, we adjust our oscillator unit for 1,130 KC. The frequencies reaching the mixer tube are predominantly this 1,130 KC. oscillator frequency, and the 670 KC. of the desired radio station. These frequencies are combined in the non-linear mixer, and four frequencies are supplied by the stage incorporating the mixer tube. These four frequencies are the two original frequencies and the sum of the two frequencies, and, what we really need, the difference of the two frequencies. The difference of the two original frequencies will be 460 KC., just what is required for the I.F. amplifier stages. If another station is to be tuned in, both the station tuning arrangement and the oscillator must be retuned. If this station is one operating on 970 KC., then the station tuning must be adjusted to this frequency, and the oscillator must be set to 1,430 KC., to produce the required I.F. (460 KC. in this case).

Check this figure.

Is this right?

Pentagrid Converter. In many radio sets, the mixing action is performed by one tube while the oscillator (needed to produce the additional frequency) uses a separate tube. The mixer tube, in such cases, is a regular R.F. pentode (58, 6D6, 6K7), and the oscillator usually uses a triode. In many more modern radio receivers, a single tube combines the function of the mixer and oscillator tubes. Such tubes are called pentagrid converters; see the data on 6A7, 6A8. In these tubes the first grid, adjacent to the cathode, is used as a control grid for the oscillator circuit. The next grid, called anode grid, acts as the plate for the oscillator section. The

The tube performing the mixing action is operated over it non-linear characteristics. The circuit employed and the potentials impressed on the elements gives this needed operation.

balance of the tube elements form a R.F. tetrode. The plate current is varied by the grid connected to the R.F. input and also by the grid of the oscillator section. Therefore, the plate current varies in accordance with both frequencies, while the tube is being operated over the non-linear section of its characteristic curve, and the sum and difference frequencies appear in the plate current.

Tubes such as the 6K8 have the oscillator elements placed separately inside the tube, but have the triode oscillator grid also directly used for the purpose of controlling the station frequency.

Look up the data on type 6K8 tube in the characteristic charts.

Block diagrams are excellent for introducing complex circuits to the beginner. The student may obtain a general view and then learn about the circuits used in each stage.

BLOCK DIAGRAM OF A SUPERHET. It is possible to represent each stage of a superheterodyne by a box. The relationship between the stages is shown by the arangement of these boxes which suggest the circuit of the receiver. Such diagrammatical drawing is called a block diagram. Please examine the illustration below.

Beginning with the antenna, we find a stage labeled, R.F. PRE-SELECTOR. This section may actually consist of one or two R.F. stages which are tuned to the frequency of the wanted station. In the lower priced radios, the pre-selector is omitted, and the antenna is connected directly to the tuning coil at the input to the mixer or pentagrid converter tube.

Any radio receiver may be tested by injecting a suitable signal in each stage. Usually, it is best to start with the output stage and proceed back to the antenna. When making this test at any one stage, you fail to obtain a response in the speaker (while you did obtain a response when testing the stage to the right of this point), the stage under the present test must be at fault.

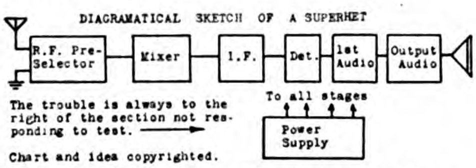


Figure 193. A block diagram shows the relationship of the different sections of a radio receiver. The signal is changed in form and intensity as it proceeds from antenna to loudspeaker.

As we have already mentioned, in some sets a separate oscillator tube is used, but our block diagram indicates that the mixer tube combines the function of the oscillator and mixer. Incidently, you may find that some books call the mixer, a first detector tube.

Although following the mixer stage, we have the original frequency of the station tuned in, the oscillator frequency, and also the sum and the difference of these frequencies, the I.F. stage passes and amplifies only the frequency which is the difference of the frequencies imposed. Most sets have one or two I.F. stages. If only one I.F. stage is used, two I.F. transformers are needed. One is connected to the input of this I.F. stage, while the second is coupled to the output and feeds the detector. If two I.F. stages are used, three I.F. transformers will be needed. It is well at this point to return to Lesson Five, and review the material on I.F. transformers.

Any of the vacuum tube detectors we have studied may be used successfully with a superhet circuit. Usually a diode detector is employed, but this is not a requirement. The stage we have indicated as the detector in the block diagram, is sometimes called the second detector to differentiate it from the mixer stage which is called the first detector by some authors.

The stages which follow the detector are used to amplify the audio output from the detector. As indicated, it is common to find the larger superhets employing a voltage amplifier (1ST AUDIO) and a power amplifier (OUTPUT AUDIO). The plate voltage is supplied by the power supply, indicated as a separate stage. If a transformer is used in the power supply, it also supplies the filament voltages.

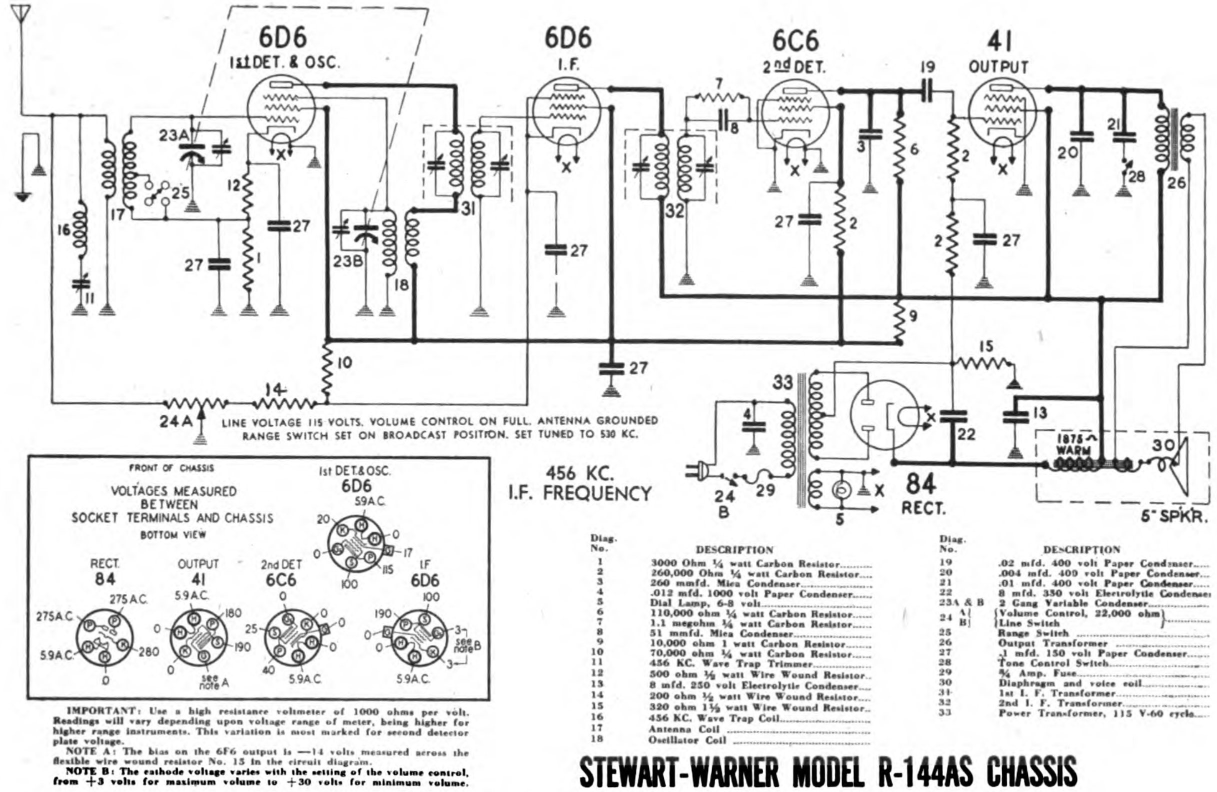


Figure 194. The different principles which we studied are used in a complete radio receiver. A radio circuit tells you which parts are employed, how these parts are connected, and how the equipment operates.

A circuit diagram of a radio receiver or an industrial electronic device gives hundreds of helpful facts about the equipment. Only a small number of all the facts included in the schematic diagram are mentioned in the discussion.

SIMPLE SUPERHET CIRCUIT. Now you are ready to study a complete circuit of a simple superhet. Look over the schematic diagram of the Stewart-Warner radio which was popular in 1936. Thousands of radios, using this and similar circuits of other manufacturers, are in use today. Observe that five tubes are used; notice that the filament connections are not shown, but are indicated by X, that they are to be connected to a winding on the power transformer. Notice that pilot-light is also placed across this transformer winding. Examine each part-symbol as included in the drawing. The numbers beside each part refer to the parts list which gives a complete description of the parts. Become familiar with these parts. A complete explanation of the circuit will be given now.

Coil 16 and condenser 11, form a wave trap for the purpose of keeping out undesirable signals which may cause interference at all settings of the tuning dial. This wave trap is adjusted once at the factory and need not be touched. Switch 25 is used to give an extended range for police station reception, but in our discussion we will assume that it is placed in the normal position, as illustrated.

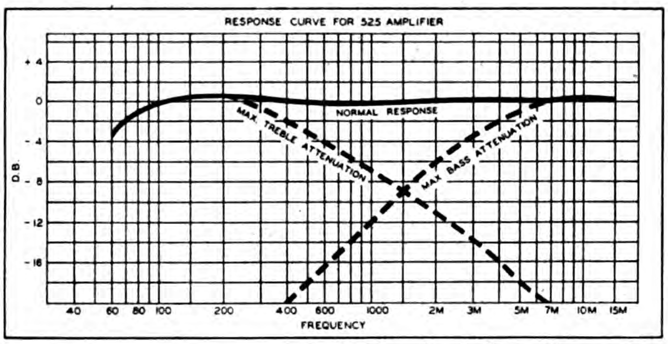
In the normal position, the switch is completely out of the circuit.

You already have noticed that 17 is the antenna coil and 18 is the oscillator coil. Both of these coils are tuned with the two gang condenser. This tuning condenser is of a cut-section type and the rotating plates of the two gangs are not alike. Since the section marked 23B, used with the oscillator, has smaller plates, the capacity will be smaller and the frequency produced by the oscillator will be higher. Of course, the condenser and coils are so chosen that the higher frequency is always greater by 456 K.C., because this is the I.F. frequency of the radio. The little, semi-adjustable trimmers, shown connected in parallel with the condenser sections, are used to make needed adjustment so that the incoming frequency and the oscillator frequency will always differ by the required amount, that is by 456 KC. in this case.

Refer back to the schematic diagram on page 179, as you read this description.

Let us review the operation of the mixer-oscillator stage which uses a type 6D6 pentode and is called "1st Det. & Osc." in the drawing. We turn the variable condenser (23A and 23B) until the antenna coil and the condenser are tuned to receive the station we want. This station's frequency is impressed on the grid which is adjacent to the cathode. Observe that the grid return, made through the secondary of coil 17, is connected to a tap (junction) of the resistors used for cathode bias (resistors 12 and 1). This circuit, therefore, places less negative grid voltage on the grid we are considering than on the suppressor grid adjacent to the plate. You recall, of course, that the ground may be considered most negative. Coil 18, and the tuning condenser are so connected to the elements of this tube that oscillation (production of radio signals) will occur at a frequency determined by the coil-condenser combination. The frequency which will be produced at the setting we have made will be just 456 KC. (the I.F.) higher than the frequency of the station we wish to receive. The mixer tube will produce the sum and difference of these frequencies, but only the difference (exactly 456 KC.) will pass through the I.F. transformer, part 31, and will be further amplified. The I.F. transformers, of course, are adjusted for the frequency required. These adjustments remain correct for long periods of time, but occasionally will need re-alignment.

It is assumed that the receiver is properly adjusted to produce these results.



Courtesy Standard Transformer Corp.

Figure 195. The solid line indicates that normal response from this particular amplifier is essentially flat from 70 cycles to 15,000 cycles. The treble and bass tone controls permit a great deal of variation in the frequency response.

The audio section of any radio receiver is equivalent to a small audio amplifier unit.

The I.F. amplifier stage uses a type 6D6 tube. There is nothing unusual about this stage except the cathode return circuit. This circuit is related to the volume control. Notice that the plate supply voltage of about 190 volts is dropped to ground through the series network of resistors 10, 14, and the sections of the potentiometer 24A which is to the right of the slider. Be sure that you have the resistance values of these units clearly in mind. If the slider is all the way to the right, only resistors 10 and 14 form a voltage divider network. Both the bleeder current and the plate current of the 6D6 I.F. tube flow through resistor 14, to ground and produce a negative bias from cathode to ground of 3 volts. As the setting of the volume control (potentiometer 24A) is changed, the negative

Since these resistors are connected in series, the same current passes through each and the voltage drops in each will be proportional to the resistance.

bias is increased to a maximum of 30 volts. Of course, the changing of the volume control setting also causes losses of the antenna signal to ground to increase, as the slider is moved to the left. Resistor 14 is used to guarantee a minimum required negative bias.

A type 6C6 tube is used as the detector (2ND DET.) and is of the grid leak type. Do you recall the action from the circuit of the two tube set in Lesson Thirteen? The audio output from the detector is sufficient to drive a sensitive type 41 pentode output tube. Condenser 20 is the usual tone correction condenser used with pentodes. Switch 28 permits the insertion of another larger capacity condenser for further reduction of high frequency audio response and the apparent stressing of bass. The output tube is coupled to a dynamic speaker through an output transformer. Notice that the field coil of this speaker is employed as the filter choke. In general, the heavy lines in the circuit indicate places where plate voltage is present.

You will notice that the cathode of the type 41 tube is at ground potential although the grid must be at a negative 14 volts. How is this bias voltage obtained? The entire plate supply current for all tubes comes from the high voltage winding of the power transformer. The center tap of the transformer winding serves as the return path, but instead of being connected directly to ground, it is connected to ground through a 320 ohm resistor, part 15. The plate current for all tubes must pass through this resistor and will produce a voltage drop of 14 volts across this resistor. The side of this resistor connected to the center tap of the transformer winding is most negative. The cathode of the 41 tube and the positive side of this resistor (part 15) are grounded. Can we connect the grid of the 41 tube, to the other side of the resistor to obtain the negative voltage needed on the grid? Yes, we can and have done this in the circuit using a network of two resistors. One of these 260,000 ohm resistors would be enough, but a certain amount of ripple voltage would then be fed to the grid and result in a loud hum in the output. The extra resistor and by-pass condenser 27, eliminate this.

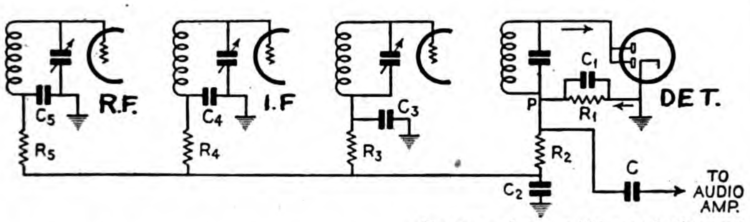
Very helpful information can be given to a radio serviceman in the form of a socket voltage chart. A chart of this type simply shows the sockets of the tubes and tell what voltages exist at the different terminals in relation to the ground. Please see if these readings appear normal to you and agree with your expectation.

UNUSUAL BIAS SUPPLY

The voltage drop in resistor 14 is always between the grid and cathode of the 6D6 tube.

The field coil of the loudspeaker is used as the filter choke. This coil has a D.C. resistance of 1,875 ohms. The average total plate current for all the tubes is about 60 ma. (.06 amperes). Since this current must pass through the field coil, we have a voltage drop across this field equal to 112.5 volts. The power dissipated in the field is equal to 6¾ watts. Look up the needed formulas and check the answers given.

The serviceman takes measurements at the points indicated and compares results observed with the values given. Wide differences suggest possible faults.



Courtesy Aerovox "Research Worker"

Figure 196. The basic circuit showing the voltage distribution in a modern AVC system.

AUTOMATIC VOLUME CONTROL. There are numerous varieties of automatic volume control (AVC) circuits, but they all work on the same principle. The AVC arrangement is intended to maintain the strength of the signal arriving at the detector nearly constant, thus compensating for different signal strengths of different stations and for fading. It does this by varying the sensitivity of the R.F. and

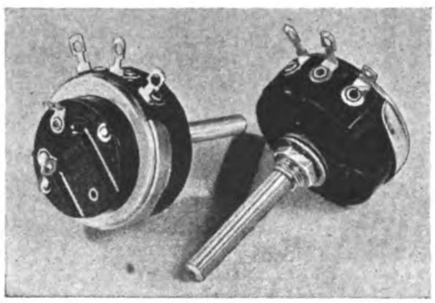
All modern radio receivers incorporate automatic volume control circuits.

I.F. amplifiers. Actually, AVC changes the bias on these amplifier tubes to obtain this action. The actual volume is of course not kept constant because it depends on the percentage of modulation at the transmitter. This is being varied in accordance with the volume of the transmitted sound and music. To try keeping this constant would be ruining the effect of music.

Follow this explanation by carefully tracing the action explained.

The schematic above illustrates an AVC system often used in up-to-date sets. Forgetting for the moment the grid return resistors in the R.F. circuits, let us begin with the detector. The signal is rectified by a diode. Current can flow only when the diode becomes positive and the coil must then be considered as the generator. This will perhaps help to explain why the resistor R_1 will carry current in the direction of the arrow, making the point P negative with respect to the cathode and the chassis. This seems to be difficult to understand by many. The current flowing between P and the chassis consists of a direct current component, a radio frequency component, and an audio frequency component. The condenser C_1 has been placed across the resistor to pass most of the radio frequency currents and the audio frequency component is taken off to be applied to the audio tube grid by means of the coupling condenser C. The steady voltage at P, which is proportional to the strength of the incoming signal, must now be fed back to the R.F. and I.F. amplifiers, but the A.F. component must be filtered out and precautions for interstage coupling must be taken. This latter requirement is accomplished by the network of resistors and condensers. Since the grids of the amplifying tubes are never drawing current, it does not matter, within limits, how much resistance there is between the point P and the individual grids.

Resistor R_2 and condenser C_2 form a resistance-capacity filter which smoothes out most of the audio frequency fluctuations. That it does so is best seen from a consideration of the laws of alternating currents. Since the condenser which is in series with the resistor R_2, forms a path for alternating currents, a great part of the audio signal will pass through C_2 in preference to following the paths through R_3-C_3, R_4-C_4, R_5-C_5.



Courtesy Clarostat Mfg. Co.

Figure 197. The same types of volume controls may be obtained with or without line switch.

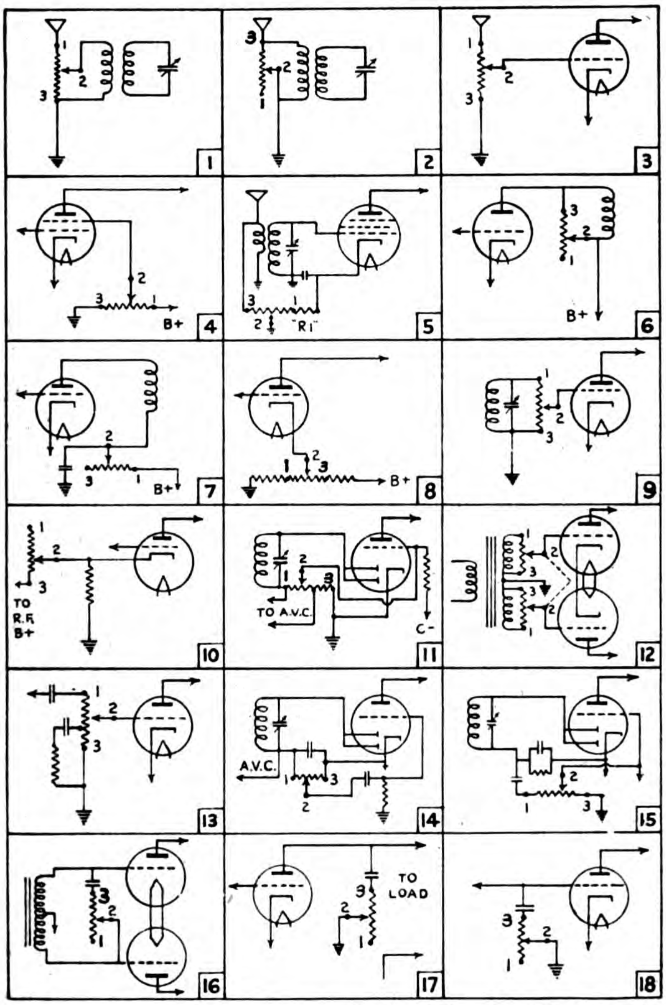
Volume controls are a common source of trouble in radio receivers. This is to be expected since volume controls receive the most mechanical wear of all parts used in the radio.

Volume Control Circuits. All radio receivers must incorporate a volume control for the purpose of adjusting the output audio intensity. This is accomplished in many different ways. In older radio receivers, not having an automatic volume control circuit, the manual volume control is always placed in the antenna or

R.F. stages. In sets having AVC, the very action of the automatic volume control circuit will try to overcome the gain adjustments made in the antenna or R.F. (or I.F.) stages, and the volume control must be employed in the first audio stage. It is important for you to understand that sets having AVC will try to keep the output volume constant even when changes in the size of the antenna is made or when the gain of the R.F. section is altered.

In sets having AVC, the manual control must come after the stage supplying the AVC voltage.

You will now be introduced to all the commonly employed volume and tone control circuits. Please refer to the proper circuit as each explanation is given. Observe that terminal marked 2, of each potentiometer is connected to the moving arm and is usually the center connecting lug. Looking at the back of the potentiometer, with the connecting lugs at the bottom, terminal 1, is to the left, while terminal 3, is to the right.



Courtesy International Resistance Co.

Figure 198. The basic volume control and tone control circuits used in radio receiving sets. These circuits represent various periods of radio progress.

Certain unusual dual type volume control circuits are not shown, but they were used in a limited number of sets, years ago, and are not important.

Circuit 1. A voltage divider circuit is used between the antenna and ground. The adjustment permits only a fraction of the voltage present on the antenna to be delivered to the antenna coil of the receiver.

EXPLANATION OF V.C. CIRCUITS

As you read the comments about the different circuits illustrated on page 183, be sure that you understand how each particular circuit gives the required action.

Circuit 2. In this circuit, the potentiometer winding is used to shunt the primary of the antenna coil. The amount of resistance shunting the coil may be adjusted from the maximum resistance value of the control, to zero. When the resistance value becomes smaller, it produces losses and has the effect of lowering the Q of the coil. But you remember that the Q value is equal to the voltage step up the coil gives, and, so when the Q is reduced, the gain is also reduced and the volume output is lowered.

This control and its associated vacuum tube circuit serves to increase the sensitivity of the receiver, but the stage adds nothing to the selectivity.

Circuit 3. The total winding of the potentiometer is connected between antenna and ground. The slider may be adjusted to deliver to the grid of the R.F. untuned stage any voltage, from maximum available at the antenna to zero if the slider is at the ground position. Common value 100,000 ohms.

Not a useful circuit at the present time since tetrodes are no longer used in R.F. stages.

Circuit 4. This is a voltage divider circuit formed by connecting the potentiometer between the B+ voltage and ground which is the zero voltage reference point. The screen grids of one or more tetrode vacuum tubes are connected to the movable arm and the positive voltage on the screen grids can be adjusted. The gain of the tetrodes is varied with the presence of different positive voltage on the screen grids. Since the voltage on the screen grid of pentodes has little effect on the tube operation, this circuit cannot be used with pentodes.

Circuit 5. Notice that this circuit has the effect described under *Circuit* 2. But also observe the additional volume control action present. The section of the resistance of the potentiometer, between terminal 1 and 2, is in the cathode circuit of one or more R.F. or I.F. tubes. As the slider is moved toward terminal 3, not only is the resistance of the potentiometer going to lower the effective Q of the antenna coil, but the extra resistance cut into the cathode circuit will increase the grid bias and reduce the gain of the tubes so connected.

Circuit 6. This circuit may be used with an I.F. or R.F. coil. It varies the value of the shunt resistance and, thereby, changes the effective Q of the coil in the circuit. The circuit illustrates an untuned R.F. coil.

See curves under Figure 199, on the next page.

Circuit 7. A series variable resistor in the B+ lead produces different amounts of IR voltage drop. If the resistor is large, the drop will be large, and little voltage will be present at the plate of the vacuum tube. Taper E curve, of the chart supplied by IRC engineers, should be incorporated in such a volume control.

Circuit 8. Although terminal 3 of the potentiometer is shown connected directly to B+, it is usually connected to an additional voltage dropping resistor which in turn is connected to the B+ voltage. The positive potential placed on the cathode with respect to ground may be adjusted. Since the grid is at ground potential, it will be at a negative voltage with respect to the positive cathode. Changing the bias, alters the gain of the tube.

This circuit is not recommended since the total resistance shunts the secondary of the coil at all times and thereby reduces to Q of this coil.

Circuit 9. In this circuit, a portion of the voltage developed in the secondary of a tuned circuit is impressed on the grid of the following stage. By selecting the amount of voltage required, the audio volume output may be adjusted.

Circuit 10. The resistor in the cathode circuit of the tube, and the portion of the potentiometer between the terminals employed, form a voltage divider with the tap connected at the junction. The voltage on the cathode (which is the bias voltage) will depend to a large extent on the value of the resistance of the potentiometer left in the circuit.

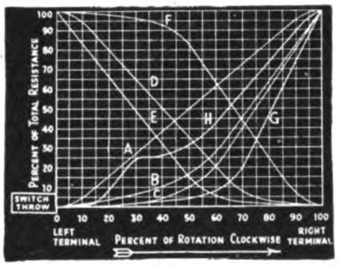
Circuit 11. This is a basic volume control circuit for sets having AVC. Terminal 2 supplies the audio signal for the triode section of the multi-purpose tube. The AVC uses a tap of the volume control since the total voltage would have been too great for this particular radio. Instead of a specially tapped volume control, a separate resistance network could have been used with a regular control.

Circuit 12. This circuit requires a "dual" type volume control (two independent controls driven by a common shaft) to control the signal input simultaneously to the grids of the two tubes connected in a balanced push-pull circuit.

Circuit 13. Automatic tone compensation is attained with this volume control which is tapped for connection to an external tone control circuit.

Circuit 14. Here the volume control serves as the load resistor for a diode rectifier, a variable audio frequency voltage being fed from the control resistance through a blocking condenser to the grid of the tube. The blocking condenser prevents the D.C. component of the diode output from affecting the grid of the tube.

This volume control circuit is used in modern sets. The required AVC voltage may be obtained also from this stage.



Courtesy I.R.C.

Figure 199. Volume controls are obtainable with various tapers to give the proper adjustments required in various circuits.

Circuit 15. In this circuit, the volume control acts as a grid load resistor to regulate the signal input to the audio frequency amplifier tube.

Circuit 16. A "grid-circuit" tone control is shown connected in the grid circuit of a push-pull audio frequency amplifier.

Circuit 17. A "plate-circuit" tone control is shown connected in the plate circuit of an audio frequency amplifier tube.

Circuit 18. A "grid-circuit" tone control is shown connected in the grid circuit of a single audio frequency amplifier tube.

AC-DC Superhet with AVC. A very interesting, modern superhet* will be explained next. Quickly examine the circuit. The antenna coil is in the form of a large loop and, thereby, serves as the coil and the source of signal pickup. Provisions are incorporated for connecting an outside antenna if desired. No outside ground should be used with an AC-DC type radio set. A separate oscillator tube, type 12J5-GT, is used. This tube is wired in a form of a Hartley oscillator which will be explained in detail in Lesson Fifteen. Please notice that the cathode (K) of the oscillator tube is connected to a tap of the oscillator coil (part 31) and

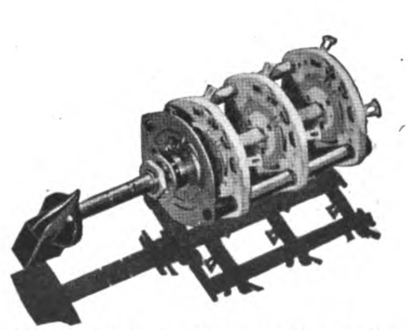
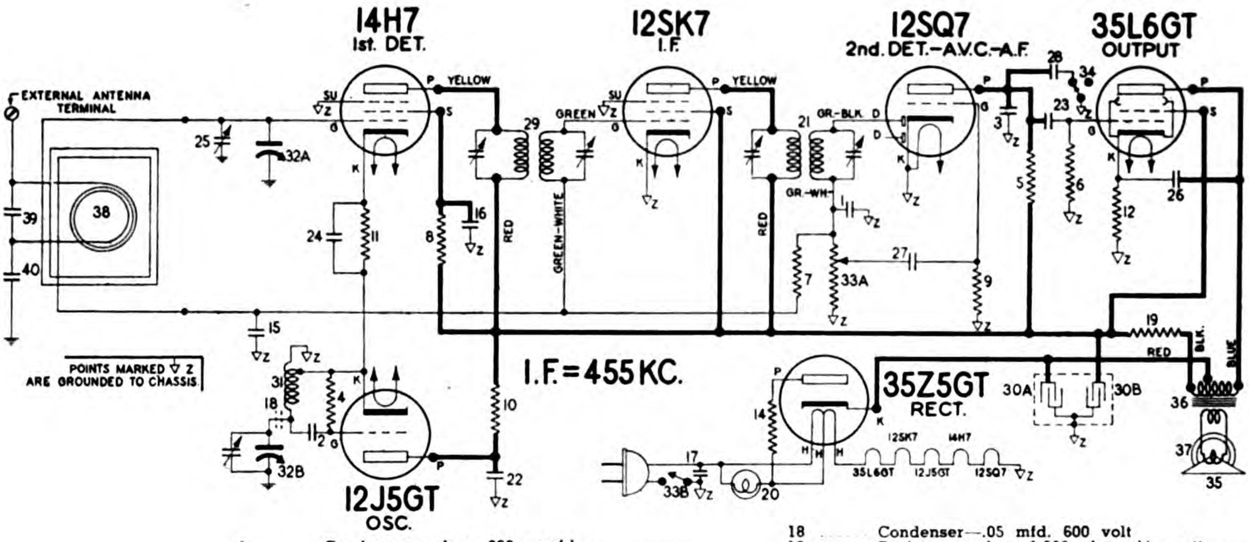


Figure 200. In better radio equipment, band-switches are made of low-loss material to eliminate losses in the circuits.

*This radio receiver is a model manufactured by Stewart-Warner Corporation.



1	Condenser—mica, 260 mmfd.		18	Condenser—.05 mfd. 600 volt	
2	Condenser—mica, 110 mmfd.		19	Resistor—carbon 1,500 ohms ½ watt	
3	Condenser—mica, 510 mmfd.		20	Lamp—dial (Mazda No. 47)	
4	Resistor—carbon 47,000 ohms ¼ watt		21	Transformer—2nd I.F.	
5	Resistor—carbon 220,000 ohms ¼ watt		22-23-24	Condenser—.01 mfd. 600 volt	
6	Resistor—carbon 470,000 ohms ¼ watt		25	Condenser—trimmer (loop)	
7	Resistor—carbon 2.2 meg. ¼ watt		26	Condenser—.02 mfd. 600 volt	
8	Resistor—carbon 68,000 ohms ¼ watt		27	Condenser—.004 mfd. 600 volt	
9	Resistor—carbon 3.3 meg. ¼ watt		28	Condenser—.002 mfd. 600 volt	
10	Resistor—carbon 680 ohms ¼ watt		29	Transformer—1st I.F.	
11	Resistor—carbon 1200 ohms ¼ watt		30A-30B	Condenser—Electrolytic	A-40 mfd. 150 volt / B-20 mfd. 150 volt
12	Resistor—140 ohms, 1 watt W.W.		31	Coil—oscillator	
13	Condenser—.2 mfd. 600 volt (206C)		32A-32B	Condenser—variable tuning with drum	
14	Resistor—33 ohms 1 watt W.W.		33A-33B	Volume Control—1 meg. (with switch)	
15-17	Condenser—.05 mfd. 600 volt		39	Condenser—mica, 110 mmfd.	
16	Condenser—.01 mfd. 600 volt		40	Condenser—.01 mfd. 600 volt	

Figure 201. The circuit of Stewart-Warner Models 206B and 206C radio receivers. This circuit represents the modern trend in the smaller AC-DC radio sets.

not to the ground. The cathode bias resistor of the 14H7 mixer is also returned to this tap. The oscillator signal is, therefore, injected into the mixer (1st Det.) through the cathode. You have probably noticed that the smaller superhet, we have studied so far, did not have a R.F. pre-selector.

You probably are beginning to see the similarity of radio receivers.

The I.F. stage is of a familiar type. The type 12SK7 tube is similar to the type 6D6 used in the first superhet we analyzed. Notice the color code used for the leads of the I.F. transformers. The I.F. transformer feeding the diode detector is of a special type with the primary and secondary of the transformer placed closer together. The type 12SQ7 tube combines a diode detector which also supplies the AVC voltage, and besides contains a triode section which amplifies the audio signal. Review in your mind the complete action of this stage. It will give you a good review of diode detector action, ACV, and audio amplification. No provisions have been made for grid bias in the triode section of the 12SQ7, but a very small voltage difference exists because of the fact that different materials are used for electron emission (cathode) and for the grid, and this voltage* is sufficient for the bias.

The characteristics of the tubes used in this receiver should be looked up in the vacuum tube charts of Lesson 9.

A half-wave rectifier is used. The filaments are wired in series and add up to about 120 volts supplied by the power line. Notice that the plate current and part of the filament current for the 35Z5-GT tube passes through the pilot bulb. However, if the bulb burns out, the filaments will still light and the plate supply voltage

The filament connections are shown separately.

*This voltage difference, about one volt, is called the contact potential.

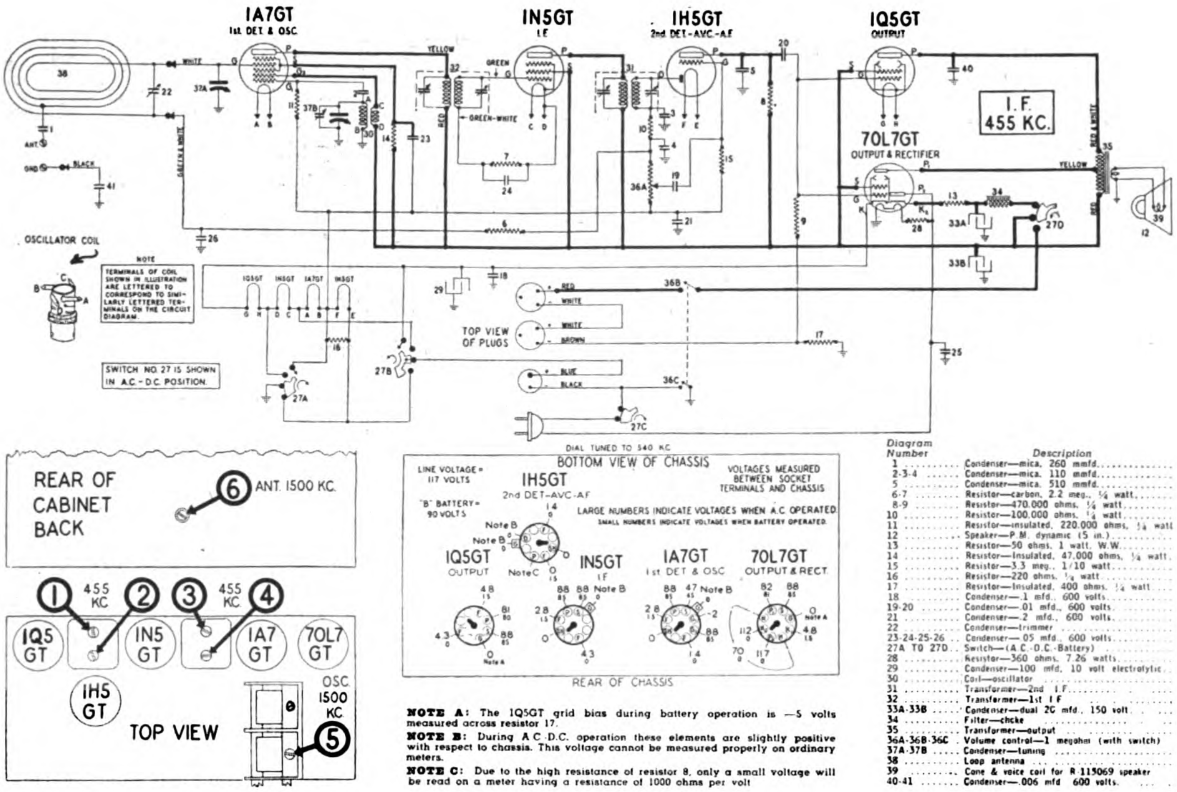


Figure 202. Circuit diagram, service information, and alignment data for Stewart-Warner Model 05-5L radio receiver. Portable sets designed for battery or line power operation were very popular during the 1941-42 period.

will be obtained after a small drop through a part of the filament of the 35Z5-GT tube. The part number 14, 33 ohm resistor prevents surges of current through the rectified tube.

AC-DC & Battery Superhet. This superhet also uses an antenna coil in the form of a large loop. An outside antenna may be connected through a condenser to a point of the loop, and this will make some of the turns of the loop act as the primary coil of a R.F. auto-transformer. The method used for making this set operate equally well on batteries or 110 volts A.C. or D.C. is so interesting that we will turn to this next.

Switches 36B and 36C, turn *on* either the battery or power line circuit depending on the position of the complex switch shown in several places as part 27. In one position, the various sections of this switch will complete the circuit so that the batteries will be connected and the type 1Q5-GT tube will serve as the output. This switch, in the battery position, will also disconnect the power supplied by the line-cord plug and eliminate the 70L7-GT tube from the circuit. In the other position, the switch will disconnect the batteries and connect the A.C. or D.C. power. One section of the 70L7-GT will serve as the rectifier, while the beam power section of this tube will automatically replace the battery type 1Q5-GT tube. Please notice that the sections of the switch 27, are shown in the AC-DC position. Trace through the operation of the power supply for both conditions.

Civilian radio sets were not made in 1943.

The same radio circuits are employed for either battery or line power operation. However, the beam power section of 70L7-GT replaces the 1Q5-GT when 110 volt power is used. In using any AC-DC radio receiver on D.C., the plug must be so inserted that the positive side of the D.C. line is connected to the wire leading to the plate of the rectifier tube.

PURPOSE OF ALIGNMENT

A picture diagram of the oscillator coil (part 30) is shown at the left of the schematic. This is a guide which informs the radio technician how to connect this coil. The letters in the schematic and picture diagrams correspond. The circuit of the receiver is similar to the superhet we have already studied, but battery type tubes are used. Please understand in tracing the circuit that the battery plugs with three terminals are for 45 volt portable batteries, while the plug with two terminals is for a $1\frac{1}{2}$ volt battery. For battery operation, the switch connects the filaments of the tubes in parallel, while for power operation the filaments are connected in series.

The battery plugs have three terminals, but only two are employed for the radio described.

Included with this schematic diagram, we have a socket voltage chart. The voltages indicated are measured with a standard voltmeter between the points indicated and the chassis which is the most negative point of the plate supply. The lower left hand corner of the illustration shows the location of all trimmers and padders needed for alignment. In the next section, we will tell you how to align superhet and TRF receivers without equipment and we will refer to this diagram. When referring to this diagram, notice also what position the parts occupy in the circuit from the electrical point of view.

For a good self-testing review, we suggest you start with the signal entering the antenna and trace through the action of the entire radio receiver.

NEED FOR ALIGNMENT. In order for a radio receiver to select the signal of a single station at one time, the various stages must operate, for any one setting of the dial, in a correct manner. In the TRF set, all tuned sections should be tuned to the desired station and must be aligned (adjusted) to receive the same frequency at the same setting of the tuning condenser.

In the TRF receiver, if the various tuned stages are not adjusted to receive the same station for any one setting, several stations may be heard at the same time.

In the superhet, the problem of alignment is a little different. In selecting any station, the R.F. section must be tuned to the frequency of this station, but the oscillator is tuned, at the same time, to a frequency equal to the incoming station frequency plus the frequency of the I.F. stages. For example, you tune in a station operating on 900 KC. The I.F. of this set is 456 KC. For proper operation at this point the oscillator frequency must be $900 + 456$, or 1,356 KC.

It is not often that a set needs alignment. For best results, a signal generator and an output meter should be used for alignment; but for the broadcast band, a passing job can be done without equipment. The methods will be outlined below. The use of a signal generator and other test equipment for this purpose will be given in Lesson 19.

ALIGNMENT OF TRF SETS. In practically all TRF type sets, the trimmers are located above the variable condenser sections. These trimmers are semi-adjustable condensers. The settings may be changed with a small screw driver. Since the metal of the tool may have an effect, a special screw driver made of insulating material may be purchased or made.

To align a TRF set without equipment, tune in a station on the high frequency end of the dial (at about 1,400 KC) and turn all trimmers until best and loudest reception is obtained.

Your hearing is more sensitive at low volume levels.

ALIGNMENT OF SUPERHETS WITHOUT EQUIPMENT.* In all cases of alignment, the manual volume control is advanced until the signal is audible. As the alignment makes the set work better, the output will become louder. This can be corrected by reducing the volume with the control as need arises. In sets with AVC, adjust

*See author's book, *Simplified Radio Servicing by Comparison Method,* for more details on radio alignment and repair without equipment.

for maximum volume also, but remember that the automatic volume control will try to keep the output at a fixed level. Because of this, let the amount of background hiss and noise help you judge the proper point of alignment. Minimum background noise with maximum volume for any setting of the volume control should be your guide.

In aligning, you actually tune in the station in the regular way (with the variable condenser) and then you supplement this tuning with exact adjustment of the trimmers and padders.

If a tuning meter or tube is a part of the radio, this may be used as the indicator. The indication of correct tuning will also serve to indicate correct alignment.

In the superhet, the I.F. transformers must be set for the frequency of this section. At first, it is safe to assume that the I.F. transformers are not much off and may be left alone. Now tune in a strong local station having a frequency of about 1,500 KC. Let us say in your locality you have a station operating at 1,350 KC. You turn the dial to 1,350 KC., but find that the station will come in best at 1,370 KC., or 137 on the dial. Set the dial on 1,350 KC. anyway. Find the trimmer mounted above the condenser gang which tunes the oscillator coil. (In multi-band sets, this trimmer will be inside of the can housing the oscillator coil). Turn this trimmer until the signal comes in as loud as possible without changing the volume control. This trimmer is No. 5, in the diagram.

Reference is made to Figure 202.

Now turn the trimmer of the antenna section gang (also R.F. if used in the set). The set screw may have to be turned in one direction or another. This is adjustment No. 6.

Now tune in a station at around 650 KC. Find the padder condenser which is usually mounted near the oscillator coil. While the station comes in, rock the tuning dial a little up and back past the point where the station comes in, and adjust the padder for loudest response. If the super uses a cut section tuning condenser, the outside moving plate of the oscillator section may have to be bent a little. The metal plates of a condenser must not touch, however. The set we described has a cut section condenser.

Now go back to about 1,400 KC. and check up on your work. Readjust a little. The trimmers of the I.F. transformers may be turned a little at this time. Be careful not to turn these too much.

Communication Receiver. For two way communication work, radio receivers must meet certain extra requirements. A communication receiver must cover the required frequencies, must have sufficient sensitivity to "get down" to the noise level, and have selectivity to separate signals of very close frequencies. Besides meeting these requirements, a good communication receiver incorporates several additional features which aid in the operation. The *National Company,* makers of communication receivers and radio components, has permitted us to explain their model HRO receiver. You will find this receiver a good example of the type of unit which is used for most exacting demands of the more advanced communication service. Much of the material below about the HRO receiver has been taken from the instruction booklet* issued by the manufacturer.

Communication receivers were used extensively by radio amateur operators, but airlines, monotoring stations, and the Armed Forces also find increasing use for these selective, stable receivers.

Antenna Connections. The input circuit of the HRO is arranged for operation with either the doublet type or the single-wire type of antenna. There are two input binding posts, marked "ANT" and "GND." When using a single-wire antenna, the lead-in should be connected to the antenna post and the short flexible lead, which is connected to the chassis near the ground post, should be clamped

In dealing with the *National* HRO receiver, the text assumes you will actually be working with the set. This tone helps to create greater interest on the part of the student.

*"Instruction Manual for the National HRO," 1940, issued by the National Company, Inc.

EXTERNAL CONSIDERATIONS

under the "GND" terminal. An external ground connection may or may not be necessary, depending upon the installation. The ground is usually desirable when receiving wavelengths above 100 meters, but for wavelengths below 50 meters, the use of a ground may actually weaken signals.

Power Supply Required. The receiver is used with an external power supply which can deliver 230 volts D.C., at 75 ma., and 6.3 volts A.C. or D.C. at 3.1 amperes.

Examine the circuit on page 192. Notice that the permanent speaker recommended, or the output transformer must serve as the correct load for the type 42 output tube.

Output Circuit Connections. A permanent magnet type of dynamic speaker is recommended, no field excitation being required. The output impedance of the HRO is 7,000 ohms, and a dynamic speaker must have a suitable built-in coupling transformer.

A headphone jack is located on the front panel, just below and to the right of the "S"-meter. This jack is wired into the output of the pentode section of the 6B7. When the phones are plugged in, the signal input to the last tube is completely disconnected.

This receiver is also available in a metal cabinet.

Figure 203. The National HRO is supplied in a metal container with a special panel for relay rack mounting. Please notice the positions of the different controls and the plug-in coil assembly.

In reading about the controls, refer to the front view illustration of the receiver, Figure 203.

Operating the Controls. The main tuning dial is located near the center of the front panel and operates the 4-gang tuning condenser. Full details of the tuning arrangement are presented in later sections.

Starting at the top right-hand side of the front panel, the upper most knob is the Variable Selectivity Control of the Single-Signal Crystal Filter. With the crystal filter in use, minimum selectivity will be found with the pointer nearly vertical. Rotating the knob in either direction from this point will increase the selectivity. When the filter is not in use, the knob should be set at the point giving maximum volume and sensitivity.

Immediately below the Selectivity Control is the Phasing Control and the Crystal Filter Switch. When this control is rotated to 0, the crystal filter is disconnected. When the control is at any other setting between 1 and 10, it acts as a phasing condenser for balancing the crystal bridge circuit, eliminating heterodynes, etc. The action of these two controls is explained in detail in another section.

The switch below the phasing control is connected in the B+ lead of the receiver and its purpose is to shut off the receiver during periods when you are transmitting or changing coils. Series connected with the B+ switch and mounted at the rear of the chassis is a pair of contacts, BSW, intended for use with relay control of the receiver.

The bottom control on the right-hand side is an R.F. Gain Control, connected to the second R.F. tube and to the two I.F. tubes.

At the botom left-hand side of the front panel is located the C.W. Oscillator Switch and Vernier Tuning Control. The c.w. oscillator is used to obtain an audible beat note when receiving c.w. signals or to locate the carrier of weak phone and broadcast stations. After the phone carrier has been found, the C.W. oscillator is turned off.

The switch just above the C.W. beat oscillator dial is for turning the AVC on or off. Above this switch is the Audio Gain Control, which is wired into the output of the diode detector and serves, therefore, to control audio volume when using either headphones or speaker.

The S-meter for indicating carrier intensity of signal strength is in the upper left-hand corner. Just below it, and to the left, is a push-switch which connects the meter in the circuit.

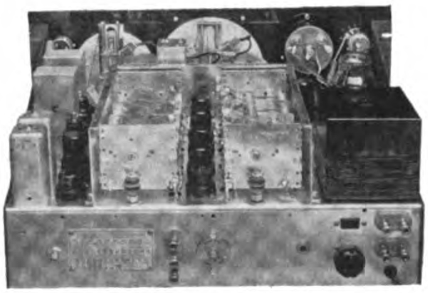
Receiving C.W. Telegraphy Stations. When receiving C.W. signals, the C.W. oscillator must be turned on and the AVC switch turned off. Best signal-to-noise ratio will usually be obtained by retarding the audio gain control considerably and controlling sensitivity with the R.F. gain control. Turning on the C.W. oscillator switch will result in a considerable increase in circuit noise. When the control is turned back and forth, the characteristic pitch of this noise will change. When the characteristic pitch is fairly high, the semi-*single-signal* properties of the receiver are very pronounced, one side of the audio beat note being several times as loud as the other.

Receiving Phone Stations. In receiving phone signals, the AVC may or may not be used, as desired. If it is not used, the audio gain control is advanced about halfway and the sensitivity is controlled with the R.F. gain control. If AVC is used (left-hand toggle thrown to the left), the R.F. gain control may be turned all the way on; i. e., to 10; and the volume controlled by the audio gain control only. The setting of the two gain controls is largely a matter to be determined by the preference of the operator and by receiving conditions. If, for instance, local noise or atmospheric static is high, it will be desirable to retard the R.F. gain control when using AVC so that the sensitivity of the receiver will be held to a definite maximum. If the c.w. oscillator is to be used for locating carriers, as mentioned above, the AVC switch must be in the off position (to the right). Turning on the c.w. oscillator with the AVC on will block the receiver, making reception of anything but extremely strong signals impossible.

Using Crystal Filter. The use of the crystal filter in phone reception is recommended particularly when the operator must contend with heavy interference, static, heterodynes, etc. To receive a phone signal when using the crystal filter, the filter is switched in by means of the phasing control and the phasing dial set at approximately mid-scale. The selectivity control is then adjusted for minimum selectivity, as indicated by maximum noise as the control is rotated back and forth. All phone signals will be reduced in volume, making it necessary to advance both audio and R.F. gain controls. The signals may then be tuned in in the usual manner, but it will be found that the selectivity is very high, with the result that all audio frequency side bands above a few hundred cycles are comparatively weak. Normally, this would result in low intelligibility of the received signal, but since the background noise, static,

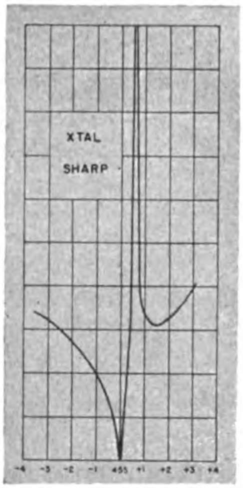
USING THE CONTROLS

Find this in the circuit.



Above is an inside chassis view of a communications receiver of the *Hallicrafters* make. Front view of the control panel is shown below. Since all communications receivers are designed for similar purposes, they incorporate similar circuits and controls.

PURPOSE OF CRYSTAL FILTER



The above curve shows the response of a Hallicrafters communications receiver with the *X'tal* set in the SHARP position. The height of the curve above the base line shows losses (drop in signal strength). Notice the sharp attenuation of the signals away from the I.F. of 455 KC. used in this receiver.

etc. have been correspondingly reduced, the net result is usually an improvement.

The principal advantage of the crystal filter, however, is its ability to eliminate heterodynes. Suppose, for instance, a signal has been carefully tuned in with reasonably good intelligibility and during the transmission an interfering station comes on, causing a bad heterodyne, inverted speech, etc., ordinarily the desired signal would be "smeared," but careful adjustment of the phasing condenser will eliminate the heterodyne and the interfering station, in most cases, completely. Intelligibility will remain practically as good as before the interfering station came on.

To use the crystal filter for C.W. reception, the filter is switched in by means of the phasing control and the phasing condenser set about mid-scale. The AVC switch must be off and the C.W. oscillator turned on. Advancing the R.F. and audio gain controls will result in a hollow, ringing sound the pitch of which will depend upon the setting of the c.w. oscillator dial. The actual pitch is not important as long as it is near the middle of the audio range, where the loudspeaker or phones have good sensitivity.

When a signal is picked up, it will be found that as the receiver is tuned slowly across the carrier the beat note will be very sharply peaked at the same pitch as that of the ringing noise, previously mentioned. All other parts of the beat note will be extremely weak and, furthermore, this peak will be found to occur on only one side of the audio beat note. The sharpness of the peak is determined by the selectivity control (upper right-hand knob). At maximum selectivity, the peak is so sharp that it may be hard to find, whereas at minimum selectivity the peak will be very broad.

Using the S *Meter.* The S-meter serves to indicate the strength of a received signal. It is calibrated from 1 to 9 in arbitrary units which correspond, roughly, to the definition of the nine points of the "S" scale of the R-S-T system of amateur signal reports.

SCHEMATIC DIAGRAM — TYPE H.R.O. RECEIVER.

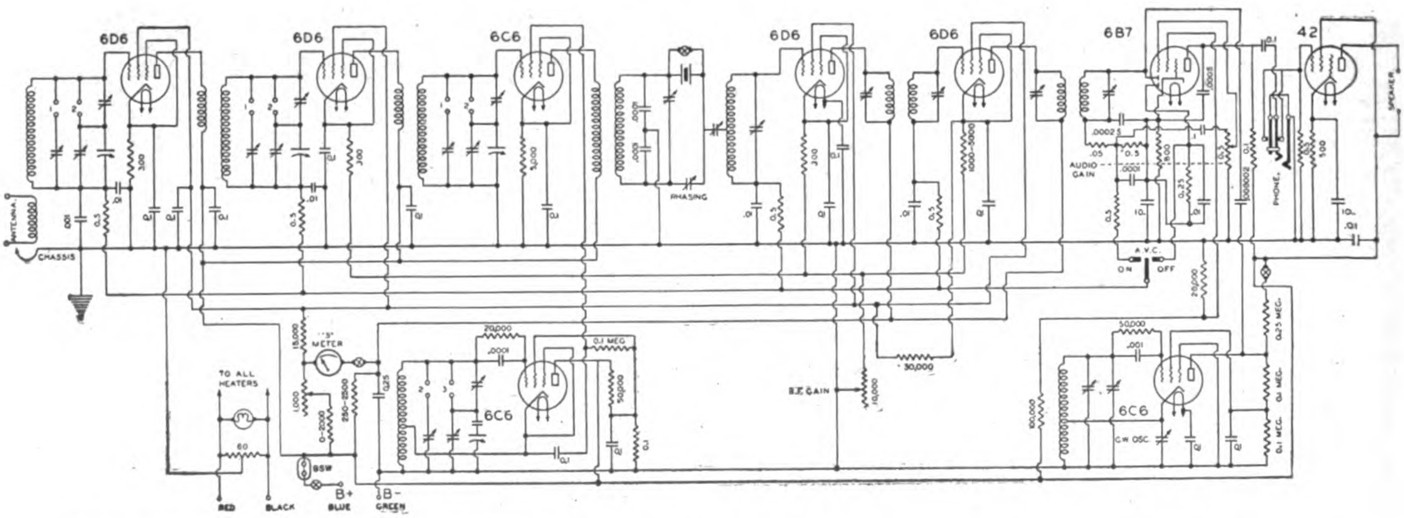


Figure 204. Schematic diagram of the National HRO receiver. A detailed parts list is given on pages 193 and 194.

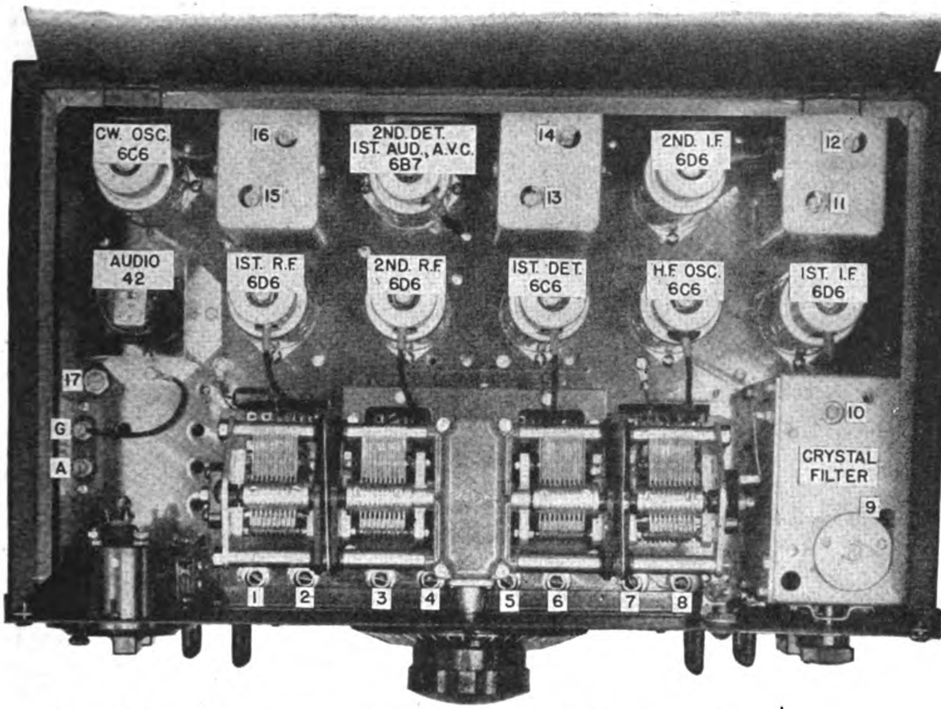


Figure 205. Looking down on the inside of the HRO receiver. The crystal filter unit is encased in a separate shielded compartment with the crystal plugged into the socket located at the top of this compartment.

In this top view, the different alignment trimmers are numbered. You should be able to locate these trimmers in the schematic diagram.

Probably no two operators will agree on just how strong a signal must be to warrant an S-9 report. After making measurements on a large number of amateur signals, the present meter scale was

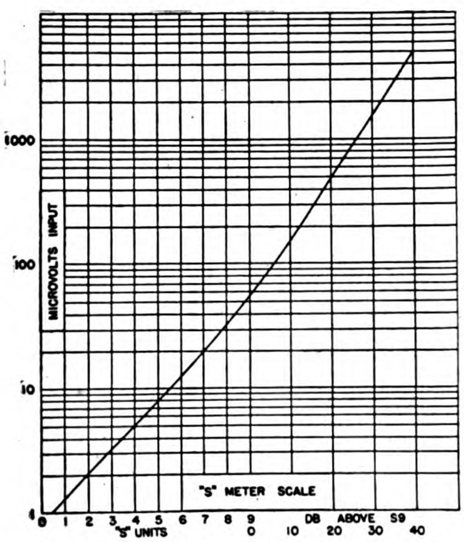
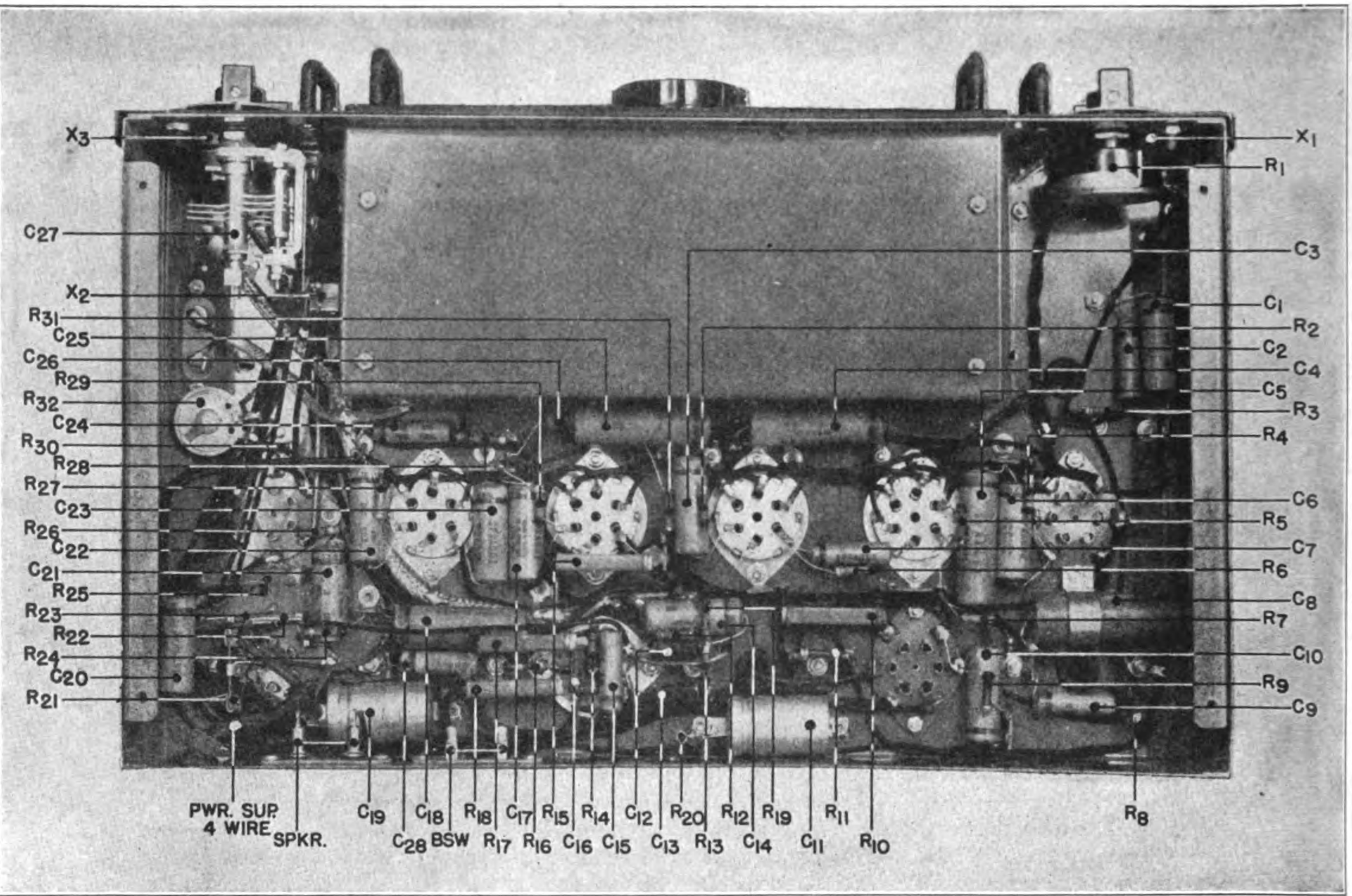


Figure 207. The relationship between "S" units and signal strength.

chosen and we believe it will provide a good practical means of giving accurate reports. The accompanying curve shows the relation between average meter readings and the actual signal input to re-

Notice that the vertical scale is logarithmic and represents the signal input to the antenna terminals of the receiver.



As a fine review exercise, we suggest you find every component, visible in the above photograph and described in the parts list, in the schematic diagram on page 192.

Figure 206. Bottom view of the HRO radio chassis.

LIST OF RESISTORS AND CONDENSERS

R_1	R.F. Gain Control	10,000	ohms	Variable
R_2	1st Detector Bias Resistor	5,000	"	½ Watt
R_3	1st I.F. Grid Filter Resistor	500,000	"	½ Watt
R_4	1st I.F. Bias Resistor	300	"	½ Watt
R_5	H.F. Osc. Screen Resistor	50,000	"	½ Watt
R_6	1st Det. Screen Resistor	100,000	"	½ Watt
R_7	H.F. Osc. Bleeder Resistor	100,000	"	½ Watt
R_8	2nd I.F. Grid Filter Resistor	500,000	"	½ Watt
R_9	2nd I.F. Bias Resistor	1,000–5,000	"	½ Watt
R_{10}	R.F. and I.F. Screen Resistor	15,000	"	2 Watt
R_{11}	S-Meter Bridge Resistor	250–2,500	"	½ Watt
R_{12}	2B7 Pentode Grid Resistor	500,000	"	½ Watt
R_{13}	Diode Filter Resistor	50,000	"	½ Watt
R_{14}	Diode Equalizing Resistor	250,000	"	½ Watt
R_{15}	Screen Bleeder Resistor	30,000	"	2 Watt
R_{16}	Pentode Screen Bleeder Resistor	20,000	"	½ Watt
R_{17}	Pentode Screen Resistor	100,000	"	2 Watt
R_{18}	Pentode Plate Resistor	100,000	"	2 Watt
R_{19}	AVC Filter Resistor	500,000	"	½ Watt
R_{20}	2B7 Bias Resistor	800	"	½ Watt
R_{21}	Heater — Center-Tapped Resistor	60	"	
R_{22}	CW Osc. Screen Resistor	250,000	"	½ Watt
R_{23}	CW Osc. Plate Resistor	100,000	"	½ Watt
R_{24}	CW Osc. Screen Bleeder Resistor	100,000	"	½ Watt
R_{25}	Output Pentode Bias Resistor	500	"	2 Watt
R_{26}	Output Pentode Grid Resistor	500,000	"	½ Watt
R_{27}	1st R.F. Bias Resistor	300	"	½ Watt

(Continued on next page)

R_{28}	1st R.F. Grid Filter Resistor	500,000	"	½ Watt
R_{29}	2nd R.F. Bias Resistor	300	"	½ Watt
R_{30}	S-Meter Bridge Resistor	0–2,000	"	½ Watt
R_{31}	2nd R.F. Grid Filter Resistor	500,000	"	½ Watt
R_{32}	S-Meter Balancing Resistor	1,000	"	Variable
C_1	Heater By-pass Condenser	.1	mfd.	400 Volt
C_2	1st I.F. Grid Filter By-pass Condenser	.01	"	400 Volt
C_3	1st Det. Cathode By-pass Condenser	.1	"	400 Volt
C_4	2nd R.F. B+ By-pass Condenser	.1	"	600 Volt
C_5	H.F. Osc. Screen By-pass Condenser	.1	"	600 Volt
C_6	1st I.F. Cathode By-pass Condenser	.1	"	400 Volt
C_7	1st Det. Screen Coupling Condenser	.1	"	500 Volt
C_8	I.F. B+ By-pass Condenser	.25	"	600 Volt
C_9	2nd I.F. Grid Filter By-pass Condenser	.01	"	400 Volt
C_{10}	2nd I.F. Cathode By-pass Condenser	.1	"	400 Volt
C_{11}	2B7 Cathode By-pass Condenser	10.	"	50 Volt
C_{12}	Diode Filter Condenser	.0001	"	Mica
C_{13}	Diode Filter Condenser	.00025	"	Mica
C_{14}	2B7 Grid Coupling Condenser	.1	"	400 Volt
C_{15}	Diode By-pass Condenser	.01	"	400 Volt
C_{16}	2B7 Plate By-pass Condenser	.0005	"	Mica
C_{17}	2nd R.F. Cathode By-pass Condenser	.1	"	400 Volt
C_{18}	Output Pentode Grid Condenser	.1	"	600 Volt
C_{19}	Output Pentode Cathode By-pass Condenser	10.	"	50 Volt
C_{20}	Heater By-pass Condenser	.1	"	400 Volt
C_{21}	CW Osc. Screen By-pass Condenser	.1	"	400 Volt
C_{22}	1st R.F. Cathode By-pass Condenser	.1	"	400 Volt
C_{23}	R.F. and I.F. Screen By-pass Condenser	.1	"	400 Volt
C_{24}	1st R.F. Grid Filter By-pass Condenser	.01	"	400 Volt
C_{25}	1st R.F. B+ By-pass Condenser	.1	"	600 Volt
C_{26}	2nd R.F. Grid Filter By-pass Condenser	.01	"	400 Volt
C_{27}	CW Osc. Receiver Tuning Condenser	30.	mmf.	Variable
C_{28}	2B7 B+ By-pass Condenser	.01	mfd.	600 Volt

X_1 B+ (stand-by) Switch
X_2 CW Oscillator Switch
X_3 AVC On-Off Switch

This is the continuation from page 193.

ceiver in microvolts, and from this curve it will be noted that each "S" unit is equal to a change of approximately 4 db. The 40 db. range above the S-9 level is used for comparative checks on extremely strong signals.

The schematic shows the "S-meter" network connected in the plate supply circuit to the R.F. and I.F. stages. Actually the meter is the indicator of a bridge circuit, three legs of which are fixed resistors, and the fourth (variable) leg the plate circuits of the AVC controlled tubes. The bridge is balanced by means of the manual R.F. gain control, which, through its action of indirectly changing the plate resistance of the tubes, automatically adjusts the R.F. and I.F. gain to a predetermined level at the same time that the meter is brought to zero. The strength of the incoming signal is, therefore, accurately indicated by the action of the AVC circuits in controlling high frequency gain.

Coil Ranges. Four plug-in coil assemblies are supplied as standard equipment for the HRO receiver, each assembly consisting of three R.F. coils and one oscillator coil, all individually shielded and provided with built-in trimmer condensers. Calibration curves are mounted on the front of each assembly.

The four assemblies cover all frequencies between 1.7 and 30 megacycles, the division being as follows:

1.7 to 4.0 mc. 3.5 to 7.3 mc. 7.0 to 14.4 mc. 14.0 to 30.0 mc.

In addition to the coils furnished as standard equipment, other assemblies are available, covering frequencies from 2.05 MC. to 50 KC.

These curves indicate the correspondence between dial readings and frequencies. These relationships change a little for each set of coils and each group of coils is individually calibrated.

This is, perhaps, the first time that you realize that ultra-high frequencies present special design problems.

Design Considerations. At the lower frequencies the circuit matching problem is relatively simple and requires only the usual precautions with regard to careful matching of coils and gang condensers sections. Above 10,000 KC., however, ordinary production methods cannot be used. Much greater precision is required. Not only are precisely adjustable trimmer condensers required in all circuits, but also some means must be employed for obtaining inductance trimming. For instance, it was found that

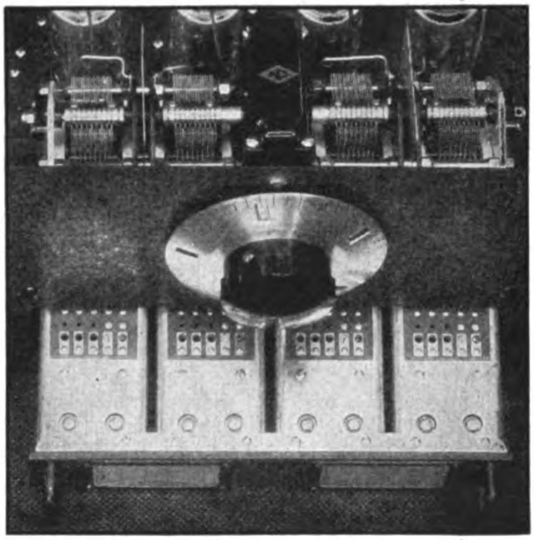


Figure 208. Illustration shows the appearance of the HRO plug-in coils as they are inserted into the receiver.

Illustrated in Figure 209.

the total length of wire in a 28 MC. tuned circuit (including condenser leads, etc.) must be held within one-quarter inch. One satisfactory method of inductance trimming is illustrated. The last half-turn of wire is brought out in a loop, normally at right angles to the rest of the coil. Bending the loop one way or the other gives an inductance variation equivalent to adding or subtracting a half-turn from the coil. The lower frequency coils can conveniently employ a different type of inductance trimmer as shown. As the disc is moved toward the center of the coil, the inductance is decreased.

Refer to the diagram of Figure 204.

You will observe similar arrays of condensers in the two R.F. stages, 1st detector stage, and the oscillator stage. C_1 in each case is the main tuning condenser, lower right hand in each group, drawn with a curved-arrow for the lower portion.

Understanding of the electrical matching and tracking will be clarified by an explanation of the exact function of each of the somewhat imposing array of condensers associated with each stage in the diagram. To begin with, the ganged main tuning condensers C_1 (those at the lower right-hand side of each group) have a capacity range determined by the widest frequency span required, namely, 4000 to 1700 kc. All the other variable condensers shown are built into the plug-in coil assemblies and are, therefore, adjusted individually in one range only. The condensers C_3 connected directly across the tuning condensers are the main trimmers, the purpose of which is to bring the minimum capacity of all circuits to the correct value. As far as the general coverage ranges are concerned, these trimmers, together with the oscillator series tracking condenser C_4 (shown just above the stator of the oscillator tuning condenser) and coils of the proper inductance, are all required for exact ganging.

When changing to amateur band-spread, two additional condensers are necessary in each circuit. The No. 1 contacts, being open, connect condenser C_5 in series with each tuning condenser, thus lowering the maximum capacity effective and limiting the tuning range so that the desired band is spread over the major portion of the dial. These condensers, now being in series with both the tuning condensers and the main trimmers, also cause the minimum capacity across the coils to be lowered considerably. With the No. 2 contacts closed, however, another condenser C_2 is connected in parallel with each of the coils, bringing the minimum capacity to the value required for properly centering the band on the dial.

Follow this explanation by referring to the schematic on page 192.

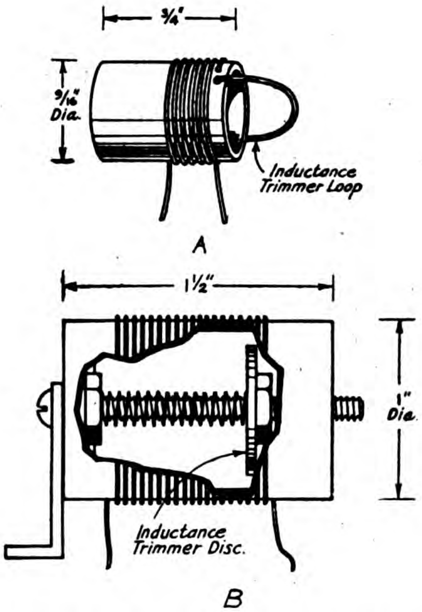


Figure 209. Inductance trimming methods used in the HRO receiver. (A) High frequency coils. (B) Low frequency coils.

By placing a half-turn of the coil at right angles to the balance of the turns, you obtain the effect of this half-turn not being present. Moving this loop will add or subtract from the inductance of the coil.

The problem of obtaining uniform gain over ranges below 14 MC. is comparatively simple since it is only necessary to use high inductance primaries with the correct amount of capacity coupling. The primary winding has a large number of turns of fine wire, so that it will be broadly resonant just below the low-frequency end of the tuning range. The point of resonance is determined by the circuit and plate capacity of the R.F. tube in parallel with the coil. The signal transfer from the tube to the primary will, therefore, increase as the resonant point is approached; in other words, as the tuning condenser is varied from minimum to maximum capacity. On the other hand, the impedance of the tuned circuit will decrease as the capacity is increased and at the low-frequency end will, therefore, require the additional signal which the primary is supplying.

It often happens, however, that the effect of the primary is predominant, resulting in higher gain at the low-frequency end. Additional compensation is obtained by a small amount of capacity

Maximum capacity of the tuning condenser will tune the lowest frequency of the band. This frequency will be closest to the resonant frequency. The closer the frequency is to resonance, the higher is the resulting impedance. With higher impedance load, greater voltage results.

coupling directly between the plate and the grid of the following tube. This coupling, being small, will have less effect at the low frequencies but will have a large effect at the high-frequency end, since the impedance of the coupling condenser decreases as the frequency is raised. This system of R.F. coupling is entirely satisfactory below 14 megacycles, but between 14 and 30 megacycles it is not effective. In this range, the gain falls off rapidly and the resonance of the primary is inadequate in its levelling action.

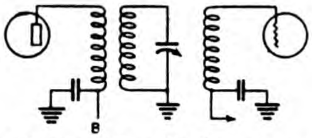


Figure 210. Tuning arrangement employed to give uniform gain in the 14-30 MC. band.

You may have to refer to Lesson 7 for review to understand this paragraph.

The system finally devised to overcome this difficulty is illustrated. The primary plate winding is coupled as closely as possible to the tuned circuit, being interwound with it, and having the same number of turns. The grid winding is also closely coupled to the tuned circuit and consists of a large number of turns of fine wire, the coil itself being resonant just outside the low-frequency end of the range. This grid winding gives considerable voltage step-up and at the same time compensates for the varying impedance of the tuned circuit in such a way that the gain is uniform. It should be pointed out, however, that the grid coil itself is resonant and not the coil plus the circuit and the tube capacity.

Mechanical Considerations. So far we have discussed principally the electrical considerations involved. The mechanics of the tuning arrangement, together with the condenser and coil construction, are fully as important.

In this sentence, *positive* means with no slipping or back-lash. *Vernier* means gradual or slow; i.e., for every turn of the tuning dial, the tuning condensers may turn but a fraction of a full turn.

A good tuning system should be convenient to operate and this requirement necessitates the use of a positive vernier drive in order that band-spread tuning may be obtained at any point in the frequency range. A little thought will show that band-spread tuning is always obtained through a combination of mechanical and electrical devices. While continuous band spread might seem possible mechanically with a condenser drive of sufficient reduction, in practice large reduction is not easy to obtain without introducing backlash, or without sacrificing accuracy of calibration.

In the mechanical section of the tuning system under consideration the tuning condensers are driven through a worm gearing, spring-loaded to take up backlash and wear. The main dial is mounted directly on the worm shaft and is rotated ten times for 180° rotation of the condensers. The auxiliary dial numbers appear through windows in the main dial shell and are changed automatically every resolution of the dial by means of an epicyclic gearing so that the calibration is numbered consecutively from 0 to 500. The actual useful length of the equivalent scale being twelve feet. The result is that signals are well spread out on the scale, even on the general coverage ranges, making tuning and logging both convenient and precise. With the coil connections shifted to give full spread on any amateur band the character of the system is especially striking. The 14 MC. band, for instance, is given 400 dial divisions, which, since the band is 400 KC. wide, means that the tuning rate is 1,000 *cycles* per dial division. This feature will be

An amateur band may occupy a small section of the total band covered with any one set of coils.

especially appreciated by anyone who is accustomed to tuning the single-signal receiver with the crystal circuit adjusted for maximum selectivity.

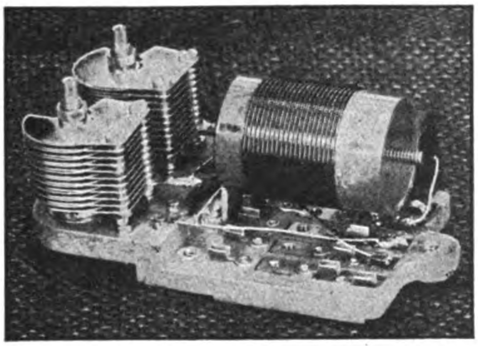


Figure 211. A medium frequency R.F. coil unit used in the HRO, shown removed from its shield.

REVIEW QUESTIONS AND PROBLEMS. 1. Is it possible to increase the selectivity of a radio receiver without increasing the sensitivity? Explain your answer.

2. How do you explain why a long antenna picks up more of the radiated energy?

3. What are the limitations of TRF receiver?

4. What is your understanding of a non-linear impedance?

5. Make a block diagram of a TRF receiver following the type shown for the superhet set.

6. In the circuit of the Stewart-Warner Model R-144 receiver, what are the values of the following parts:

a. Grid leak,
b. Tone control condenser,
c. Voltage of the pilot bulb,
d. Volume control,
e. Resistance of the field coil,
f. Line fuse.

7. In the circuit of the AC-DC receiver, how many diodes does the type 12SQ7 tube have? Are all these diodes used?

8. In the receiver mentioned in question 7, what is the purpose of part 27?

9. How could a tone control be added to the circuit of the AC-DC receiver described in the text? Make a sketch to explain your answer.

10. Without reference to the text, explain how one of the receivers described in the lesson can be properly aligned.

11. What are some of the special features of the communication receiver not found in ordinary home receivers?

12. In an all-wave receiver, about what ratio is there between the lowest and highest frequencies covered on any one band?

REVIEW QUESTIONS & ANSWERS

1. What does a tuned circuit do?

7. Circuit on page 186.

9. You can make the circuit in the diagram on page 186.

11. What circuits or adjustments make these features possible?

LESSON 15

Electronic Oscillators

Oscillator circuits are employed to produce high frequency currents for radio transmission. Practical electronic oscillators obtain power for operation from a D.C. source — batteries or a power supply.

NATURE OF OSCILLATIONS. Let us connect a good quality condenser to a battery. After a short period of time, the condenser will be charged approximately to the potential of the battery. Now we will disconnect the condenser from the battery, being careful not to short the terminals of the condenser, and connect this condenser to a low-loss coil. What will take place is of prime importance, for this same action permits radio transmission. Even before we had equipment to detect the effects of the action which will take place in this circuit, scientists knew from mathematical analysis what was to be expected. Since then, we have studied the action of such simple circuits, made up of a charged condenser and an inductance, and know exactly what takes place.

As soon as the condenser is connected to the inductance, it will start to discharge and a current will flow through the inductance. A current in the inductance will set up a magnetic field. After a short time, the condenser will be completely discharged and have no stored energy, while the magnetic field around the inductance will be maximum. Now the magnetic field will break down, sending current through the coil in the opposite direction and charging the condenser with the reverse polarity. Then the cycle will repeat itself. As you can see, the current in the circuit is of an alternating nature, constantly increasing or decreasing with time, and the action is repeated periodically. The coil and condenser, and no other parts, have created an alternating current from the D.C. of the battery used to charge the condenser.

Perhaps you are wondering about the voltages existing in this oscillating circuit. The voltage across each component (inductance, capacity, or resistance of the wires making up the connections) is changing also. Since the voltage across the inductance is leading the voltage drop across the resistance of the circuit, while the voltage across the capacity is lagging behind this voltage drop of the resistance, the voltages across the inductance and the capacity are 180° out of phase. When the voltage across the inductance is increasing, the voltage across the capacity is correspondingly decreasing. This is to be expected from the explanation in the text.

This exchange of energy between the capacity and inductance would continue forever were it not for the losses occuring in the circuit. The condenser has some losses and, of course, the inductance has resistance present. All the losses of the circuit may be expressed as an additional resistor connected in series with the condenser and inductance. If this is done, the condenser and inductance may be assumed to be perfect without any losses; the losses have been included in the resistor described. As the alternating current surges up and back through the circuit (oscillates is a good way to describe this), a certain amount of power is wasted in the series resistor. In a pure condenser or inductance, the current and voltage are 90° out of phase and no power is lost. As each repetition of the current reversal happens, some energy is used up in the resistor, and the intensity of the remaining electrical energy is diminished. Notice the effects on the wave form produced by the presence of the resistance; the figure shows three different conditions. If the resistance is very high, so much of the energy delivered by the charged condenser is used up on the first half of the cycle of the oscillating action, that no additional repetitions occur. This statement tells us that if the resistance of the circuit is too high, no oscillations will take place.

Refer to Figure 212, on the next page.

What determines the frequency of the oscillatory current? We know that a series L-C circuit has the least opposition to its natural frequency and would favor this frequency. The frequency is, therefore, determined by the expression:

$$f = \frac{1}{6.28\sqrt{LC}}$$

which is familiar to us from our work in Lesson Seven. This formula tells us many things. We can tell from the formula that the frequency depends on the inductance and capacity. The frequency has nothing to do with resistance in a series circuit. Increasing L or C, lowers the frequency. Many values of L and C, will give the same frequency, provided that the product of the two gives the same number.

In this formula, f is in cycles, L is the inductance in henries, and C is the capacity in farads. If L is expressed in microhenries and C in microfarads, the answer for f will be found in megocycles (MC.).

Memorize these two very important sentences.

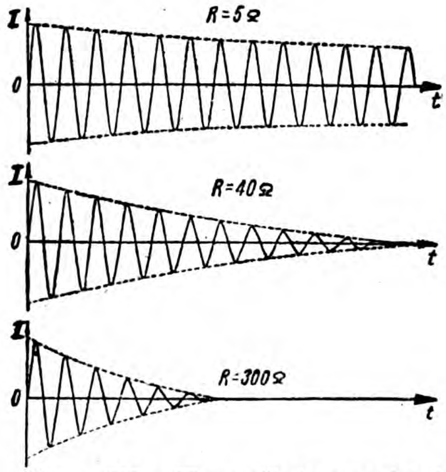


Figure 212. The oscillations produced by the same L-C circuit but with different values of series resistance.

Even with very little resistance (losses), some energy is lost during each cycle with the corresponding reduction of the circulating current, I.

The action of a parallel L-C circuit is very similar and, for practical problems, the same formula can be applied. However, the resistance has a minor effect on frequency and for absolutely correct results a somewhat different formula is needed.

More advanced radio books present special development for the parallel circuit.

The understanding of the function of an oscillatory circuit is so important that we will now associate the idea with a mechanical analogy. Imagine a pendulum—perhaps a weight suspended on a fine string, or perhaps a child's swing. We swing the weight all the way to one side. This is equivalent to charging the condenser. Now we will let the weight go. It comes down, pauses in its normal position, and then swings up. The normal position corresponds to the condenser being discharged and all the energy being present in the inductance. The swinging-up action corresponds to the charging of the condenser in the opposite direction. The swinging will continue, but will it be as great each time? The losses of the mechanical system, just like the resistance losses in the electrical circuit, will reduce the amount of the swing and finally will bring the pendulum to rest. We will come back to this mechanical analogy again when we talk about producing continuous waves.

Make a simple pendulum using a string and a weight, and experiment setting this pendulum into oscillation.

It is clear that no particular amount of energy is needed to start a L-C circuit oscillating. Any amount is sufficient. But the intensity of the oscillations will depend on the initial amount of energy supplied to the circuit. The reason for the oscillation is due to the properties of the inductance and capacity. These properties are determined experimentally and are as decreed by Nature.

It is assumed, of course, that the losses per cycle are small.

CONTINUOUS OSCILLATIONS. If our L-C combination can be made without losses, all the re-occurant waves would be of the same intensity and the oscillations, once started, would go on for all time. Of course, all L-C circuits have losses, but this problem can be solved another way. The losses use up a certain amount of energy every cycle. If we could replace the lost energy with an equal amount, the oscillations would be the same, i.e. continuous, of the same size, and not damped. This is exactly what is done with the aid of vacuum tubes.

Receiving type tubes or other small size tubes are used in oscillator circuits. The small amount of energy generated may be amplified in additional stages.

Figure 213. For high frequency oscillators, special vacuum tubes, having very small inter-electrode capacity, are employed.

Let us return to our mechanical analogy of the swing. The swing loses very little of its movement (energy) each time it swings up and back. Suppose we gave the swing an added push when it returned to the approximate original starting place, then the swing action would go on without reduction and without a stop. This added push must come at the right instant and must be about right in intensity. It would help little to push too hard or not enough, and it would be detrimental to push in the wrong direction against the motion of the swing. The best place to add the energy needed is at the end of the swing, at the highest point of the swing, when the motion is about ready to reverse. The energy to be added must be of a value, over the time it is applied, to combine with the energy still left and the total must equal to the original quantity of energy. This sounds like a big order, but great things can be done with electronics.

Using the pendulum you constructed, see if you can keep it in continuous *oscillation* by adding, during each *swing-cycle*, the energy lost.

TICKLER COIL OSCILLATOR. All modern transmitters use vacuum tubes for the production of radio frequency oscillations. Early radio transmitters employed spark gaps and arcs for this purpose. The function of a vacuum tube oscillator can be best understood from a simple tickler type feedback arrangement. Please examine the circuit on page 203. The coil and tuning condenser connected to the control grid and ground form our L-C circuit. We know that a vacuum tube amplifies and this suggests the possibility of taking a little extra energy from the plate side and feeding this energy back to the grid L-C circuit to make up for the losses. This is exactly what the circuit accomplishes and we will see why this is so.

The fact that a vacuum tube amplifies, implies that there is much more energy in the plate circuit than in the grid circuit.

Let us assume that some disturbance, no matter how minute, has produced a charge on the variable condenser. Stray fields in the air or a slight potential change in the filament or plate supply would be enough for this purpose. Oscillation in the L-C circuit will take place. The voltage across the condenser will be changing at the frequency of the circuit, and this volage will be impressed on the control grid of the tube. This grid voltage change, in turn, will

Oscillations would take place since the condenser would have a higher (or lower) potential than present, a moment before, for an equilibrium condition.

vary the plate current producing a voltage drop across the tickler coil. Please refer to the diagram and follow this reasoning. For the moment we will not consider the .00025 mfd. grid condenser, since it acts as a short circuit to the R.F., or the grid leak resistor of the value indicated which is required to supply a grid return path and bias.

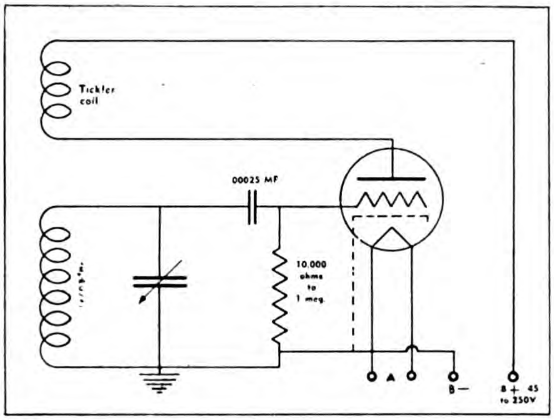


Figure 214. A basic vacuum tube oscillator employs some method for returning a little of the energy from the plate circuit to the grid circuit.

The energy in the tickler coil can be made of the proper intensity and correct phase relationship to feed back to the coil of the L-C combination the required amount of energy to overcome the losses. In practice, however, more than this amount of energy is returned to the L-C circuit, and so the intensity of the oscillations is increased with each cycle. This increase continues until the characteristics of the tube used, limit any further increase. If the tickler is in the wrong phase relationship, it will prevent oscillation. This is equivalent to pushing the swing in the wrong direction, to come back to our mechanical analogy. If not enough energy is returned to the L-C circuit, the oscillations will be sustained for a few cycles, becoming smaller each time, and finally dying out.

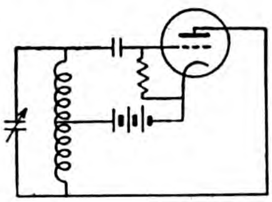
In the circuit of a tickler oscillator, no regular cathode resistor is incorporated and the required grid bias is obtained in a special way. The pulses supplied to the grid are of alternating nature, and the grid is driven positive during a part of the cycle. When the grid is positive, it acts as an anode (plate) and conducts current to the cathode. Under these conditions, the .00025 mfd. condenser in the grid circuit is charged, and during the balance of the cycle this condenser discharges through the grid leak resistor which may be between 10,000 ohms and 1 megohm. Notice that the condenser took a charge which made its grid side negative and the coil side positive. While the condenser discharges, the circuit is completed by the resistor and the coil. It is possible for the coil to be the R.F. inductance and at the same time offer a low D.C. path for the current leaking off the condenser. In this circuit, the grid leak resistor will be negative at the grid side and positive at the cathode (ground) side. The voltage developed across the grid resistor will serve as the bias since it is applied between the grid and cathode. Since the energy in the condenser is replenished every cycle, and since the discharge rate of the .00025 mfd. con-

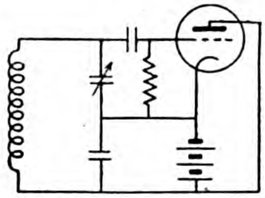
This impedance (reactance) of the .00025 mfd. condenser is so low for radio frequencies that its opposition to R.F. currents may be considered equal to zero.

The oscillations (in a practical circuit) build up to the maximum value very quickly — in a fraction of a second.

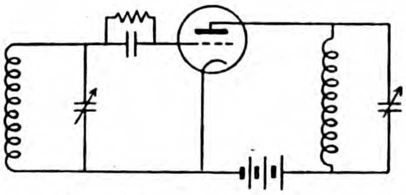
Actually, electrons are attracted from the cathode to the grid which is positive at the moment.

Be sure you understand this action. Circuits of a similar nature are used in electronic equipment.





Above are the basic circuits of Hartley and Colpitts oscillators.



A tuned-grid tuned-plate oscillator.

A mathematical treatment on the input impedance of a triode is presented beginning with page 228, in *Principles of Radio Engineering*, by R. S. Glasgow.

TGTP oscillator operates on this principle.

denser through the grid leak resistance is relatively slow, the bias is kept about constant. The oscillator tube is biased to give Class C operation.

Hartley Oscillator. Many circuits use a tapped coil and a single tuning condenser to form our L-C circuit. The energy is fed back through magnetic coupling between sections of the inductance connected in the plate and grid circuits. If the coil has a tap and is connected to the grid and plate, or to the grid and screen grid in pentodes, the circuit used is a form of a Hartley oscillator.

Colpitts Oscillator. In many circuits, only a single coil is used and the tap is brought to a junction of two capacitors. Such circuits are named after Colpitts, the inventor of the basic circuit of this type.

Negative Resistance Concept. Physically, negative resistance does not exist. It is possible, however, to create circuits which will nullify or reduce the actual resistance physically present in a circuit. We say that such circuits possess negative resistance which overcomes regular (positive) resistance. If negative resistance can be combined with an inductive-capacitive circuit, and kept at a value which will just nullify the actual resistance present, the L-C circuit would oscillate without a stop. This technique is used in some oscillators.

A coil-condenser combination is connected to the grid side of a vacuum tube. Another coil-condenser combination is connected in the plate circuit of this vacuum tube, but there is no magnetic coupling between these coils and no electrical connection between these L-C circuits. And yet the inter-electrode properties of the triode permit the operation of this circuit as an oscillator. This oscillator is called tuned-grid tuned-plate, or TGTP type.

It is possible to prove by experiment and by mathematical derivation, that upon looking into the grid to cathode circuit of a vacuum tube, one does not always find only capacity present. You must understand that engineers say that they are *looking into a circuit*, when they mean the appearance of the circuit connected to two terminals from the point of view of another electrical circuit. The terminals of a coil appear as an inductance. The two terminals of a L-C circuits with losses, will appear as a pure resistance, at resonance. The grid to cathode input of a tube appears as capacity, except when the plate circuit has inductance connected to it. In such instances, the grid to cathode circuit appears as negative resistance in the sense that we defined it. These peculiar results are primarily due to the inter-electrode capacity in the triode. Since the tetrode and pentode have very little grid to plate capacity, they are not used to produce negative resistance in this fashion.

In an oscillator, where there is no direct (outside the vacuum tube) connection between the grid and plate circuits, the operation is obtained in the following manner. The grid circuit L-C is adjusted to the desired frequency. If the oscillator is to produce 4.6 MC., L and C are selected to give this frequency. The plate circuit parallel-connected L-C, however, is adjusted to a higher frequency, not very much removed from 4.6 MC. The plate L-C parallel combination will be driven by the vacuum tube which is being excited by a frequency of 4.6 MC., and this frequency is lower than the resonant frequency of the plate parallel L-C. This circuit will, therefore, behave inductively. This means that the plate of the tube is loaded with an inductive load, and, recalling that an inductively loaded triode presents negative resistance in the grid circuit, we can understand that the grid circuit L-C combination is looking into a circuit with negative resistance. But this negative resistance overcomes the losses in the grid L-C circuit and the oscillations continue.

The plate circuit L-C, as explained in the previous paragraph, is not tuned to the exact frequency of the signal driving it, but is excited with this signal. This plate circuit acts very much as a load consisting of a resistor and inductance. The tuning methods will be covered in a later section.

The plate circuit, to the frequency exciting it, must behave as an inductive circuit.

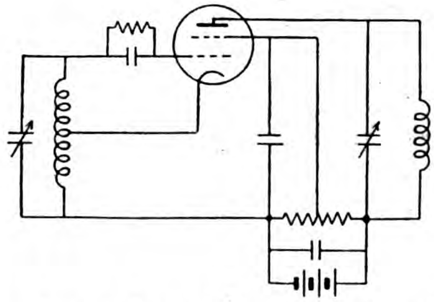
Limitations of Self-Oscillators. We have already learned that the frequency of a parallel L-C circuit depends primarily on the values of the inductance and capacity and to a limited degree on the resistance present in this circut. If the inductance, capacity, and losses of the parallel L-C circuit used in the oscillator could be kept constant, the unit once adjusted would deliver the very same frequency at all times. However, all these factors change with temperature, age, voltage, and other conditions. As the value of inductance, capacity, or resistance changes because of the conditions mentioned, the frequency will also change. An oscillator which has its frequency varying is not stable. A transmitter, using an oscillator with poor stability, will not stay in the same spot in the receiver. The signal will appear to fade and constant retuning of the receiver will be needed. Stability is very important; frequency drift cannot be tolerated; broadcasting stations must not vary more than 20 cycles from their assigned frequency which may be 1,000,000 cycles (1,000 KC.), for some stations.

For example, variations are caused by vibration of the condenser plates, wires of the coil, moisture deposits on the coil changing the inductance, change of tube characteristics with age, changes in the voltage delivered by the power supply.

Reference is made to U. S. broadcasting stations in 1943.

The amount of energy taken from the oscillator has an effect on the voltage fed back and also on the function of the tube. As the load is varied, the frequency of the oscillator will also shift.

Electron-Coupled Oscillator. In order to eliminate the frequency shift which may be due to changes in the load circuit, a special circuit was developed and employs a pentode radio tube. Any of the oscillator arrangements we have described can be employed, but the screen grid is used as the anode (plate) for the circuit. The plate of the pentode is wired to the load and, since the plate is not one of the tube elements which function in the oscillator circuit, the load has little effect on the frequency. The plate current, of course, is of the frequency produced in the grid oscillatory circuit. The load may be in the form of a parallel tuned circuit or a pure resistor. Electron-coupled oscillators give the best stability of all self-excited oscillator types.



A circuit of an electron-coupled oscillator. You will observe that a basic Hartley oscillator circuit is employed.

Quartz Crystals. All oscillators of high stability employ quartz crystals and the study of this material and the circuits employed is of importance to the radio technician. When quartz is distorted mechanically, an electric charge will be developed; and mechanical distortion will result if the substance is placed in an electric field. This property permits quartz crystals to be used in electric frequency-control circuits.

The action of an oscillating quartz crystal may be analyzed by reference to its equivalent electrical network as illustrated.* The L, C, and R represent the actual crystal equivalent, while the capacity C_1 is formed by the metal electrodes used to hold the

*Many of the illustrations dealing with crystals and their circuits are reprinted from "Frequency Control with Quartz Crystals," 1940, published by Bliley Electric Company.

Courtesy Bliley Electric Co.

Figure 215. A group of natural quartz crystals.

crystal in place. C_2 capacity is present if the electrodes are not in direct contact with the crystal. We will not consider this capacity in our discussion. From your knowledge of resonance, you can see that at some frequency L and C will have their reactances exactly equal and we will have these two behaving as a series resonant

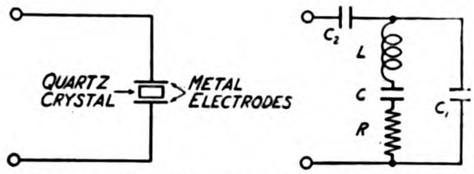
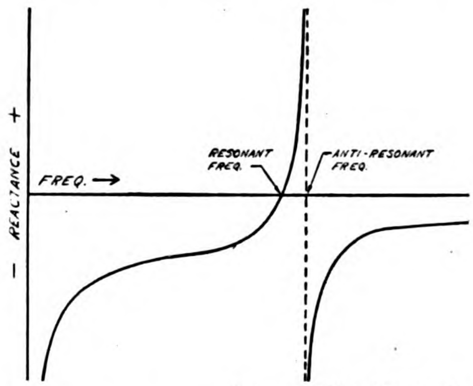


Figure 216. The equivalent electrical circuit of an oscillating quartz crystal.

circuit. This frequency is also called the natural frequency of the crystal. At a slightly higher frequency, the effective reactance of L and C combined will be inductive. You recall that a series L-C circuit behaves inductively at frequencies above resonance. Now if L and C, acts as an inductance, there will be a frequency at which



Courtesy Bliley Electric Co.

Figure 217. Reactance curve of a quartz crystal. Please notice that at a certain resonant frequency, the equivalent series circuit behavior is obtained. At a somewhat higher frequency, the parallel circuit anti-resonant action results.

Type of reactance offered by a quartz crystal at different frequencies. Positive (+) reactance is inductive, while negative (—) reactance is capacitive. At the resonant frequency where the quartz behaves as a series circuit, the reactance is zero (center horizontal line represents *zero* reactance). At a somewhat higher frequency, the circuit behaves as a parallel resonant circuit offering almost infinite reactance as the equivalent reactance shifts from inductive to capacitive.

this *equivalent* inductance and the capacity C_1 will form a parallel resonant circuit. You must realize, from this explanation, that at one definite frequency the crystal behaves as a series circuit at resonance, while at another frequency the circuit acts as a parallel or anti-resonant circuit.

The inductance, L, of a crystal is very large, reaching 100 henries in extreme cases. To operate at high frequencies, the C of the equivalent circuit must be very small. Since the Q of the circuit is obtained by dividing inductive reactance by the resistance, the Q of a crystal is in the order of 6,000 to 30,000. This makes the crystal circuit have a very steep resonance curve. If any reactance of the circuit changes (this may be the changes we mentioned and which have an effect on frequency), a very minute shift in frequency will be enough to bring conditions back to resonance. This explains why crystals are adaptable for frequency control work.

Using the formula for the frequency of a series resonant circuit (see page 201), solve for the value of C, for the case where L is 100 henries, and f is 10 million cycles. (10 MC. frequency is used for short wave transmission). It is more important for you to realize how small C is, rather than to get the exact answer.

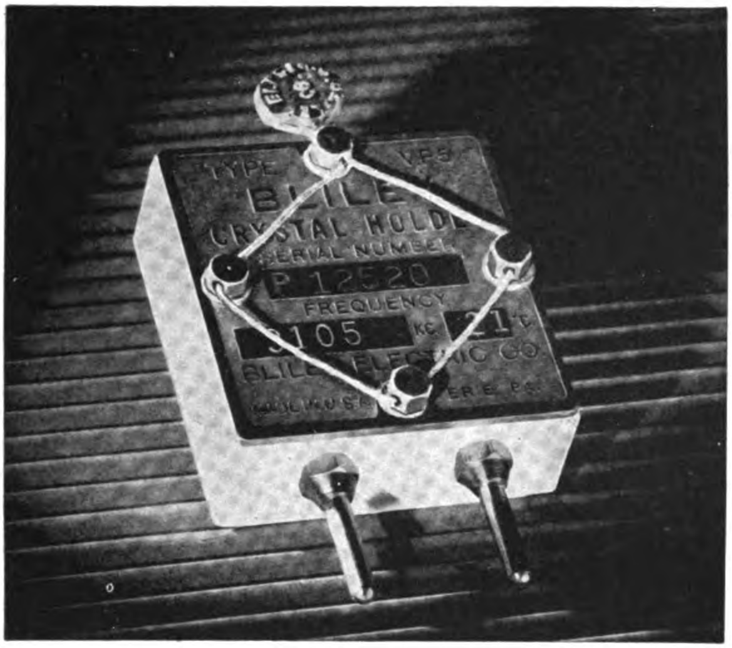


Figure 218. Usually crystals are housed in containers which are marked with the frequency of the unit and the temperature at which the calibration was made. The crystal holder plugs into a 5 or 6 prong socket.

Usually crystals are supplied in holders which plug into five or six prong sockets. Only two prongs are used and the crystal holder may fit into the socket in several different ways. Always be certain that you are using the terminals of the socket which are connected to the circuit. Most of the usual cut crystals have a slight frequency variation with temperature. For extremely accurate requirements, the crystals are housed in thermostat controlled heated containers and all temperature variations are prevented.

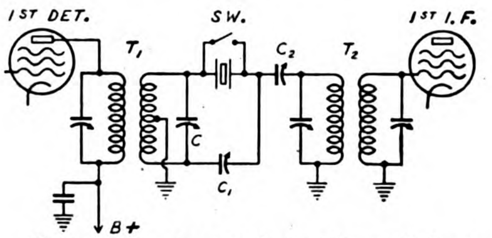
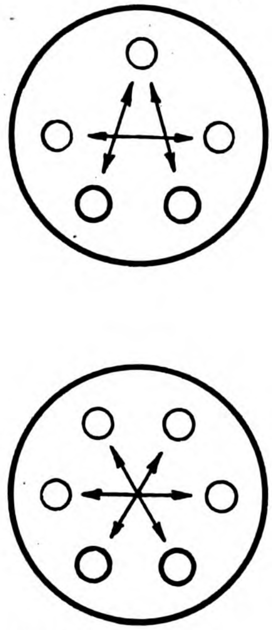


Figure 220. A crystal may be used in a radio receiver to give extremely sharp selectivity.

Crystal Filters. The resonant properties of quartz crystals are employed in communication receivers (as covered in the last chapter) to obtain a very high degree of selectivity. Since the crystals ground for filter purposes have extremely high Q values, the frequency discrimination, or selectivity, will be many times better than could be obtained with ordinary tuned circuits.

Crystal Power. An oscillating crystal is a mechanically vibrating body. Internal stresses are present and heat is developed as a result of the motion. If the vibration amplitude is permitted to become too great, the stresses can reach a value sufficient to

QUARTZ CRYSTAL HOLDERS



Arrows point to the two corresponding terminals of a 5-prong and a 6-prong socket that are used together for a standard two-prong crystal holder. Notice that there are several alternate choices.

Figure 220 shows the fundamental arrangement of a crystal filter stage in a modern superheterodyne communications receiver. Notice that the tapped transformer, the crystal, and the variable condenser, C_1, form a bridge circuit. The use of a tapped transformer can be avoided by employing a dual condenser for C, and grounding the common connection between the two; the final effect, however, is the same. At frequencies remote from the resonant frequency of the crystal, the bridge circuit is balanced and no voltage appears on the grid of the following amplifier tube. When, however, the transformer voltage is at the resonant frequency, the crystal impedance drops to a low value, thereby, upsetting the balance and permitting a signal voltage to appear on the grid of the amplifier tube.

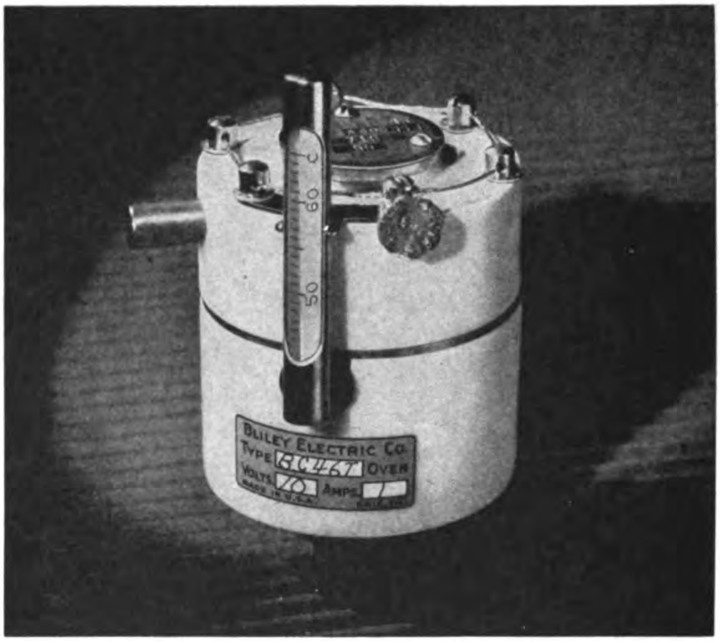
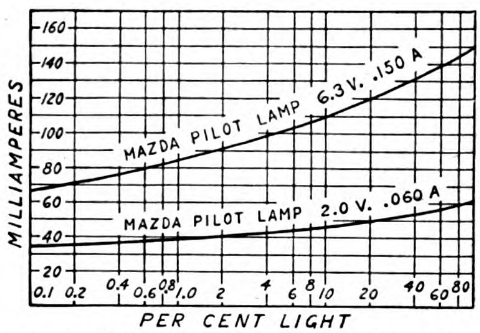


Figure 219. To eliminate variations due to temperature, specially constructed thermostatically controlled ovens are employed. The temperature inside the oven is kept at a constant value.

The temperature inside the oven is higher than the highest expected room temperature. Electric heaters are employed. The moment the oven temperature reaches the selected value, the electric heaters are automatically shut off. As the temperature inside drops a tiny amount, the heaters go on again to bring the temperature back to the required value. In this manner, the temperature inside the oven is kept at a relatively constant value as may be needed.

shatter the crystal. As a precaution in practice, you should check the crystal current when a new application is tried. A thermo-milliameter (which reads R. F. currents) may be connected in series with the crystal. Most crystals should have currents less than 100 ma. If a suitable meter is not available, a pilot lamp can be used instead. Standard pilot bulbs rated at 2 volts, .06 amperes, or the type rated at 6.3 volts, .15 amperes, can be employed. The current is estimated by judging the brilliancy and comparing to the information presented in the graph.

A pilot lamp of the 2 volt type will permit you to judge the value of the crystal current and also act as a fuse in case the current rises much above 60 ma.



Courtesy Bliley Electric Co. and General Electric Co.

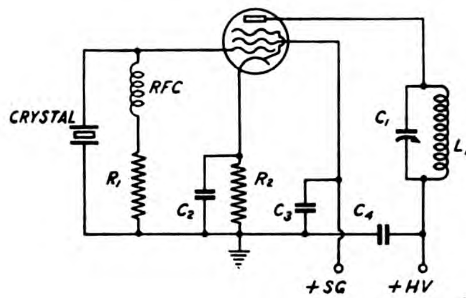
Figure 221. Pilot lamp current characteristics.

CRYSTAL CLEANING. Foreign matter, especially oil or wax, on the surfaces of a crystal may prevent oscillations. The best cleansing agent is carbon tetrachloride, but soap and water can be used. The crystal should be carefully washed and then dried with a clean lint-free cloth.

Care must be exercised, when replacing the crystal in its holder, so as not to chip the corners or to break the crystal by placing it in such a position that it will bind. Where both of the crystal electrodes are separate from the holder assembly, the crystal is merely placed between its two electrodes and inserted into the holder cavity; the edge of the crystal should not protrude beyond the edge of the electrodes as chipping might result. It should be noticed that one face of each electrode is very finely finished while the other face is rough, in comparison—it is imperative that the finely finished faces be in contact with the crystal.

In some types of holders, one electrode is part of the assembly and cannot be removed. This electrode may be slightly larger than the crystal or it may be a small circular *button*. It generally fits into a recess in the holder body and has a spiral spring beneath it. The button-type holders such as the Bliley BC3 and HF2, necessitate the exercise of care in reassembly to prevent binding the crystal when the cover electrode is placed in position. If the spiral spring prevents the electrode from seating in its recess, the electrode can be held in position, for reassembly, by the tip of a screw driver.

In other types of holders, such as Bliley BC6 and CM2, the bottom electrode is fixed and the removable top electrode is held by a flat spring in the top of the assembly. The spring pressure is adjustable by bending the spring until the desired tension is obtained. If the second electrode is a small disc, for use with high-frequency crystals, the position of the disc electrode, and its pressure, should be determined by experiment for optimum crystal performance.



Courtesy Bliley Electric Co.

Figure 222. The basic crystal controlled oscillator. The crystal replaces the L-C circuit.

This is actually a tuned-grid tuned-plate oscillator. As illustrated, a pentode is used in the circuit, but a triode could be employed instead.

The by-pass condensers, C_2, C_3, C_4, should be .002 mfd. or larger. The suggested values for the risistors are given in the text on the next page.

Crystal Controlled Oscillators.* Almost any type of an oscillator can be made crystal controlled by connecting the quartz crystal into the circuit in a manner which will permit the crystal to become the frequency determining element. For example, the crystal may replace the grid circuit L-C in a tuned-plate tuned-grid oscillator we talked about early in this chapter. Very little energy is used by the oscillating crystal and, therefore, little power must be fed back to the grid circuit. Even screen grid tubes will have enough plate to grid capacity to permit oscillation. With some tubes, however, a small condenser is connected between the control grid and plate to add capacity.

This extra grid to plate capacity should be very small. Usually, sufficient capacity can be obtained by bringing a wire from the plate close to a grid connecting wire. A small (10 mmfd. capacity) variable condenser may be used.

Grid leak bias can be used. In general, the larger the value of the grid leak, the greater the bias, and this will be accompanied

***See the footnote on page 205.**

CRYSTAL OSCILLATORS

The circuit mentioned is illustrated under Figure 222.

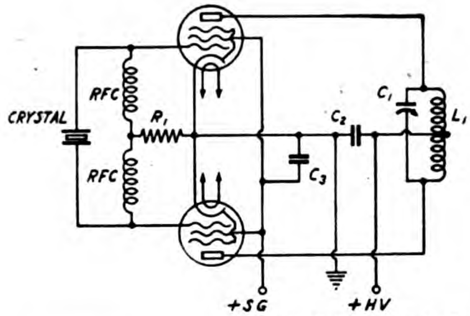
Tubes incorporating letters *RK* are of Raytheon make. Transmitting tubes of the *800* series are made by RCA and other manufacturers.

RFC = Radio frequency choke
R_1 = 5,000 to 10,000 ohms, 2 watts
C_1 = Tuning condenser
C_2 and C_3 = .002 mfd. or larger

with higher crystal excitation. The higher bias will cause an increase of crystal current and a small gain in power output.

PENTODE AND TETRODE OSCILLATORS. The circuit illustrated is commonly used in practice. A combination grid leak and cathode bias is used. R_1 is the grid resistor and may be 10,000 ohms, while the cathode resistor, R_2, should be about 300 ohms. The screen grid must be by-passed and is operated at a voltage lower than the potential on the plate. Notice the use of by-pass condensers.

Pentode and tetrode tubes, having a high amplification factor, will provide greatest power output for a given crystal current. Furthermore, the frequency stability with such tubes is must better than obtainable with conventional triode oscillators. With tubes such as the RK-23, 802, and 807 (these are transmitting tubes and are not listed in the tube data charts in this book), power outputs of 10 to 15 watts can be obtained at frequencies above 1,000 KC. with a reasonably low crystal current.



Courtesy Bliley Electric Co.

Figure 223. Crystal controlled oscillator using pentodes.

PUSH-PULL OSCILLATORS. Oscillators employing two tubes in a push-pull circuit may be used with a quartz crystal. The only advantage such oscillators present is the elimination of the even harmonics in the output. The two tubes used will require twice as much driving power as a single tube, and only tubes which require very low grid drive will permit a substantial increase in power output with the push-pull arrangement.

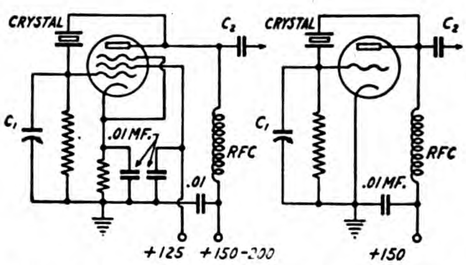


Figure 224. Two types of Pierce crystal oscillator. The crystal is used as the plate inductance in an oscillator of this type.

PIERCE OSCILLATORS. In the Pierce circuits, as illustrated, the crystal is connected between the plate and control grid of the tube used. This arrangement is essentially a Colpitts oscillator with the crystal displacing the usual tank (plate circuit) inductance. It can be seen that the crystal is connected in series with the feed-back condenser C_1, directly across the plate circuit.

The advantage of the Pierce circuit is the simplicity of circuit components. Tuned circuits are not required in this type of an oscillator and, therefore, a rather wide range of crystal frequencies can be used without any serious change in circuit values. The Pierce oscillator, however, is limited to low power output and requires careful circuit adjustments to prevent excessive excitation. Also this type of oscillator is not as stable as other types and is dependent to a larger extent on the stability of associated component parts.

PURPOSES OF OSCILLATORS. Much has been said about oscillators, but the reader may wonder how oscillators are used and what practical function they perform. An oscillator is a generator of radio frequency energy. The power for operation comes from a D.C. source—batteries or power supply. This radio frequency energy can be used as the carrier of a transmitter. Usually, the power available from the oscillator is not sufficient even for a small transmitter and additional R.F. amplification is employed. But the original generation of R.F. is accomplished in the oscillator. In an emergency, any oscillator can be used as a transmitter. The antenna is coupled to the tank coil, and code can be sent by interrupting (breaking) the cathode circuit.

TUNING THE OSCILLATOR. A suitable plate-current milliameter is connected in the plate circuit and is used as a guide for properly tuning any of the oscillators that were described. If the tube is not properly excited so that no oscillation takes place, the plate current will remain constant as the circuit is tuned with the variable condenser. However, when oscillation takes place, the plate current will vary depending on the adjustment made. Please observe the two graphs illustrating the plate current variation as the tuning capacity is altered. The graph marked (a) is for a conventionally operated oscillator, while the graph marked (b) is for a special oscillator circuit known as the Tri-tet.

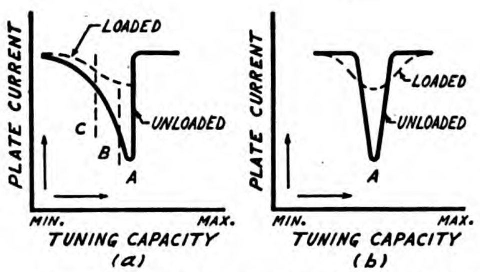


Figure 225. Plate current variation as the capacity of the tank circuit is tuned through resonance.

Best operation is obtained with minimum plate current, but this will not give stable operation since the smallest change, increasing the capacity, will stop the oscillation of the circuit. It is best, therefore, to operate the oscillator with the condenser adjusted to give a value of plate current corresponding to the section of the graph between points B and C.

ADJUSTING THE OSCILLATOR

To change the operating frequency of a transmitter using a Pierce oscillator, a new crystal is inserted and various other stages used in the transmitter are returned. But no adjustment is needed in the oscillator stage.

Where low transmitting power is sufficient, the oscillator may serve as the complete transmitter. Because of regulations, this is permissible only for code transmission.

Please understand that this (or any other) meter is not needed for the proper operation of the circuit. The meter serves as an indicator of proper operation and adjustment.

The meter indicates the RMS value of the current. You may think of the current indicated by the meter as being the *average* amount.

Adjustment for point *A* is best but is unstable. Proper adjustment corresponds to the operation between points *B* and *C*.

Special Oscillators. The requirements of special electronic circuits call for oscillators possessing peculiar properties. We will tell you about the dynatron oscillator because it will help you understand negative resistance a little better. To prepare for this explanation, you should review the limitations of a tetrode tube, as explained in Lesson Nine.

An electron, which escapes from the cathode of a vacuum tube, travels with an increasing velocity towards the positive plate. Any of such electrons may strike the plate with a velocity sufficient to knock out several other electrons. These electrons, which have been knocked out of the plate, will tend to return to the nearest positive body. In an ordinary triode, these electrons return to the plate. In the tetrode, these electrons present a problem and require that the screen grid be at a lower positive potential than the plate.

Even with the screen grid at a lower potential than the plate, a certain number of electrons will be attracted to the screen grid.

What will be the result if we wire a tetrode with the screen grid at a *higher* positive potential than the plate? You can almost guess the answer. The stray electrons, after being knocked out of the plate, will prefer to go to the screen grid. Now let us analyze the action. If the control grid is kept at a constant potential, and the voltage on the plate is increased, more electrons will be attracted to the plate. But an increase of electrons striking the plate, will knock out a larger number of stray electrons; usually much more than their own number. And most of these stray electrons will move to the screen grid since it is the most positive body in the neighborhood. So what net effects will result? An increase in plate voltage caused the plate to have less net electrons, which means less current. The plate circuit of this tube behaves the opposite to a regular resistor. You recall that a resistance circuit has an increase of current with an increase of voltage. This special vacuum tube circuit behaves as negative resistance. If this property is utilized to sustain oscillations, the circuit is called a dynatron oscillator.

The electrons come initially from the cathode.

Secondary emission will be increased.

More electrons have been lost than gained.

In a regular resistance circuit, when the voltage is increased, the current is also increased.

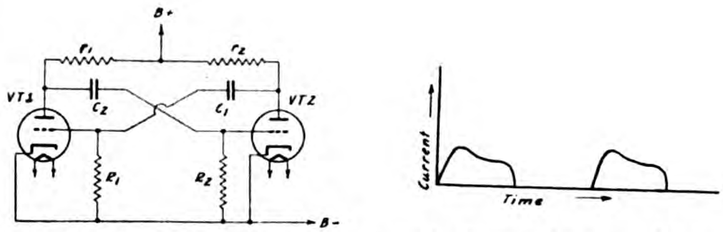


Figure 226. The basic multivibrator circuit and the type of wave produced by a single tube of this circuit.

Multivibrator Oscillator.* The multivibrator is one form of a relaxation oscillator used to control the sweep circuits in cathode ray oscilloscopes, television transmitters, and other special equipment. One of its simpler forms is nothing more than two capacity-resistance coupled amplifiers, so connected that the output of one is coupled to the input of the other, while the output of the second is coupled to the input of the first. This type of oscillator employs no inductance.

Many special electronic circuits employed to generate or change pulses of current operate on principles similar to those employed in the multivibrator.

The basic circuit of such a simple multivibrator is shown. On first examination it would seem that upon connecting the filament

*Explanation of the multivibrator action is reprinted from the author's book, "Television Facts," 1939, Supreme Publications.

and plate supply, the two tubes would draw steady current. However, this is far from what actually takes place. The circuit oscillates violently, producing waves that approach a square shape. This represents sudden rise and fall of current and is exactly what might be expected from a closer examination of the circuit.

Once the circuit is connected, a steady current will begin flowing through the two vacuum tubes and the associate plate resistors r_1 and r_2. Suppose that through some outside disturbance (no matter how minute) the current through r_1 is increased. Since the voltage drop across this resistor is equal to the product of the resistance by the current, the voltage across r_1 will increase with the increase of current.

Follow this explanation with care. Refer to the basic circuit of Figure 226.

The condenser C_2 will act as a short circuit for the sudden change of voltage, and a higher negative voltage will be placed on the grid of VT-2, reducing the current through it.

You can see that the increase of current in one tube will decrease the current in the other, so that the reduction of the plate current in VT-2 will further increase the current in VT-1 and resistor r_1. This action will continue until finally, in this case, VT-1 will have a maximum current limited only by the emission, while VT-2 will have such a high negative potential on its grid that it will be entirely blocked.

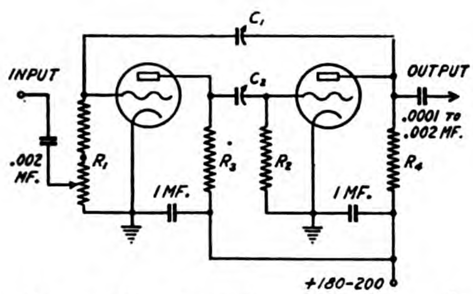


Figure 227. A practical multivibrator circuit. The input potentiometer should be 5,000 ohms.

This action takes place during but a fraction of the total cycle and accounts for the sharp rise of the plate current. At this stage, when one tube is not passing any current and the other is passing the maximum current, the circuit is no longer symmetrical and the condenser begins to discharge. This discharge continues until the blocked tube begins to draw current and then the entire action repeats in the second tube.

The instant the blocked tube begins to pass plate current, the entire cycle is repeated with the two tubes exchanging their functions.

These oscillations by the proper design may be made to appear at any frequency between 50 KC. and 1/50 of a cycle per second. The period is proportional to the product of the capacity and resistance.

These oscillators are very unstable, the frequency shifts a great deal, and by themselves multivibrators serve no useful purpose. However, multivibrators can be made as stable as some controlling frequency (equal to or a fraction of the multivibrator natural frequency), and this fact makes the multivibrator especially useful.

The sharp corners of the plate current curve, of course, indicate the presence of a large number of harmonics. As high as the fiftieth harmonic is detected with ease. This presence of many harmonics and the fact that a multivibrator will lock in step with any frequency that is a multiple of its own approximate frequency, makes it adaptable as the frequency control and a generator of subharmonics. For example, in the practical circuit illustrated, it is possible to produce frequencies which are sub-multiples (fractions) of the crystal controlling frequency connected to the input. The values of suitable parts are listed on the next page:

QUESTIONS TO BE ANSWERED

50 KC.	10 KC.
R_1—10,000 ohms (total)	R_1—25,000 ohms (total)
R_2—10,000 ohms	R_2—25,000 ohms
C_1—750-1500 mmfd.	C_1—1000-3000 mmfd.
C_2—750-1500 mmfd.	C_2—1000-3000 mmfd.
R_3—20,000-25,000 ohms	
R_4—200,000-250,000 ohms	

In case this multivibrator, designed for about 10 KC. operation, is used with a crystal oscillator producing 100 KC., the output of the multivibrator will give frequencies of 10 KC. and multiples of this 10 KC. frequency at the same degree of accuracy as the original accuracy of the crystal. The crystal oscillator is connected to the input, while 10 KC. and its harmonics are obtained at the output.

The output frequencies obtainable from a multivibrator may, in turn, be employed to control another multivibrator which will, further, deliver sub-multiples of the new controlling frequency.

REVIEW QUESTIONS AND PROBLEMS. 1. What is the minimum voltage required to set a L-C circuit into oscillation?

2. What determines the frequency of oscillation of a series L-C circuit?

3. At what frequency will a circuit consisting of 100 mmfd. condenser and 100 microhenries choke oscillate? Refer to earlier chapters for required method to change the units to farads and henries for use in the formula.

3. If you substitute the quantity in mmfd. for C, and microhenries for L, in the regular formula, you will obtain your answer in megacycles.

4. What determines the rate with which the oscillations produced by a L-C circuit, die out?

5. What is the main difference between a Hartley and a tickler-feedback oscillator?

6. What is the purpose of a grid leak resistor?

6. Is it possible to omit the grid leak resistor in an oscillator?

7. Can a single radio part possess negative resistance? Explain your answer.

7. A part not connected in any special way.

8. What are the limitations of a self-oscillator?

9. Explain the function of a crystal using the equivalent circuit to help you with the explanation.

10. Why is the Q of a quartz crystal very high?

10. Write the formula for Q. What effect does L have on the value of Q? Is L large in a crystal?

11. For what purpose are oscillators used?

12. Explain how an oscillator is adjusted for proper operation. Does the tuning have any effect on the frequency?

LESSON 16

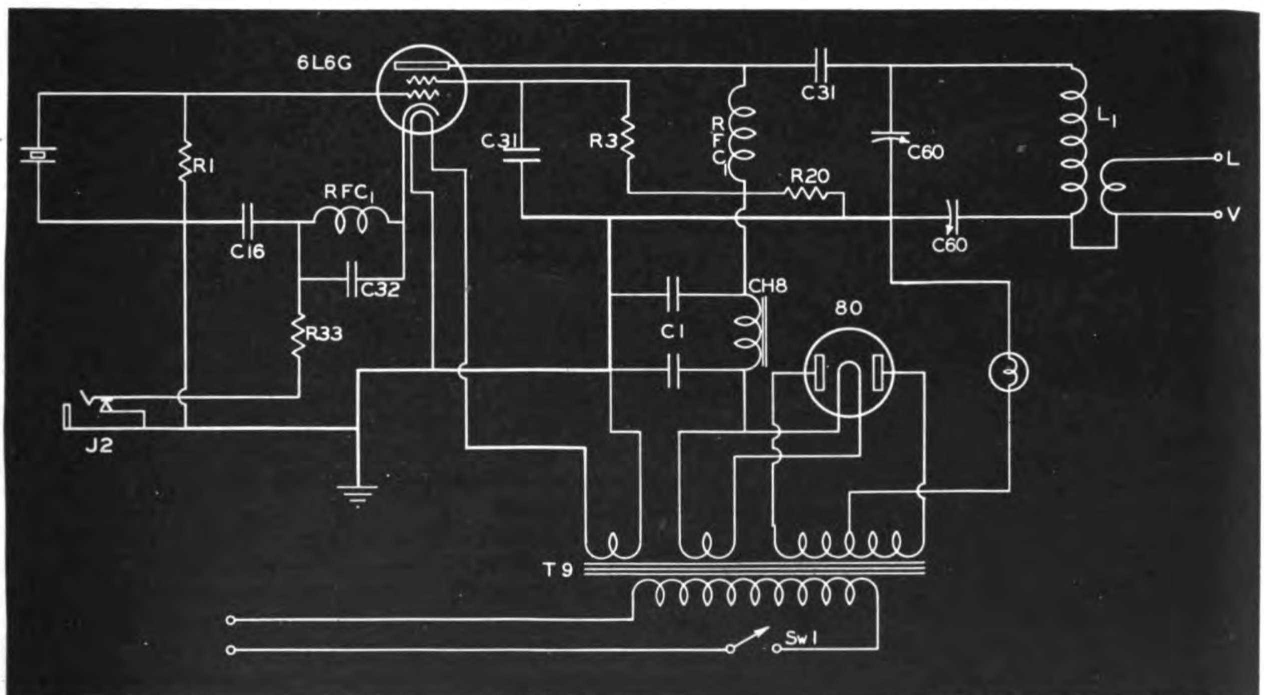
Radio Transmitter Circuits

A CRYSTAL CONTROLLED TRANSMITTER. You probably recall that any oscillator may serve as a low power transmitter. We will begin our study of practical transmitters by considering a unit which employs a type 6L6-G tube as a crystal oscillator and contains the required full-wave power supply in the same chassis. This simple transmitter will give excellent results and has been used by thousands of beginner amateur radio operators.

As the first step, study the schematic diagram. The list of parts is given and you must know to some degree of accuracy the actual values of the different parts used. Notice that the complete schematic illustrates a crystal oscillator similar to the types you have already studied, and also a power supply which is very well known to you. The few unusual features will be discussed in detail when we review the function of the circuits.

Thousands of individuals in the United States have operated their own amateur radio stations and carried on two way communication. Many of the facts about transmitters presented in this lesson will stress application for amateur radio requirements. Many of the readers of this *course* will become amateur radio operators and station owners after the War when licenses will be issued once again.

Ten to fifteen minutes should be spent studying this circuit.



Courtesy Standard Transformer Corp.

Figure 228. The circuit of a crystal oscillator transmitter.

COMPONENTS

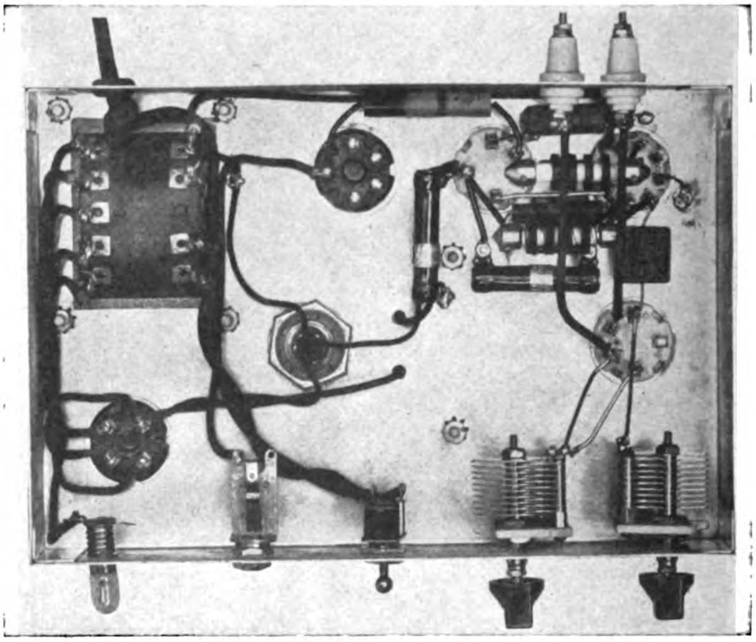
C 1	8-8 mfd. 450 volt electrolytic
C 16	.01 mfd. 400 volt paper condenser
C 31	.002 mfd. mica dielectric condenser
C 32	100 mmfd. mica dielectric condenser
C 60	100 mmfd. midget variable
R 1	50,000 ohms, 1 watt carbon resistor
R 3	25,000 ohms, 10 w. wire-wound type
R 20	40,000 ohms, 10 w. wire-wound type
R 33	400 ohms, 2 watts, resistor
T 9	Stancor P6335 power transformer
CH 8	Stancor C2305 filter choke
RFC	2.5 uhy. 125 ma. R.F. choke
J 2	Closed circuit jack
SW 1	S. P. S. T. toggle switch

Compare the schematic diagram with the top and bottom views of the chassis. You should be able to locate every part indicated in the schematic in either of these two photographs. If you wish, you may mark the parts in the photographs with the actual symbol numbers as shown in the schematic diagram. See how neatly the unit is wired and resolved to do as good work when you build radio equipment.

Refer to the schematic diagram on the previous page.

The A.C. cord comes through a protecting rubber grommet. The two stand-off feed-thru insulators are for the antenna connections.

Since the rotors of the variable condensers are at ground potential (see schematic), they are mounted directly on the metal chassis.



Courtesy Standard Transformer Corp.

Figure 229. Bottom view of the small transmitter described in the text. It is important that you are able to locate all the parts, as shown in the schematic diagrams, in the corresponding photographs of the unit.

Circuit diagram, Figure 228. Chassis illustrations, Figures 229 and 230.

Let us review how the power supply operates. The power transformer, T-9, is designed for the available A. C. power line voltage and frequency. In most cases, this power supply is 110 volts, 60 cycle, A.C. The switch, Sw-1, places the unit in operation by completing the circuit of the transformer primary. Please follow our discussion by referring to the circuit diagram and the two chassis illustrations.

The power transformer has three secondaries. The first one, at the left, as shown on the schematic diagram, supplies 6.3 volts for the filament of the 6L6-G tube. Please trace this connection through and notice that one side of this filament winding is grounded to the chassis. The middle secondary supplies 5 volts for the filament of the type 80 rectifier. The remaining secondary winding is the center-tapped high voltage secondary. Usually, in full-wave power supplies, the center tap of the high voltage secondary is grounded. In our circuit, this center tap completes the circuit to ground (this is the negative plate voltage connection) through a small pilot-bulb. This bulb acts as a fuse since it will burn out if the current, taken from the power supply and passing through the bulb, is too great. The bulb may be used also to indicate approximately the amount of plate current taken by the oscillator. In this manner, the bulb may be used as an aid for properly adjusting the oscillator. Of course, a meter, 0 to 100 ma.

A 150 ma. 6.3 volt bulb is suitable for this application.

D.C., may be connected in place of the bulb or may be connected instead into jack, J-2, which is employed for the transmitting key.

From your early study of power supplies, you probably recall that positive plate voltage is taken from one side of the rectifier *filament* connection (or center-tap of the filament secondary if available). Find this point, and remember for future reference that this is the most positive voltage point of any power supply. Notice that the filtering is accomplished with a two section electrolytic condenser, marked C-1, and a filter choke, CH-8.

By any power supply, we mean types using similar circuits.

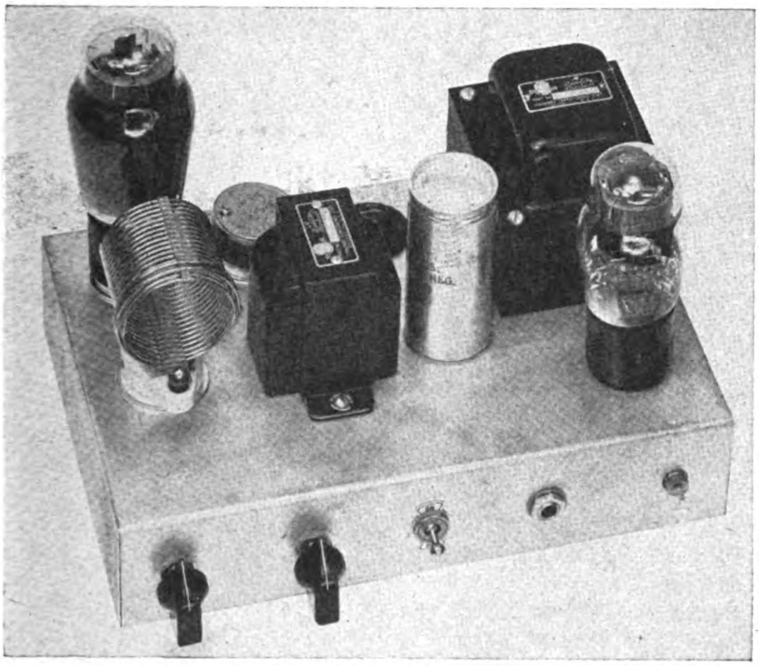


Figure 230. Top view of the transmitter. The tank coil and antenna coupling link are self supporting and are mounted on a form which plugs into a five prong socket.

Such close placement of parts is permissible in small transmitters.

Now we can study the circuit of the oscillator. The grid side of the 6L6-G, oscillator includes the quartz crystal and resistor R-1 used as the grid leak. Placing an R.F. choke (called an aperiodic coil in this application) in the cathode circuit, produces regeneration. The effect of this action provides harmonic output and permits operation on several bands with a single crystal. Frequency doubling procedure is important and will be explained later in this chapter.

For economy reasons, the amateur operators prefer to use but a single crystal for operation at different frequencies on several bands.

This oscillator uses a circuit known as parallel-plate-feed. Notice that the positive plate voltage reaches the plate of the 6L6-G through RFC_1, a choke coil. No D.C. from the power supply can enter the plate inductance L_1, since condensers C-31 and C-60 block the passage of direct current. The radio frequency energy supplied by the tube, on the other hand, cannot enter RFC_1 since this choke has very high impedance (opposition) to R.F. The radio frequency energy from the tube finds a path through the condensers C-31 and C-60, to the tank coil, L_1. Since the plate choke, RFC_1, and the plate inductance, L_1, may be considered in parallel, we have the name parallel-plate-feed.

Follow this explanation making reference to the circuit on page 215.

FREQUENCY DOUBLING

The present amateur hands are:
160 meter band, 1,715 to 2,000 KC.
80 meter band, 3,500 to 4,000 KC.
40 meter band, 7,000 to 7,300 KC.
20 meter band, 14,000 to 14,400 KC.
10 meter band, 28,000 to 30,000 KC.
5 meter band, 56,000 to 60,000 KC.
and above 110,000 KC.

This power is produced, in the true sense, only if a suitable load for the frequency of the second harmonics is provided.

Bear in mind that when the wave-length is *halved*, the frequency is doubled. The product of the wave-length in meters by the corresponding frequency in kilocycles (KC.) is 300,000, the speed of light in kilo-meters.

The L-C load for the oscillator is formed by the coil and the two condensers, C-60. The lower condenser, C-60, further may be used to *match* the antenna line. The plate inductance L_1, and the small winding for antenna connection, are of the self-supporting air core type. A different coil is used for each one of the amateur bands and, since these coils are of the plug-in type, they are easily interchanged.

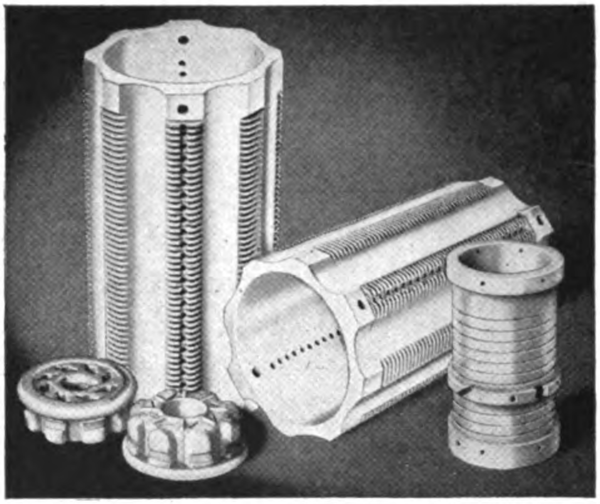


Figure 231. Coil forms and sockets used in high frequency work are made of special materials which have small dielectric losses.

It is possible to double the crystal fundamental operating frequency with many transmitter circuits. Let us suppose, for an illustration, that you have this transmitter properly constructed and in operating condition. You are using a 160 meter crystal. This corresponds to 1,875 KC. If the coil covering this band (which includes 1,875 KC.) is inserted in the socket, the transmitter can be adjusted to operate properly at this frequency. Oscillators and other stages operated in Class C, produce considerable power at the second harmonic of the excitation frequency. If the tube is loaded with a parallel tuned circuit adjusted to the fundamental frequency, the second harmonic voltage finds practically zero impedance and is lost. But what happens if we use a coil which is tuned to the second harmonic? This L-C circuit will offer high impedance to the second harmonic frequency and will be excited by this frequency. This same L-C circuit will appear as very low impedance to the fundamental frequency and the energy of this fundamental frequency will not be utilized.

We see, therefore, that we can operate the transmitter on 80 and 160 meters, with a crystal designed for the 160 meter band. You must understand that when the frequency is doubled, the wave-length becomes one-half the previous value. If we use an 80 meter crystal, we can operate the equipment on 80 and 40 meters. A crystal ground for any of the frequencies of the amateur band around 80 meters, is called an 80 meter crystal. The use of the special cathode choke helps to obtain good results when doubling. At high frequencies, doubling is not practical. Although this simple transmitter may be used with a 10 meter-band (28 to 30 megacycles) crystal, no doubling is possible at this frequency.

The transmitter we have described is intended for low power requirements and can be used to send code telegraphy. If the transmitter is placed in operation and an antenna connected, a carrier wave will be transmitted. Receivers with regenerative detectors or with a beat-frequency-oscillator (B.F.O.) incorporated in the circuit, can receive such transmission which will sound as a *buzz* of a definite frequency. If the transmission is interrupted according to the telegraph code, words and phrases can be sent. The interruption, or keying, is accomplished by breaking the cathode return circuit. A key is connected to the jack, J-2, and the cathode circuit is only completed when the key is depressed. When the cathode circuit is broken, the oscillator stops operating.

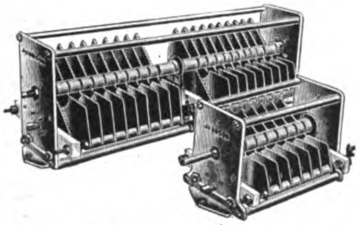


Figure 232. Large transmitters use tuning condensers which have greater spacing between plates.

When operating the transmitter on the crystal fundamental frequency or when doubling, the tuning is performed with the tank condensers. The adjustments are made so as to deliver the maximum energy to the antenna, with the minimum plate current. The pilot bulb or plate current milliameter may be used as the indicator for minimum plate current. Another pilot bulb, connected to a one or two turn loop which may be held near the tank coil, will indicate maximum energy being delivered to the antenna when it is brightest. An R.F. ammeter is better for this purpose.

How the Power of a Transmitter Is Computed. In considering the power of any transmitter, only the stage which is connected to the antenna is involved. In the case of the transmitter we discussed, the oscillator is the only stage and is connected to the antenna. What is the power input to this stage? The power input is the power delivered to the plate of the tube. The power for the screen grid, if used, and for the filament is not considered. We can measure the plate current with a D.C. milliameter. Although the current to a *Class C* stage varies a great deal during each cycle, the meter will indicate an *average* value. The voltage of the plate supply is usually known or may be measured with a D.C. type voltmeter. If this voltage and current are multiplied, the plate power delivered is obtained.* If the plate voltage is 300, and the current is 50 ma. (.05 amperes), the power is 15 watts. Amateur transmitters are rated in terms of power input.

A properly matched antenna acts as a pure resistor. You will understand the reason for this in the next chapter, but for the present please accept our word for this. The value of the antenna resistance can be predicted or a pure resistor may be used in

*This practice is an approximation. The D.C. meter does not indicate the exact RMS value of the complex pulse of current which flows during each R.F. cycle.

The Continental telegraph code is used for radio transmission. It is presented below.

LETTERS

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

NUMBERS

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

PUNCTUATION

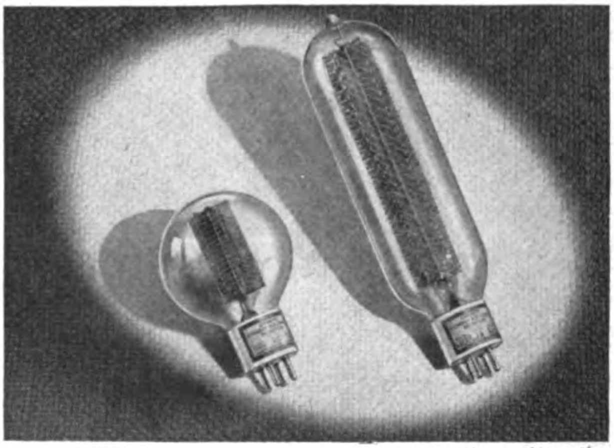
· — · — · —	Period
— — · · — —	Comma
· · — — · ·	Question Mark

Reprinted from "Allied's Radio Builders Handbook."

Broadcasting stations are rated in terms of actual power radiated by the antenna.

place of the antenna while making the adjustments and measuring power output. Let us assume that we use a 72 ohm resistor, or dummy load, in place of the antenna. We connect an ammeter (R.F. type) in series with this resistance load. Let us assume further that our ammeter has very low internal resistance which can be ignored. The meter may indicate, in the case of our transmitter, a current of 0.4 amperes. We recall that power in watts is equal to I^2R, and the current, I, in this case, equals 0.4 amperes, the resistance, R, equals 72 ohms. Solving this equation, $I^2R = 0.4 \times 0.4 \times 72 = 11.5$ watts. This is the power delivered to the antenna.

The power delivered to any resistor is equal to I^2R.



Courtesy Ohmite Mfg. Co.

Figure 233. In testing and adjusting transmitters, the antenna is replaced by the equivalent dummy load. The "tubes" illustrated are used for this purpose, and have the correct resistance value.

It is easier to make the needed adjustments when the antenna is replaced with an equivalent dummy load. Also, under such conditions, the adjustments are carried out with no actual radiation taking place.

Please notice that the power delivered to the antenna is always less than the power delivered to the plate of the tube connected to the final-tank-coil. The difference of power, 15 watts minus 11.5 watts in our example, is the power used in heating the plate of the tube. This power is wasted as heat.

The efficiency of a transmitter is measured by dividing useful R.F. power delivered to the antenna by the total power delivered to the plate, and multiplying the result by 100 to obtain the answer in percent. Amateur transmitters have efficiencies from 55% to 80%.

Transmitting tubes are rated in terms of permissible power which the tubes can dissipate. If a tube is operated under conditions where maximum power is being dissipated by the plate and the oscillations or driving signal suddenly fails, the plate current will rise and increase the power handled by the tube. Unless a safety device is incorporated in the circuit, the plate of the tube will become red hot and melt.

Need for Additional Amplification. The power output from a crystal oscillator is limited. The crystal current must be kept within the safe value and even pentodes have a limit to their power amplifying ability. The question, "Can the radio frequency energy delivered by the oscillator be amplified further in another stage?" comes up. Certainly another stage, using larger tubes, can be constructed and excited with the output from the crystal oscillator stage. But we must look out for possible limitations and see how these are eliminated in practical circuits.

Power is required to drive a radio frequency amplifier in a transmitter. Since the grid is driven positive, it will *take* current and this current must be supplied by the previous stage.

We realize that the voltage, which will be developed across the plate tank-inductance of the crystal oscillator, will be used to excite the next amplifying stage we are considering. Will this voltage be of the correct radio frequency of the crystal even if the tank L-C circuit of the crystal stage is slightly detuned? You recall that the plate L-C circuit actually is detuned in practice to make the tube *look into* an inductive circuit. This condition (to return to our analogy using the mechanical swing), corresponds to the swing having a natural period of movement different (slightly) from the period of the force driving it. When the driving force is applied to the swing, it will begin to move under its influence and assume its frequency. Since the driving force is present for only a short period, the swing will try to change its pace (frequency) while acting on its own, but before this change can become noticeable, the force is applied again and brings the frequency back under its influence.

The plate L-C circuit acts very much the same. It is shock-excited by the energy which has the crystal frequency. After the shock, while the tank L-C circuit acts on its own, it tries to shift into its natural frequency, but before much change is accomplished in the fraction of the cycle, the next shock-excitation brings the frequency in line. We can see, therefore, that the exact voltage of the crystal frequency is available across the plate L-C circuit to excite the next amplifying stage.

METHODS OF COUPLING. The radio frequency voltage from one stage must be impressed across the grid to cathode circuit of the next stage. The required grid bias for this stage may be obtained by any of the methods described, but since grid current is present during a portion of the cycle, the grid-leak method is commonly employed. The grid circuit of the stage to be excited may use a tuned circuit, but since this will require an extra adjustment it is not often employed. The plate voltage of the preceding stage is kept out of the grid circuit with a blocking condenser. This condenser is of sufficient capacity to offer negligible reactance to the radio frequencies. Since the grid is driven positive, grid current will flow during a fraction of the cycle. A D.C. milliameter inserted in the grid circuit will indicate the *average* amount of grid current.

NAMES OF R.F. POWER AMPLIFIERS. The stages, which follow the crystal oscillator, amplify radio frequency power. They are power amplifiers and require driving power to excite their grid circuits. The R.F. power amplifier stage, which is connected to the antennna circuit, is called the *final* power amplifier. Several R.F. power amplifiers may be used, each succeeding stage handling more power and requiring greater driving power. If three stages are used, the stage, between the oscillator and the final power amplifier stage, is called the *buffer stage.* If frequency doubling is accomplished in this buffer stage, it may be called the *doubler.* If several stages are placed between the oscillator and the final, these may be called the first buffer, the second buffer, etc. In some stages, two or more tubes may be used and these may be connected in parallel or in push-pull.

NEUTRALIZATION REQUIREMENTS. In transmitters having several stages, only the oscillator stage should oscillate. The other stages must amplify the signals delivered to them. But if any tube has a fraction of the plate energy returned to the grid side, oscillation will begin. If the stage uses a tetrode or pentode vacuum tube, very little capacity coupling exists between the grid and plate circuits of the tube. In the case of the triode type radio frequency amplifiers, however, the energy fed back to the grid circuit, because of the grid to plate capacity, must be balanced out. With the aid of a small adjustable condenser (capacity usually under

This is forced oscillation.

The *shocking* frequency is close to the natural frequency of the L-C used in the plate circuit.

In considering the coupling of a plate circuit of one R.F. stage to the grid circuit of another stage in a transmitter, the plate load may be tuned L-C, untuned L-C, or untuned L, the grid circuit may be any of these or a high resistance, and any of these (except the high R) may be used with capacity coupling, link coupling, or mutual coupling.

A popular transmitter with active amateurs is the type which uses a self-excited oscillator and a final amplifier. From the names *master oscillator and power amplifier*, we have the abbreviation MOPA.

Neutralization is required to prevent radio frequency amplifiers (using triodes) from acting as oscillators.

NEED FOR NEUTRALIZATION

25 mmfd.), a voltage is fed back to the grid circuit out of phase with the voltage developed because of the tube inter-electrode capacity, and oscillation in this stage is prevented.

Good quality neutralizing condensers must be able to withhstand high voltage, be easily adjusted, and present the same (unchanged) capacity for long periods of time.

Figure 234. A high voltage neutralizing condenser used in radio transmitters.
Courtesy E. F. Johnson Co.

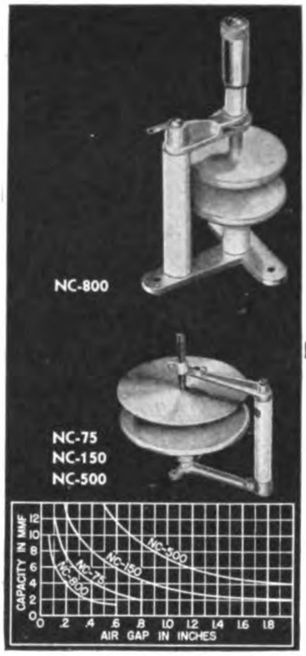


Figure 235. Illustrations of *National* neutralizing condensers with the variation in capacity expressed in terms of the air gap between the plates.

A portion of the R.F. plate voltage may be fed back to the grid through the neutralizing condenser. A tap on the tank coil may be used for the purpose of obtaining the correct value of voltage and proper phase relationship. Such arrangements are called plate neutralizing circuits. If the entire plate R.F. voltage is used and delivered to the grid circuit through the neutralizing condenser, a tapped grid inductance (or capacity) provides correct voltage value and phase relationship. These arrangements are called grid neutralizing circuits.

If an amplifier is used for frequency doubling purposes, it will not require neutralization even if a triode vacuum tube is employed in that stage. In a frequency doubling stage the main energies of the plate and grid circuits are of different frequencies, and no oscillation will result even if there is considerable coupling between the grid and plate circuits.

If a stage of a transmitter which is to be employed for frequency doubling does incorporate a neutralizing condenser, it may be left at the setting made for neutralizing this stage for straight amplifying.

How to Neutralize a R.F. Amplifier. If a radio frequency amplifier uses a triode and is *not* employed for frequency doubling, it must be neutralized. The stages before the one to be neutralized must be in operating condition properly adjusted. This will permit the stage which is to be neutralized to receive grid excitation. In all cases, the plate supply voltage, to the tube of the stage to be neutralized, is removed. Sometimes, a special switch is provided for breaking the plate supply circuit. If such a switch is not incorporated in the circuit, the B+ wire may be disconnected. The filament of the tube used should be heated from the power supply while making these adjustments.

It is important that you know how to neutralize a radio frequency amplifier. This process is a part of placing a complete transmitter in operation.

When a radio frequency amplifier (using a triode) is properly neutralized, the grid circuit may be excited, but no R.F. energy should be present in the plate circuit while the B+ is not present.

A sensitive indicator of R.F. is needed for the plate circuit for this test. A neon bulb, in contact with the plate connection of the tube, may be employed for this purpose. A small pilot-bulb, connected to several loops of wire held close to the plate coil, may also be used. With conditions as described above and the indicator in place, rotate the plate circuit tuning condenser for maximum indication of R.F. shown by the maximum brightness of the bulb indicator. This will occur at resonance and indicate the need for neutralization. Now turn the neutralization condenser until the light of the indicator goes out. It may be possible to bring the light back (probably very dimly) by rotating the plate tuning condenser once again. Adjust the neutralizing condenser again for minimum light. If required, repeat this procedure once again.

NEUTRALIZATION METHODS

One terminal of the neon bulb is brought in contact with the plate terminal. The circuit is completed through the capacity existing between the bulb and the chassis.

If the light does not go out completely, minimum light will indicate correct adjustment.

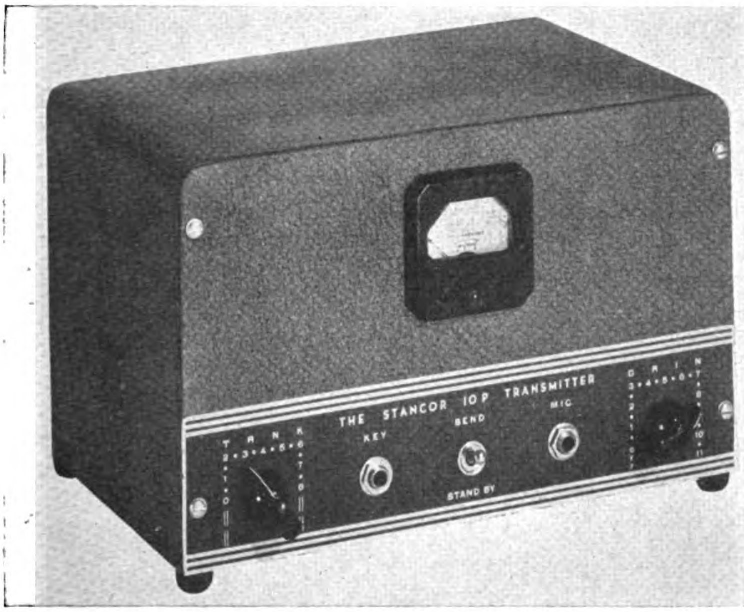


Figure 236. A small, two-stage transmitter is easily operated. The meter included is used to indicate correct adjustment.

If the stage being neutralized has a grid current meter, it may be used to check your adjustment. In a properly neutralized R.F. amplifier, the grid current will remain constant as the plate L-C tuning condenser is tuned past resonance. If the neutralization was not carried out correctly, a flicker of the grid current meter needle will be observed as the plate circuit is tuned through resonance.

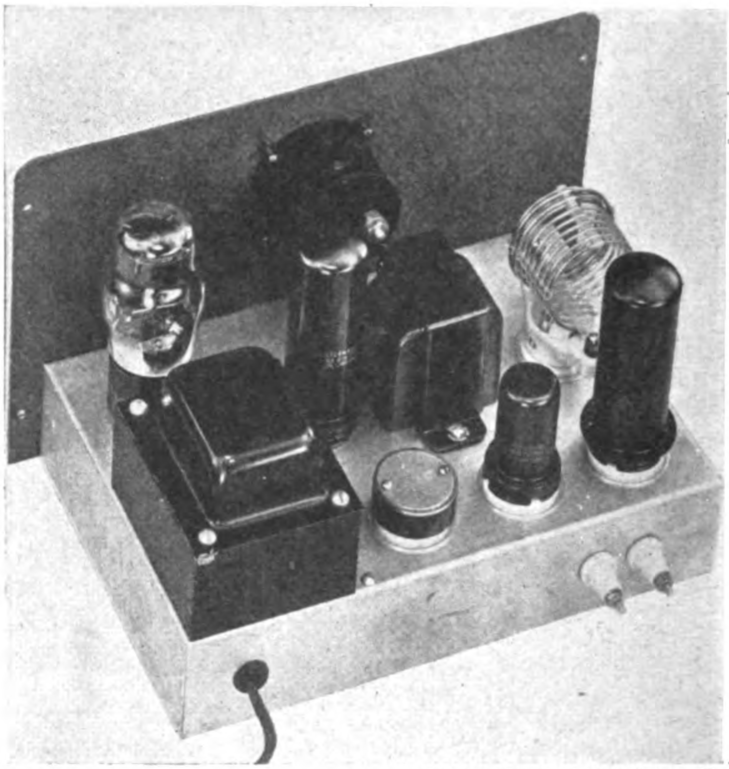
After neutralization, the plate voltage is applied and the stage is tuned for proper operation.

A TWO STAGE TRANSMITTER. You will notice that the crystal oscillator stage of this transmitter is not tuned. The output of this untuned stage drives a final amplifier which uses a 6L6 tube and is tuned with condenser C-60. If a key is wired to a plug and inserted into the jack, J_3, the transmitter may be used for telegraphy (C.W.) and the audio stage, in the lower left hand corner of the schematic, is not used. Please observe that when the key plug is inserted, the secondary of the output (modulation) transformer T-8 is shorted, and the cathode circuits of both R.F. tubes are connected to ground only when the key is depressed.

That is, this stage is not tuned manually. The signal produced is of the crystal frequency.

Refer to the circuit on page 225.

The placement of parts on the chassis of this transmitter is logical and simplifies the wiring.

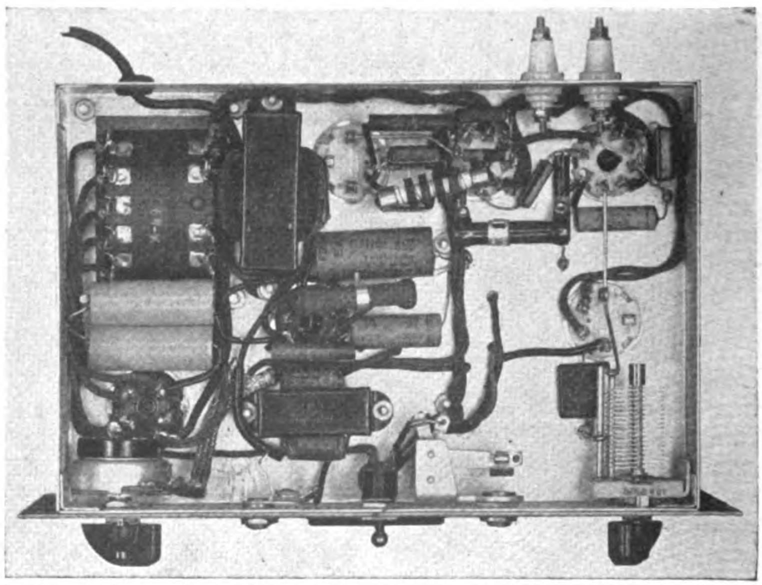


Courtesy Standard Transformer Corp.

Figure 237. Inside, top view of a two-stage modulated transmitter. See if you can find the corresponding parts in the schematic diagram.

Plug-in coils are used to permit operation on several bands. The R.F. tubes and the crystal plug into low-loss sockets.

Locate the parts visible in this photograph in the circuit diagram of this transmitter.



Photograph Courtesy Standard Transformer Corp.

Figure 239. Bottom view of the two stage transmitter, showing the location of parts. Notice that the wires are short and direct and that A. C. voltage leads are twisted to reduce the magnetic fields produced.

Only one adjustment is needed. Condenser, C-60, is adjusted to give minimum plate current as indicated on the 0-100 ma. plate milliameter. Loaded, the correct value will be about 40 ma. The transmitter can be used for doubling.

The power is turned on with the switch in the transformer primary circuit. The switch, Sw_1, in the center tap connection to the high voltage secondary, breaks the plate voltage circuit and stops the transmitter from operating. This switch is used to shut off the unit during the stand-by periods while signals are being received. Since the tube filaments are kept heated, the instant the plate supply circuit is completed with this switch, the transmitter is ready for operation and no delay results.

A stand-by switch is always included in transmitters employed in two way communication service.

Modulation. To transmit music or voice, sound must be changed to electrical energy and amplified. This is accomplished with a microphone and a simple audio amplifier. Please notice that our modulator (incorporated in the transmitter chassis) is designed for a carbon microphone. The microphone current is obtained from the cathode circuit of the modulator 6L6 tube. A single tube serves in this circuit, but modulators may consist of many audio stages.

Sound is changed to corresponding electrical energy and then amplified to the required level.

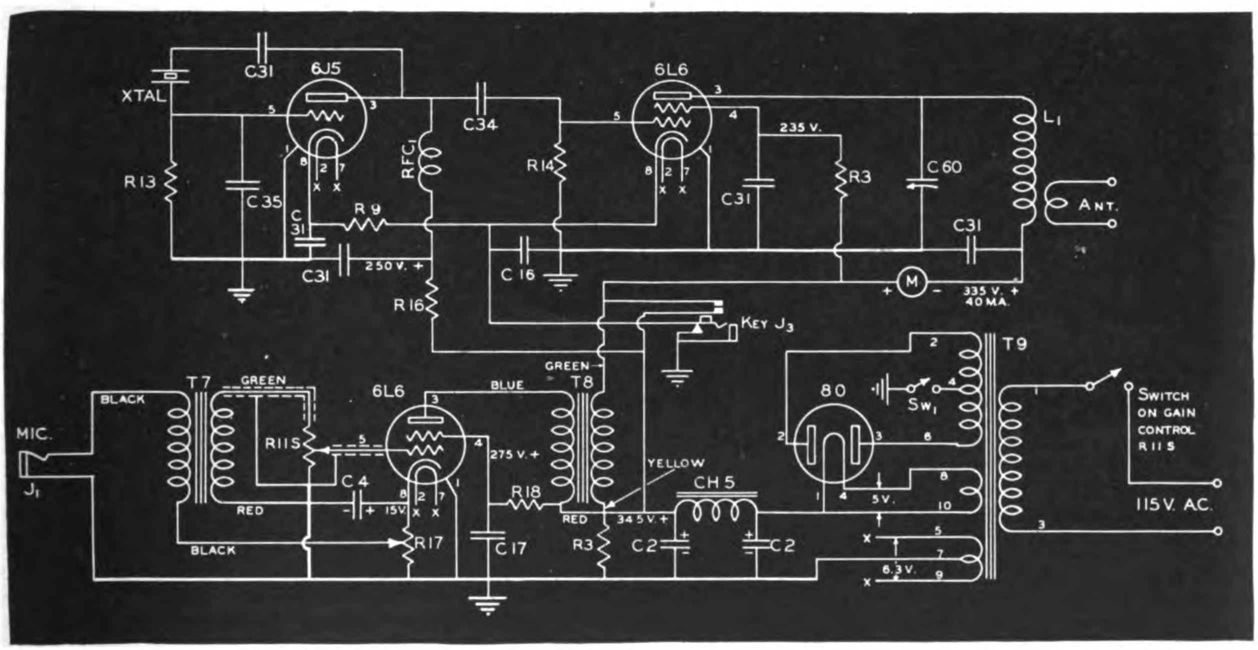


Figure 238. Stancor-10P transmitter.

COMPONENTS

C 2	4 mfd. 450 volt electrolytic
C 4	10 mfd. 25 volt electrolytic
C 16	.01 mfd. 400 volt paper condenser
C 17	.1 mfd. 400 volt paper condenser
C 31	.002 mfd. mica dielectric cond.
C 34	250 mmfd. mica dielectric cond.
C 35	50 mmfd. mica dielectric cond.
C 60	100 mmfd. midget variable cond.
R 3	25,000 ohms, 10 w. wire-wound
R 9	1,000 ohms, ½ w. carbon resistor
R 11S	500,000 ohms potentiometer
R 13	25,000 ohms, ½ w. carbon resistor
R 14	100,000 ohms, 1 w. carbon resistor
R 16	5,000 ohms, 1 w. carbon resistor
R 17	300 ohms, 10 w. wire-wound
R 18	25,000 ohms, 1 w. carbon resistor
T 7	Stancor A4706 microphone transformer
T 8	Stancor A3871 modulation transformer
T 9	Stancor P6335 power transformer
CH 5	Stancor C2303 filter choke
RFC	2.5 uhy. 125 ma. R.F. choke
Sw 1	S. P. S. T. toggle switch
J 1	Open circuit jack
J 3	Two circuit control jack
Meter	O-100 ma. D. C. type

Review these steps in this order: From your understanding of audio amplifiers, you know that the voltage developed across the primary of the modulation transformer is controlled by the sounds reaching the microphone. This voltage is transformed to the secondary of T-8. This new voltage adds or subtracts from the supply voltage connected to the final amplifier tube. The intensity of the oscillations produced by the L-C tank circuit (C-60 and L_1) is proportional to the actual voltage present at the moment.

Please notice that the plate current for the 6L6 final R.F. amplifier must pass through the secondary of the modulation (matching) transformer, T-8. This secondary winding may be considered equivalent to a series voltage generator. This series voltage generator may add or subtract voltages from the power supply voltage and, thereby, alter the amplitude of the R.F. carrier produced by the final stage. But the actual voltage impressed on the secondary of the modulation transformer is a function of the audio signal, and so you can see that the carrier is being varied at the audio rate. This is the condition required for the carrier to be amplitude modulated. Other forms of modulation are also used and the modulator must supply the proper amount of audio power for correct percentage of modulation.

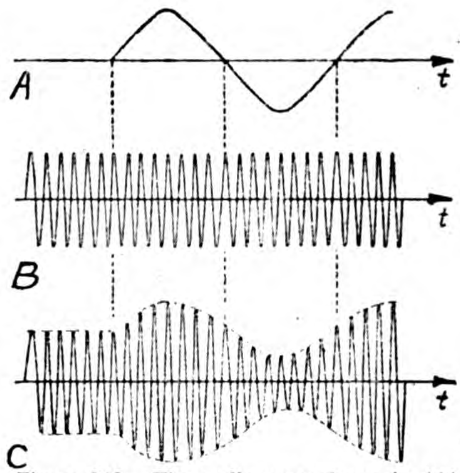


Figure 240. The audio wave shown in (A) is made to act upon the circuit producing R. F. carrier (B), and the modulated wave (C) is the result.

For power economy reasons, the radio frequency tube modulated usually is operated in *Class C*. The tube modulated may be the one which is the final stage of the transmitter and is connected to the antenna. However, if the modulated stage is not the final, and additional stages follow, these stages are (in practice) *Class B; Class C* cannot be used after the modulated stage.

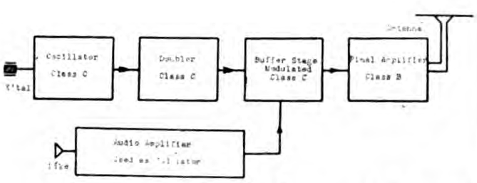


Figure 241. A block diagram of a typical 'phone transmitter of about 100 watts power. The modulation may take placc in any stage except the oscillator, but all stages following the stage which is modulated are operated as *Class B* amplifiers. The buffer stage is shown in the block diagram as the stage being modulated.

TUNING PROCEDURE. The majority of commercial, medium-power transmitters (100 to 500 watts input) are placed in operation, or *fired up,* in a similar manner. If the transmitter is intended for 'phone transmission, the modulator is shut off. If terminals for a key are provided, these must be shorted. A careful examination of the power controls must be made. You are safe in placing filament voltage on all tubes, but keep the plate power off for the time being. The plate power should be applied first only to the oscillator stage. Usually a plate current meter is included in the circuit of the oscillator. In some units, the proper meter can be switched in this plate circuit. In such transmitters, one meter may serve several circuits. The oscillator can be adjusted according to the explanation given in the previous chapter.

Plate power is now applied to the very next stage. Watch the meter in the plate circuit of this stage and tune for minimum plate current. Turn the condenser quickly and stop at the approximate position for minimum current. Allowing excessive plate current for a few minutes may damage the tube or other equipment. Once the approximate position is found, exact adjustment can be made with care.

You may now proceed to the next stage. The plate power is turned on and the same adjustments are performed. The final stage should be adjusted with the antenna connected, or a re-adjustment will be necessary when the antenna is connected. If grid current meters are included in the last stages, these may be employed as a further aid in obtaining the best operation from the transmitter. You may go back and retune the different stages slightly striving for maximum grid current in each following stage. Of course, the oscillator is never re-adjusted after the initial correct setting.

Courtesy Cornell-Dubilier Elec. Corp.

Figure 242. In large transmitters, small capacity condensers may be required to work in circuits with extremely high voltages. In such special circuits, mica insulated condensers are employed. Although the units may be small in capacity, these units are quite large physically.

REVIEW QUESTIONS AND PROBLEMS. 1. How could a simple crystal controlled transmitter, described in this chapter, be converted for battery operation? What parts could be left out in this case?

2. Describe the condensers which are used to by-pass R.F. currents and tell of their position in the circuit.

3. What type of socket is used for the crystal? You can find the answer in one of the illustrations.

4. If the pilot-bulb burns out and a replacement is not available, how can an emergency repair be accomplished?

5. Can a crystal stage be employed for frequency doubling?

6. Explain how the actual power dissipated on the plate of the vacuum tube used in the final stage can be computed. What meters are needed for this purpose?

7. Why are several stages used in most transmitters?

8. Why must a R.F. triode amplifier be neutralized?

9. Tell in your own words how you would neutralize a stage of a transmitter.

10. What precautions must be taken in *firing-up* a transmitter?

QUESTIONS ABOUT X'MITTERS

This process is continued for all the stages of the transmitter. If neutralization is needed in any one stage, this is carried out before that stage is tuned.

1. Make the needed changes in a copy of the schematic diagram.

4. Reference is made to the pilot bulb used in the one stage transmitter.

7. Is there a limit to the number of stages that could be used?

LESSON 17

Lines, Antennas, and Radiation

In fact, every conductor (in the broadest sense) has the properties of inductance, capacity, and resistance. In the practical sense, only one of these properties predominates.

CIRCUITS WITH DISTRIBUTED CONSTANTS. You must realize that even a straight short piece of wire has both capacitance and inductance. In considering a piece of wire, focus your attention on a very tiny piece of the wire at one end and another tiny piece of the wire a short distance away. Certainly these metal pieces, as such, are separated by the wire between them which may be considered as a resistor. This wire does have resistance. The two tiny pieces of wire, we are considering, form the two plates of a condenser, with the surrounding air serving as the dielectric. No fixed quantity of air, or any special section of air serves as the dielectric, but all air (and all other insulators in the universe for that matter) serve as the dielectric of this condenser which we described. In a similar fashion, all other tiny portions of our wire, form condensers with each other.

At low frequencies (power frequencies, for example) these effects may be ignored.

In a like manner, it can be shown that the magnetic field, produced by any infinitesimally small portion of the wire, cuts other sections of the wire and the effects of self-inductance are present. We begin to see that any wire, which may form a transmitting antenna, has both capacity and inductance and is, therefore, resonant to some frequency. An antenna acts as a resonant circuit to a definite frequency, and (under such conditions) appears as a pure resistance.

RADIATION. In any oscillating circuit, and this includes a properly operating antenna, the energy of the circuit is continuously exchanged between the inductive and capacitive members. While the energy oscillates between these members, it produces a magnetic field when the energy is stored mainly in the *inductance,* and an electrostatic field when most of the energy is stored in the equivalent *capacitors* of the circuit. You must realize that as the magnetic field is becoming smaller, the electrostatic field is increasing, and vice versa. The two fields always exist together, continuously exchanging the total energy between themselves, not only in the circuit but also in the surrounding space.

These fields are always at right angles to each other, but their complete analysis requires the knowledge of higher mathematics.

The process of building up a magnetic field around the circuit (or antenna), having this magnetic field collapse as the energy takes the form of an electrostatic field, which in turn collapses and serves to build up the magnetic field once again, takes place in all circuits at all frequencies. These alternations, however, occur at a very high rate in radio frequency circuits, and before the energy can collapse back into the antenna circuit, the next oscillation occurs to re-inforce the energy escaping, and radiation takes place. The desirable radiation is greatest when the antenna is resonant to the frequency of the exciting current and when the antenna is mounted in space free of obstacles.

Resonant Line. Using a high frequency generator (transmitter), let us connect two adjacent, parallel wires to this generator. In a practical experiment, these parallel wires (or line) could be made by mounting two lengths of copper wire on supporting insulators, so arranged that the wires would run parallel, perhaps two inches apart. The line could be coupled to the transmitter, by being connected to a link coil placed near the final tank coil.

The energy which flows along this line from the transmitter is not delivered instantaneously to the far end of the line once the equipment is placed in operation. The energy proceeds along the line at a definite rate. If our transmitter is producing a sine wave voltage, sine wave currents and voltages occur at all points along the line but at a time displacement which depends on the distance from the generator. The end of the line will reflect voltage and current waves. These may re-inforce or reduce the original waves. In particular, if the line is an odd multiple of a quarter wave length (1/4, 3/4, 5/4 of a wave length), the reflected energy will be in phase with the new waves, and large standing waves will be developed.

This energy moves with almost the speed of light.

To fix the idea, assume that at the instant the generated voltage is maximum. An instant later, this maximum voltage value will be a distance down the line, while the voltage at the connection of the line to the generator will be of a somewhat lower value. Each value of the voltage exists at definite points along the line at certain instants.

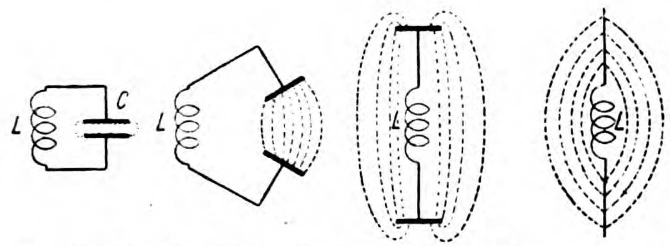


Figure 243. Progressive steps showing how a L-C circuit may be made to appear as a radiating antenna. The electrostatic and magnetic lines of force exist everywhere in space and originate at the antenna.

The fields produced by the two wires of a line oppose each other and very little radiation takes place. The main losses are the actual resistance losses of the conductors used. A resonant line, therefore, has small losses and a high Q. As the two wires of a resonant line are spread apart, radiation increases. Radiation resistance (losses of energy from the system because of radiation) also increases. If a quarter wavelength line is spread apart completely, we have a half wavelength long wire with the high frequency generator connected in the center. Such an antenna is known as a *dipole* and has the equivalent radiation resistance of about 70 ohms.

You may think of this cancellation as being due to the current moving in opposite directions in the two wires of the line.

Under the usual conditions in a practical installation.

Infinite Line. If the line we used for our explanation were made infinitely long, there would be no reflection from the far end since this end would never be reached. There would be no standing waves on the line for any frequency. In looking into the line, the generator would see a definite value of impedance which depends on the spacing of the conductors, size of wire used, and the dielectric employed. This impedance is called the *surge* or characteristic impedance. Suppose we cut our line a short distance from the generator, and consider what this short line sees when it looks into the balance of the infinite line remaining. You must understand that a few feet of wire removed from an infinitely long

Infinitely long means without end and not just very long.

This characteristic impedance depends on the capacity and leakage between the wires, and on the resistance and inductance of the conductors.

When looking into an infinite line, the characteristic impedance is always seen.

What is more, the short-line can be any size (length), but it must be of the type that would have the terminating characteristic impedance value if this short-line were made infinitely long.

By selecting different dual set of points along the antenna, various values of impedance may be secured.

The same line may be resonant or non-resonant depending on the termination impedance.

line, leaves the line just as long from any point of view. Looking into the infinite line remaining, the short-line connected to the generator will see the charactristic impedance of this infinite line. Let us say that in this case the characteristic impedance is 100 ohms. If we replaced the infinite line with a 100 ohm resistor, the short-line connected to the generator would behave exactly the same and would not distinguish between a 100 ohm resistor, or a 100 ohm characteristic-impedance infinite line. In turn, the radio frequency generator connected to the input of our short-line would see a 100 ohm impedance whether the line is infinite in length and has a 100 ohm characteristic impedance, or whether it is of finite size and is terminated in its characteristic impedance of 100 ohms, as in this case.

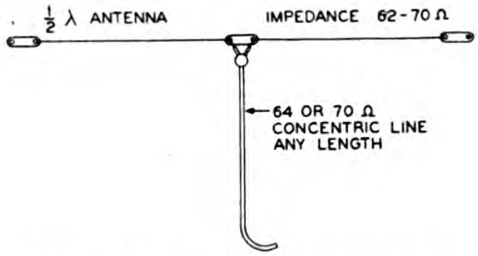


Figure 244. A half-wave horizontal antenna, current-fed with a coaxial cable which has a characteristic impedance to match the antenna.

Feeder Systems. A non-resonant parallel wire line radiates a negligible amount of energy and does not produce standing waves if it is terminated in its characteristic impedance. The line may be any size within reason. The effective voltage and current vary along an antenna, giving different impedance values between any two points along the antenna. A non-resonant line may have its two wires make contact to the antenna, a short distance on each side of the antenna center. By moving the contact points closer together or further apart, the impedance needed to match the line is obtained. Maximum power transfer will also occur when impedances are correctly matched.

A single wire feed may be used. In this case, the wire is connected to a point of correct impedance. This point is usually some distance away from the center of the antenna. The return circuit is completed through the antenna-to-ground capacitance. The proper adjustment of a non-resonant line can be checked by striving to obtain the absence of current or voltage maximum points along the line. The presence of current maximums can be detected with a bulb connected to a loop containing several turns of wire. Test for voltage maximums with a neon bulb in contact with the wire under test.

If a transmission line is not terminated in its characteristic impedance, it will act as a resonant line. The line may be considered a part of the antenna wire folded back upon itself. The line will radiate very little since the fields, produced by each of the wires of the line, will cancel each other. If the line is connected to a dipole antenna in the center, the two halves of the dipole are separated and each half is connected to one of the wire leads. Maximum current is needed in the center of the dipole antenna, therefore, the end of the line connecting to the dipole must have maximum current. If such a line is a quarter of a wavelength long (or some odd multiple of a quarter wavelength), then the side which couples to the antenna has maximum current and minimum voltage. The input to this line will require a source of maximum voltage and minimum current. Such a line is voltage fed. It may be connected across the final parallel L-C circuit.

For every quarter wavelength size of the resonant line, voltage and current maximums will reverse.

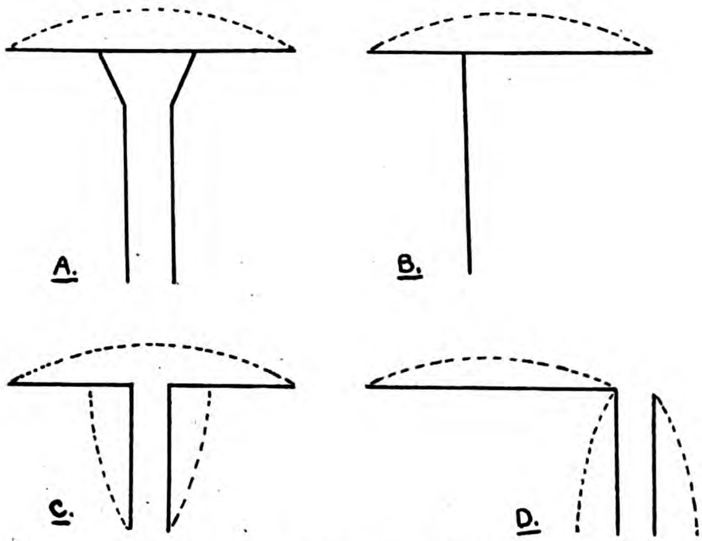


Figure 245. The dipole antenna may be fed in many different ways. In (A) the characteristic impedance of the line is matched correctly by terminating the line the proper distance away from the center. A single wire fed line is used in (B). A resonant line is used in (C) to current feed the antenna. In (D), the antenna is voltage-fed with a resonant line.

These illustrations show four practical antenna feeding methods. Study and become familiar with these basic methods.

A dipole may be voltage excited; then the line is connected to an end of the dipole. Only one wire of the line is connected directly to the dipole. See the illustration. This line is also resonant and is an odd multiple of a quarter wavelength long. It is fed from a source of high current and low voltage in the transmitter.

Courtesy American Phenolic Corp.

Figure 246. Coaxial cables consist of an external conductor with the inner conductor placed in the exact center position internally. The characteristic impedance of coaxial lines is well suited for antenna feeder requirements and, further, these lines have the advantage of radiating almost no energy even if terminated incorrectly. Notice that beads are used to keep the center wire in the proper position even when the cable is bent.

A coaxial cable is a two wire line with one conductor completely surrounding the second. The characteristic impedance of any line may be computed from the formula:

$$Z_o = \sqrt{Z_{oc} \cdot Z_{sc}}$$

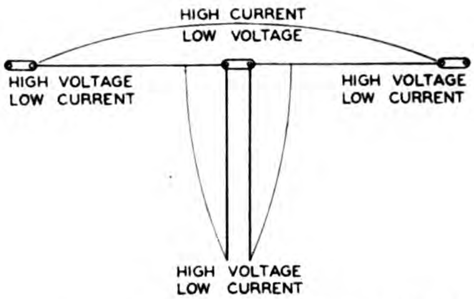
where Z_o = characteristic impedance
Z_{oc} = open circuit impedance
Z_{sc} = short circuit impedance

ANTENNA TYPES. A dipole antenna has its physical length equal to one-half of the wavelength of the energy to be radiated. In a dipole antenna, the current is maximum in the center, and minimum at the ends. The voltage, in a dipole antenna, is almost

Sketch this distribution of current on a full wavelength antenna.

zero in the center and is maximum at the ends. If an antenna is excited with energy of the second harmonic (frequency) the new energy will be of one-half the fundamental wavelength, and the same dipole antenna will appear as one whole wavelength long. The minimum points of current will be at the ends and in the center. The maximum points of current will lie between these minimum points. If an antenna, designed for any one frequency, is to be employed with the transmitter *doubling* (say fundamental of 80 meters doubling to 40 meters), the feeding method must be changed to take care of the altered points of maximum current, or voltage, distribution. Such ungrounded antennas are called *Hertz* antennas.

The antenna in the illustration is connected to a quarter wavelength resonant line.



Courtesy E. F. Johnson Co.

Figure 247. Diagram showing the current distribution in a half-wave horizontal antenna with quarter-wave open wire feeders.

The earth behaves as an extensive conducting plane and may be considered an electrical mirror. If a quarter-wavelength antenna is grounded at one end, the electrical reflection of the antenna in the earth will appear as another quarter-wavelength, making an equivalent half-wavelength, or dipole, antenna. Such grounded antennas are known as *Marconi* types. These antennas may be analyzed in terms of Hertz antennas if you will remember to add the reflection-length which is due to the earth.

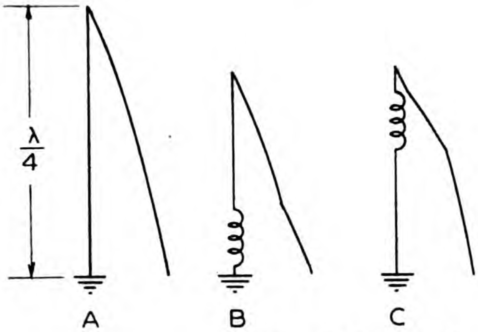
This is a practical example and is applicable in case you are called upon to design an antenna system for an amateur radio station.

For example, if you have a radio station operating on 80 meters and wish to construct an antenna, you proceed as follows. You recall that a meter is equal to about 3.28 feet. A dipole for 80 meter operation, will be 40 meters, or 131.2 feet, long. In practice, the antenna should be made 5% longer than the calculated size. If the antenna is to be current fed, the resonant line is coupled to the center of the antenna; if the antenna is to be voltage fed, the line is coupled to an end point where maximum voltage must be present.

Both Hertz and Marconi antennas are described on this page, directly above.

To use this Hertz antenna for energy of half the frequency; i.e., 160 meters, the antenna may be grounded and, thereby, made into a Marconi type. Electrically this same antenna is now a dipole for 160 meters. This antenna may be current fed by the same system, but the line will come between the end of the antenna wire and ground connection since this is the new point of maximum current.

ANTENNA LOADING. If a single antenna is to be used for the transmission of several frequencies which are not in harmonic relationship with each other, it is not practical to change the physical length of the antenna for each such alteration. The electrical length, however, can be changed by lumped-impedance loading. An antenna which is too short may be increased in size electrically by adding inductance in series. An antenna which is too long for the application on hand may be shortened electrically with the aid of a condenser connected in series. If these reactive members are made variable, adjustment to a value suitable for the conditions present may be made with ease.



Courtesy E. F. Johnson Co.

Figure 248. Various current distributions in quarter-wave, grounded, vertical antennas. In (A) a regular quarter-wave antenna is shown. Illustration (B) indicates a physically short antenna loaded at the base. In (C), we have a top-loaded quarter-wave antenna. The exact size of the loading coils will depend on the height of the antenna and position of the coil.

PROPAGATION OF RADIO WAVES. The electro-magnetic radiation from an antenna may be considered to consist of two parts. The energy which travels along the surface of the earth is called the *ground wave.* The energy which is propagated at an angle above the earth is called the *sky wave.* The ground wave of high frequency transmitters is quickly lost. At broadcast frequencies, the ground wave may be of some importance.

Figure 249. Diagram showing a simple half-wave antenna or dipole. Regardless of how power is fed to the dipole from the transmitter, it always has the same characteristics. For maximum radiation, it must be cut to exactly the right length.

The sky wave may reach the ionized layer, which surrounds the entire earth, and be bent back to reach a receiving antenna many miles away. This phenomena permits communication over great distances with low power transmitters. Frequencies above about 30 MC. are not *reflected* from the ionosphere and, therefore, can be transmitted over visual distances only.

The direction in which the maximum amount of radio energy is radiated from an antenna is of importance to a radio operator. A half-wave (dipole) antenna will radiate maximum energy broadside. If the antenna is placed horizontally in the East-West direction, maximum energy radiation will take place North and South.

Loading the antenna with a *small* adjustable lumped-impedance is helpful since it is difficult to install an antenna of the exactly correct size.

Current distribution is altered on any antenna if lumped-impedance is used.

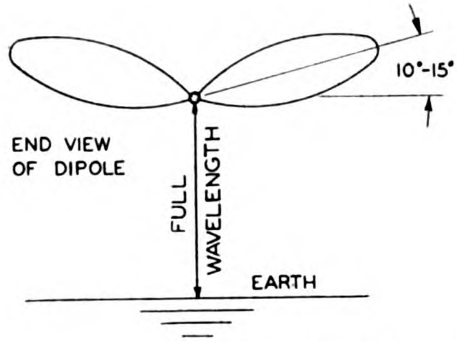
The radiation characteristics of a dipole antenna remain the same with any type feeder arrangement.

The ionized layer, also called Kennelly-Heaviside layer or the ionosphere, consists of charged particles known as ions, and acts as a reflector of radio waves. Changes occurring in this layer are responsible for fading.

DIRECTION OF RADIATION

Since the maximum radiation will take place at right angles to the wire direction, it will also occur sideways and upwards, at right angles to the wire. If the antenna is vertical, the radiation is uniform in all directions along the earth.

Since a loop antenna has directional pick-up characteristics, a special radio receiver with a loop antenna may be used to locate sources of radio interference — creation of man-made static.

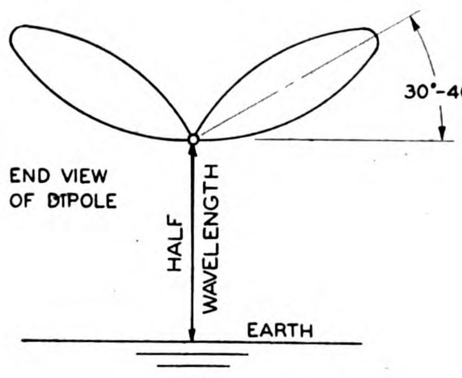


Courtesy E. F. Johnson Co.

Figure 250. Method for plotting the angle of radiation for an antenna. The lobes imply the maximum direction of radiation, but some radiation, of course, occurs at all angles.

If a full-wave antenna is employed, the energy distribution is such that four lobes of maximum radiation results. If the antenna is extended East-West, the maximum radiation will be in the four directions of North-West (half-way between North and West), North-East, South-West, and South-East. Still more complicated patterns are obtained if longer antennas are employed. If the antenna is several wavelengths long, most of the radiation will occur *from the ends.*

Bear in mind that the change from the direction of maximum radiation to minimum radiation is gradual.



Courtesy E. F. Johnson Co.

Figure 251. Diagram showing the angle of radiation from a horizontal antenna. Compare the height and angle of radiation of this antenna with the one illustrated in Figure 250.

Antennas are placed above the ground and much of the energy radiated towards the ground is reflected back into space. The reflected energy reinforces the original space radiation at certain angles and cancels the radiation at other angles. These factors must be considered in connection with reflection from the ionosphere in order to obtain the type of radiation which will give maximum energy at the location of the receiving station.

The characteristics of an antenna such as the dipole may be greatly improved by placing one or more additional dipoles in front or behind the radiating antenna. These extra dipoles may be excited in proper phase relationship or may be parasitically driven

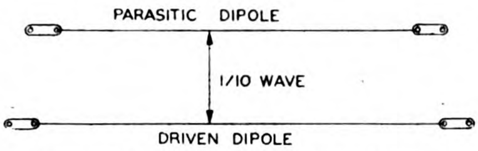


Figure 252. An additional dipole may be placed some distance away from the dipole which is excited, and parallel to this dipole. Better directional characteristics may be obtained from such simple arrays.

from the energy of the main radiator. The radiation from these extra dipoles change the radiation pattern in a manner which may be helpful. For example, such an array of dipoles may lower the vertical angle of radiation or eliminate the unwanted signals radiated to the rear of the direction of the receiving station. Further, this *rear* signal can be employed to reinforce the forward radiation.

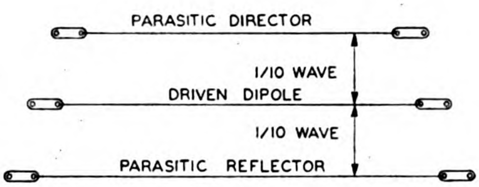
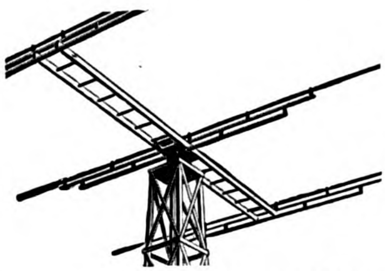


Figure 253. Diagram showing a driven dipole or antenna located between a director and a reflector. There is no electrical connection between them.

Coupling Methods.* The problem of coupling the feed line to the transmitter is largely one of properly matching impedances. Since the impedance across the entire tank is usually several thousand ohms, and the impedance of the feed line to be coupled to the

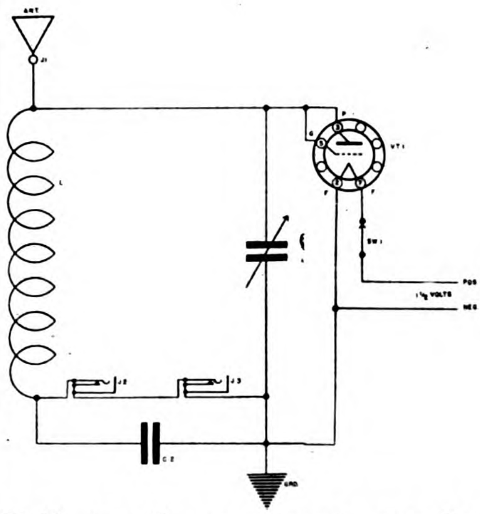


Courtesy E. F. Johnson Co.

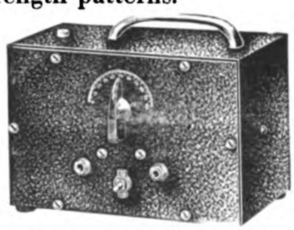
Figure 254. A directional antenna array may be constructed so that it can be revolved and the directional qualities, thereby, may be extended in the required direction.

*Certain parts of this section have been taken from "Johnson-Bassett Antenna Handbook," by permission of E. F. Johnson Company, Waseca, Minn.

Radio locators (RADAR) must use directional antennas to send the signal in a *single* direction.



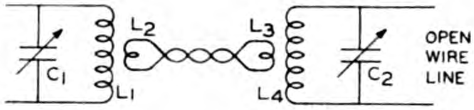
Field strength measurements may be made with a simple absorption meter. The unit is tuned to the frequency of the radiation. A sensitive meter and phones are used as indicators and are plugged into the jacks. The unit may be used to compare the transmitter output under different adjustments, to help neutralize the transmitter, to check antenna adjustment, and for obtaining field strength patterns.



Courtesy Lafayette Radio Corp., Chicago transmitter is much lower, some sort of transformation must be accomplish. This may be done by tapping directly a section of the tank inductor or by using an inductively coupled link of a few turns.

Tapping is difficult because the wire employed may be insulated and the turns of the coil are closely placed.

With the manufactured type of inductor in general use today, tapping the coil directly is very difficult. Most inductors are provided with some form of variable link and the impedance match and loading of the final amplifier is accomplished by changing the relation of this link with regard to the tank winding.



Courtesy E. F. Johnson Co.

Figure 255. Diagram showing method of coupling the transmitter to a non-resonant line. Either L_2 or L_3 should be variable.

Such placement of the link will not only prevent *shorts,* but will eliminate the capacity-tuning effects of the wires connecting the two link coils.

It should be pointed out here that the link should be located at the "cold" portion of the coil; i.e., at the low R.F. portion of the coil. This is at the center of a push-pull stage or a balanced tank circuit from a single tube. With the conventional single ended tank circuit, the link should be placed at the end of the coil away from the plate connection to the tube.

In the figure, C_1—L_1 is the final tank circuit of the transmitter. L_1—L_2 may be a commercially manufactured tank coil. L_4—C_2 must be capable of being resonated to the same frequency as the final stage of the transmitter. L_3 should be set for maximum coupling with L_4 and both C_1 and C_2 *tuned* to resonance. Loading or coupling may be controlled with the coupling adjustment between L_1 and L_2. Since the impedance transformation in the above circuit depends on so many variables including the type tube, voltage and current to the tube, and the constants of the two resonant circuits, this arrangement may not always load the final stage to full input. If it does not, the following arrangement may be used.

These suggestive circuits are very practical and are used in many actual transmitters.

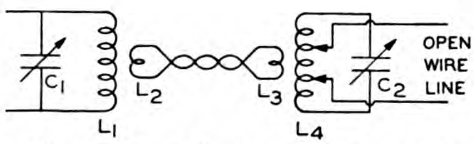
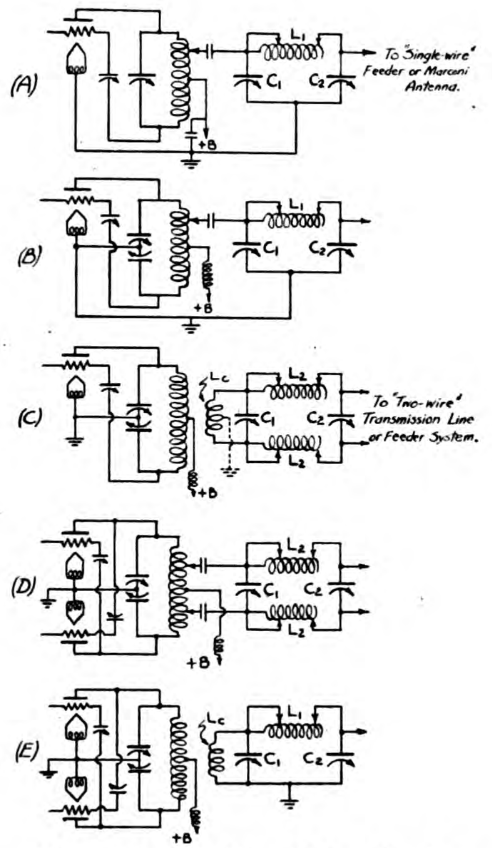


Figure 256. Diagram showing another method of coupling the transmitter to a non-resonant line in case the method shown in Figure 255, will not provide sufficient loading.

In this new circuit, the constants and method of adjustment described above should be followed. The taps from the feed line should be adjusted inward on the coil until the required loading on the final stage input is secured. The two taps should be kept balanced with the ends of the coil. Since each impedance adjustment affects the loading of the final stage and the power output also affects the impedance across the final tank, the final tank condenser should be again tuned to resonance after each adjustment.

A practical pi-section impedance matching network consists of a combination of two variable condensers and one or more inductances, connected between the transmitter output and the transmission line or radiating system. When properly adjusted, the network efficiently matches the impedance of line or radiating system to the transmitter output and provides the proper load for the output stage. In most cases, no additional tuning of the antenna system or feeders is necessary. The troublesome problem of adjusting coupling coils to the proper relationship to the output tank coil is eliminated entirely, for the transmitter loading is adjusted by tuning two variable condensers. Since the network has the form of a low-pass filter, it attenuates frequencies above the carrier and, hence, reduces harmonic transmission.



Figures 257 to 261. Various impedance matching networks described in the text. In the above circuits, Lc should have about ⅓ the number of turns used in the tank inductor.

The impedance-matching network is not a "cure-all" for an improperly designed or inefficient antenna system, nor does it eliminate the desirability of matching the antenna to the transmission line at their junction point to avoid reflection power loss. However, the network will usually result in a better power transfer to any given radiating system. The ideal system, from a maximum efficiency standpoint would consist of an impedance-matching network coupling the transmitter to an "untuned" (infinite type) transmission line, which is in turn accurately matched to an efficient radiator.

Theoretically, a pi-section matching network may be made up of three reactances, one of which is different from the other two. This means that an inductance and two condensers may be used as explained in the text, or two inductances and a single condenser may be employed. The pi-section network operates as a sort of transformer and also serves as a filter.

Study these circuits. Notice how in each circuit neutralization is incorporated. Each schematic shows the final stage of a transmitter (single or push-pull tubes) and a suitable pi-matching network.

Such an arrangement will eliminate radiation losses from the feeder line and will produce maximum power transfer to the antenna.

NETWORK ADJUSTMENT

The pi-section network may be used in either the balanced or unbalanced forms, depending on the nature of the load or the type of transmission line or feeders. The unbalanced type employs one inductance in the "hot" side of the line, while in the balanced type two equal inductances (each half as large as the inductance of the corresponding unbalanced system), are placed in each side of the line. Obviously the unbalanced network should be used with unbalanced loads such as grounded Marconi antennas, single-wire feeders of all types, and concentric transmission lines. All two-wire feeder systems or transmission lines should employ the balanced system.

These circuits are shown in Figures 257 to 261.

The schematic circuits show practical methods of connecting impedance matching networks to various types of output stages. Note that an unbalanced network can be clipped directly to the tank inductance of a single-ended stage, and a balanced network can be similarly connected to a push-pull stage. Blocking condensers should be used.

Study this procedure. You may be required to tune a transmitter with a similar network when applying for more advanced radio work.

The procedure in adjusting the network for small (such as amateur type) transmitters is as follows: (1) Disconnect the network from the tank inductance or output coupling coil. Then tune the final tank condenser for minimum plate current in the usual manner. Do not disturb this setting of the tank condenser during the remainder of the tuning process. (2) Adjust the impedance-matching inductor (or inductors) to include all coil turns for the lowest frequency band (160 meters if for amateur use), approximately half the total turns for the band around one-half the wavelength—for amateur use this would be 80 meters, one-quarter for 40 meters, etc. Connect the network input to tank inductance or coupling coil. When the network is clipped directly to the tank, the clip positions should be approximately where shown in the diagrams. When this is done plate current will probably increase. (3) Set C_2 at maximum value and adjust C_1 for minimum plate current. If the value of minimum plate current is not correct for proper loading of the output stage, reduce the capacity of C_2 slightly, and adjust C_1 again for minimum plate current. Repeat the operation until the correct plate current is obtained. If it should be impossible to fully load the final stage, use fewer turns in the network inductor or inductors or change taps on final tank coil and repeat step (3).

REVIEW QUESTIONS AND PROBLEMS. 1. Using a sketch, explain that a short piece of wire has capacity.

2. Make a drawing of a resonant line and mark the distances to represent two wavelengths. Show the line coupled to a high frequency generator. At the instant that the generator voltage is maximum, show the voltage distribution along the line. Assume that the generator produces sine waves.

2. In this case, the voltage sine wave will be maximum right at the generator. At the next quarter wavelength this voltage will be minimum, and a quarter wavelength further along the line, the voltage will be maximum in the opposite direction.

3. In looking into a coaxial cable of 70 ohms surge impedance, what does a circuit *see?* The cable is terminated in a 70 ohm resistor at the other end.

4. Make a drawing of a dipole antenna with a resonant line feed coupled to a point of maximum current. Indicate dimensions in terms of wavelength (¼λ, ½λ, etc.).

4. Refer to Figure 245.

5. What are some advantages to a pi-section coupling network?

6. Two parallel dipoles are placed one half-wavelength apart and are excited in phase. Is this an efficient radiating system? Explain.

LESSON 18

Test Equipment Using Meters

NEED FOR TEST EQUIPMENT. The correct function of radio circuits can be established by determining the presence of the proper electrical values at several points in each stage. Since it is easiest to measure voltage and current directly, and resistance by an indirect (but simple) method; these measurements are most commonly employed. Visual and aural tests are also employed. The oscilloscope, using a cathode ray tube and described in the next chapter, is especiallly well suited for visual observation of the signal behavior in its progress through sections of radio equipment.

This lesson deals primarily with the purpose of test equipment and the circuits and operation of testers which use meter indicators. Very little about radio and electronic equipment *servicing* is included in this lesson since this material is covered in greater detail in separate lessons of Volume 3.

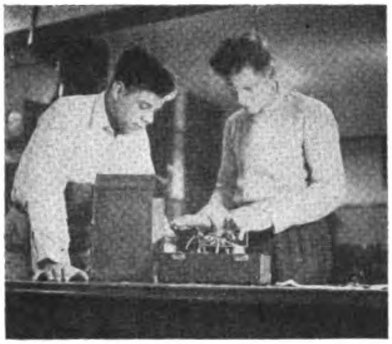


Figure 262. Radio faults are discovered with the aid of test equipment.

The correct operation of a newly developed or experimentally constructed circuit can be determined with the aid of test equipment. In a similar manner, knowing what electrical values to expect at different points in various circuits, we can make the measurements required. The proper or improper measured values obtained will guide the radio technician to the stage and then to the actual part or item at fault.

USING INDIVIDUAL METERS. The voltage between any two points in a radio circuit can be measured with a voltmeter having a suitable scale. In all cases, the meter must be able to measure the maximum voltage anticipated. Further, the reading obtained should be indicated somewhere in the center of the scale employed. It will not do to use a meter having a scale reading from 0 to 1,000 volts, and expect to get an accurate reading of a voltage around 2 volts. To obtain a correct reading when the value expected is 2 volts, a meter with a maximum scale of 5 or 10 volts should be used.

If there is no voltage difference between the two points selected, the voltmeter will indicate *zero* volts.

Usually voltage measurements in radio equipment are made between any point in question and the ground potential which in most instances is the negative return from the power supply. However, voltage measurements can be made between any two points.

Refer to Figure 202, page 187. The voltages indicated at different points are measured with respect to the chassis potential.

METER MEASUREMENTS

Because the circuit must be actually broken to make a *current* measurement, these measurements are not made very often in servicing and measurements of voltage and resistance are preferred.

Measurements may be made to determine the amount of current passing through a circuit. Most radio circuits depend primarily on a D.C. source of power and D.C. meters are employed. To make a current measurement, the circuit must be broken (the wire may be cut or unsoldered at a point). A current measuring meter, usually a milliammeter with a suitable scale, is connected in the *circuit-break* observing the proper polarity. If a D.C. meter is connected in reverse as far as the polarity is concerned, the indicating needle will tend to move in the wrong direction.

Courtesy Hickok Electrical Inst. Co.

Figure 263. A dynamic tube tester which will detect all possible faults in vacuum tubes.

If you follow the suggestion in this paragraph, you will never damage a meter.

A meter with the proper scale should be chosen for the required measurement. If the electrical value, such as voltage or current, is not known, it is safe to start with a meter which has a high maximum value, and if the reading obtained is trivial compared to the scale employed, a scale (or meter) with a lower maximum value can then be tried.

Review the explanation about an ohmmeter given in Lesson 8.

Values of resistance can be measured with an ohmmeter. You understand, of course, that an ohmmeter actually indicates the amount of current flowing in the meter-circuit and in the external part to be measured, and this current is supplied by a battery incorporated in the unit. However, the amount of current, moving through this circuit, and that which causes a deflection of the meter needle, is proportional to the resistance being measured. Therefore, it is possible to calibrate the meter scale directly in ohms.

COMBINATION VOLT-OHM-MILLLIAMMETER. We have already learned from the contents of Lesson Eight that a single meter (usually a low value milliammeter) can be employed with a suitable selector switch and resistance network to permit various measurements of voltage, current, and resistance. Such a combination instrument is called a volt-ohm-milliammeter or a multimeter. Since different types of measurements are required in radio servicing, a single instrument of this type is more convenient and less expensive than a collection of individual meters.

WHAT THE WRONG METER-READING INDICATES. Your knowledge of radio circuits, the information contained under various topics, and especially the tube characteristic data charts, suggest proper values of voltage, current, and resistance for various parts of any circuit. The usual servicing technique is to proceed to ascertain whether the values at different points are as expected. If the values are not right, then you can determine with further tests what actual components or items are at fault and are upsetting the operation to the extent of giving you the incorrect reading.

Let us consider an example. You turn on a radio receiver and find that it does not operate. Noticing that the vacuum tube filaments glow a dark red, you will know that power is being supplied to the radio and is being delivered to the filaments. Next you choose a voltmeter with a sufficiently high scale (usually 300 volts) and measure between the point of B+ voltage and ground. Your knowledge of power supply circuits will enable you to locate this point. If you obtain the expected reading (anywhere from 200 to 300 volts in an A.C. radio receiver) then you may assume that the fault does not exist in the power supply and you may

It is important to understand that meters and test equipment do not actually say, "This part is bad — replace it," or "That circuit is open." Meters simply indicate what values of voltage, current, resistance, etc., exist in different circuits and this information, coupled with your knowledge of the correct values expected suggests a *possible fault* or the realization that the particular section of the circuit is functioning properly.

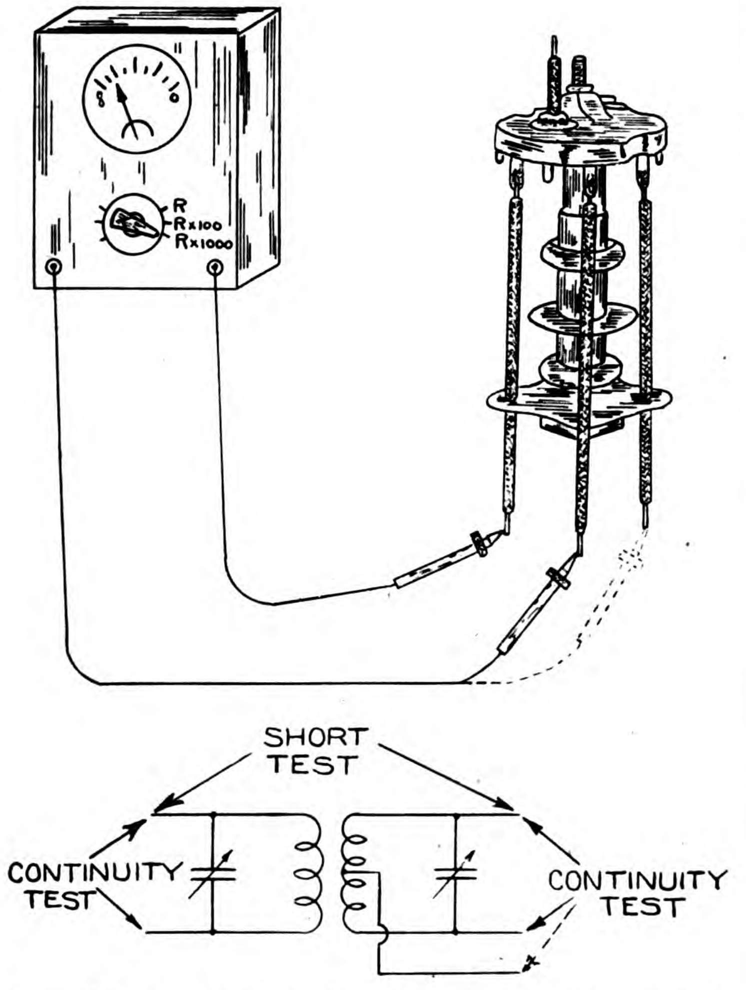
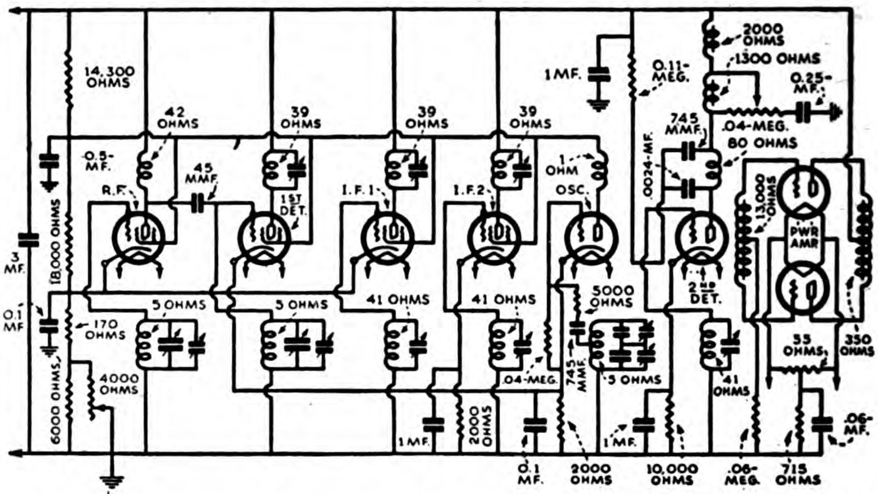


Figure 264. A method for testing coils for short circuit, and continuity. Short circuits, which should not exist, will be indicated on the ohmmeter as zero ohms resistance. Continuity will be indicated as low values of resistance.

The actual terminal contacts shown in the illustration may be made at any of the points where the leads from the I.F. transformer happen to terminate.

proceed to make other tests. On the other hand, if the voltage obtained is unusually low or is missing completely, then the power supply is at fault and only this stage need be tested further to locate the actual trouble.

This schematic diagram does not show the correct wiring of the complete circuit, but is re-drawn to indicate resistance values existing across various components.



Courtesy P. R. Mallory & Co.

Figure 265. An operational circuit of the Radiola 80 receiver showing the expected resistance values which may be measured with an ohmmeter.

A circuit diagram of the receiver to be serviced, of course, will prove of great help. The publishers of this *course* have issued manuals of most-often-needed radio diagrams. These are described on the inside front cover of each volume.

WHAT MEASUREMENTS HELP YOU TO FIND THE FAULT. Before any measurements are made, the radio unit to be repaired must be carefully examined visually. You should try to find some very obvious fault which may exist and also become familiar with the type of circuits that are combined to make up the complete radio unit. On one job, you may find that the radio receiver is of the A.C. operated type, has six tubes, and is a superhet. You will also notice the function of each tube. This radio set is made up of a pentagrid converter mixer stage, one I.F. stage, a separate diode detector also supplying AVC, an audio voltage amplifier stage, and the power output stage. One tube is also used as the rectifier for the power supply.

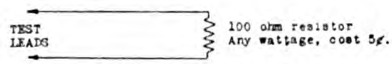


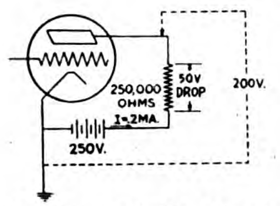
Figure 266. The presence of voltage may be observed with the aid of a resistor and test leads. This is an emergency method for locating faults and should not be used if test instruments are available.

A very similar servicing technique is employed with electronic equipment.

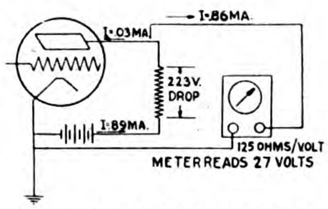
If the tubes light when the power is turned on, a voltmeter may be used for a quick test to determine that plate voltage is present at several points. Tests are made to determine that circuits under suspicion are not at fault. A great many tests may be required before the actual fault is localized. If power failure is detected, the ohmmeter may be employed. The set must be in operating position (power switch *on*) for voltage tests; but the power must be *off* for ohmmeter tests. Besides measuring the actual values of resistors, the ohmmeter may be used to test for continuous (unbroken) leads, and for open circuits and short circuits. For example, if two points (terminals) are wired with a piece of hook-up wire, they will *test* zero ohms. A paper condenser, when not at fault, will show open circuit;* i.e., very high resistance. Windings of coils will test as low resistance, 5 to 70 ohms.

Occasionally it is advisable to make a current measurement. The proper setting is made on the multimeter, and the circuit to be tested is broken for the insertion of the test-meter. Because the circuit must be broken to make a current measurement, this type of test is not recommended.

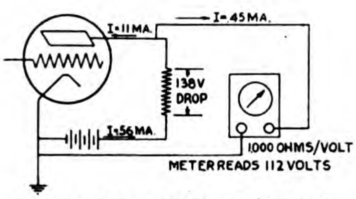
Meter Range—250 Volts Full Scale in All Cases



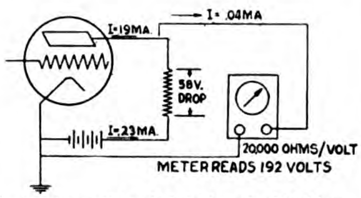
Normal Operation No Meter In Circuit



Conditions Using 125 Ohms Per Volt Meter



Conditions Using 1,000 Ohms Per Volt Meter



Conditions Using 20,000 Ohms Per Volt Meter

Figures 267 to 270. Voltage distribution in the same circuit when connected to a voltmeter of various sensitivities. Please notice that in all instances somewhat lower readings than the actual values are obtained.

You must understand that a circuit is altered when a meter is connected for test purposes. In most cases, the presence of the meter will not change the operation of the circuit or the voltages present at various points, but this explanation shows how considerable errors may occur.

Notice that the current is a fraction of one milliampere, in each case. It is 0.2 ma. (2/10 of a milliampere or .0002 amperes) in the normal circuit.

Errors in Voltage Readings. A voltmeter connected to make a voltage measurement is always across a circuit containing resistance. If you will recall that batteries have internal resistance, you will realize that this is so even when the voltage of a battery is being measured. Now consider the resistance-loaded plate circuit as illustrated. A plate voltage supply of 250 volts is indicated. The current passing through the 250,000 ohm resistor and plate circuit of the tube is 0.2 ma., or .0002 amperes. You can easily calculate the voltage drop across the plate resistor as 50 volts. This leaves 200 volts at the plate of the tube as measured to ground. The tube is actually a pentode with a plate resistance of about one megohm.

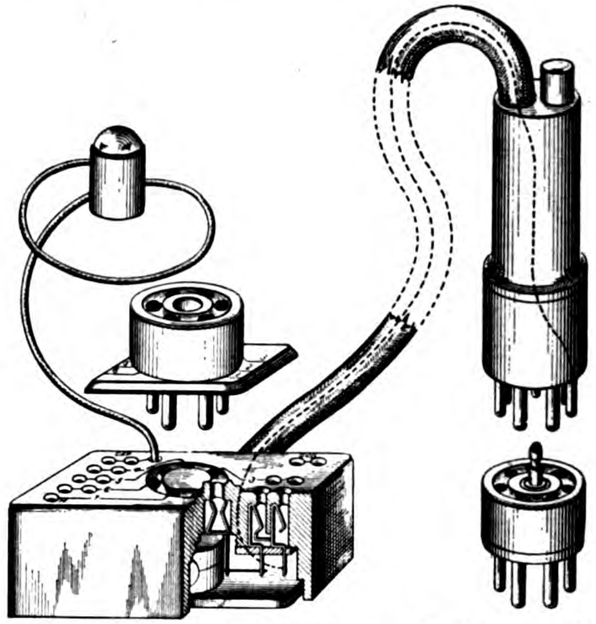
Let us see what happens when we use a none too sensitive voltmeter of 125 ohms/volt to make the measurement of voltage from the plate to ground. Because the meter has such low internal resistance, it will pass a great deal of current. The IR drop in the circuit leading to the plate will increase to 223 volts. The current through the tube will be smaller, and the voltage at the plate under these conditions will be only 27 volts. The value will be closer to the actual voltage with more sensitive meters, but in all cases will

*The instant the condenser to be tested is connected to the ohmmeter there will be a sudden deflection of the pointer due to the charging current passing into the condenser. The amount of deflection and the speed with which the pointer will return to the "open circuit" position depends on the actual capacity and other factors. In most cases this deflection and return of the pointer occurs in but a small fraction of a second.

be somewhat smaller than the value actually present without the meter being connected in the circuit. A vacuum tube voltmeter, described in the next chapter, takes almost no current and gives the correct reading in all practical circuits.

You must remember when making voltage tests in circuits where high resistance is present, that the reading will be *off*. By considering the circuit with the meter connected, you can estimate whether, the much lower value obtained with the meter implies, the actual voltage is correct (without the meter being in the circuit).

You can also measure the voltage present before the resistor and use an ohmmeter to check the resistor itself.



Courtesy Weston Electrical Inst. Corp.
Figure 271. A view of one type of analyzer plug showing adapter sockets and methods for connecting the meter to the circuit.

ADVANTAGES OF ANALYZERS. Many multimeters are constructed with suitable sockets for all commonly employed vacuum tubes. These sockets have their terminals wired to leads of a multi-wire cable. One lead is used for the plate connection, one for the cathode, etc. Not all leads, of course, are needed for all sockets. The four prong socket uses but four leads. At the other end of this cable, the leads terminate in an octal plug. With the aid of a set of adapters which plug into the octal plug, various plugs to fit different type of sockets (four prong, five prong, etc.) can be obtained. This arrangement permits the placing of the proper plug in place of any tube in any radio unit; and, in turn, the placing of this tube in the corresponding socket in the analyzer. Because of the long leads, the operation of the radio unit may no longer be possible when this connection is completed, but the *terminals* of the socket from the radio stage are now conveniently located in the analyzer unit. All required D.C. and filament A.C. measurements may be made with the analyzer multimeter. Usually the meter may be switched into any circuit, or across any two terminals of the socket, by just pressing a button which controls a switch. Many analyzers also combine a tube tester on the same panel. With analyzers it is possible to test and determine the trouble in a radio receiver, without removing the chassis from the cabinet.

Since the chassis must be removed from the cabinet anyway to make the needed repair, there is no special advantage in discovering the trouble without removing the chassis.

TUBE TESTERS. Although faults in vacuum tubes can be detected without the aid of a tube tester, to make a positive statement that a vacuum tube is in good operating condition requires the use of a good tube tester. Testing and replacing tubes constitutes a large amount of work of radio servicemen. A very large number of apparent radio receiver defects do not actually require any repairs, but merely a replacement of one or two tubes.

Courtesy Supreme Instruments Corp.

Figure 272. Some tube testers combine a multimeter and permit the selection of the proper settings with the aid of push-buttons.

Different test methods are used by the various tube-tester manufacturers. Tube checkers and testers are usually A.C. operated and employ from six to as many as twenty-five sockets. The grid-shift method is commonly used in the testers. The grid voltage is altered a small amount which in turn causes a corresponding change in the plate current. This change in the plate current is the index by which we judge the condition of the tube and this current is indicated on the meter. The tube-tester meter is usually marked GOOD-BAD, so that the public can understand the results. If A.C. is employed as the grid voltage, the test is called dynamic. If D.C. is used, the test is static.

In some testers, the majority of the elements are tied together, in others each element receives a relatively correct potential for the test. In the emission type tester, all the elements are tied together with the exception of the cathode and the filaments and the current passing to the cathode is measured. Obviously, if the screen grid prong of a 24-A tube is completely missing, the tube will still test GOOD and, this is why, the grid shift dynamic testers are superior and do detect such faults.

If a tube in electronic equipment is suspected as being at fault, you may substitute for this tube one known to be good and see if the operation of the equipment is restored to normal. If this is the result, the tube *tested* was at fault.

Notice the *rolling* chart on which the tube number of the vacuum tube under test is found. This chart tells what settings to make for each test.

Courtesy Triplett Electrical Inst. Co.

Figure 273. A novel tube tester which is adjusted for testing any one tube by pressing a certain number of push-buttons.

Figure 274. A tube tester with its meter scale calibrated GOOD-BAD. This permits the non-technical customer to see for himself the results of the test.

Courtesy Sprague Products

Figure 275. A condenser tester employing a bridge circuit is a handy instrument for the laboratory or the more advanced radio shop.

The emission type tester is much simpler and is much cheaper to build than the dynamic type. For modern tubes and requirements, the emission test proved to be accurate enough and does serve the purpose. Instructions for operating different testers are usually included with the unit.

Besides low emission, about the only other defect that occurs in a tube is a short between some elements. Modern tube testers of all makes incorporate a *short-test,* placing a high potential between the different elements and using a sensitive neon bulb for the indicator.

CONDENSER TESTER. Special testers to determine the capacity, leakage, and power factor of commercial condensers are available. Of course, such testers may also be employed to determine if the condenser under test is in good operating condition. Detailed instructions for operating different units are supplied with the tester. The majority of condenser testers use a bridge circuit with a sensitive meter or tuning eye tube employed as the indicator. The condenser under test serves as one arm of a bridge circuit, and some other arm is adjusted to give the required balance. This variable arm usually consists of a variable resistor and is employed with a scale which is calibrated to indicate the capacity being tested.

Bridge circuits are used often in laboratories where very accurate tests are required. The four arms of a simple bridge consist of three known impedances and one unknown which is to be determined. Some of the known impedances are altered until balance is achieved and then the unknown impedance can be calculated.

REVIEW QUESTIONS AND PROBLEMS. 1. What measurements are commonly employed by radio servicemen?

2. Will a single scale voltmeter serve to make all necessary measurements in a radio receiver? What limitations may come up?

3. How can the plate current of a vacuum tube, used in a radio set, be measured? What equipment will be needed?

4. Can a multitester be made to measure only voltage and resistance, but not current? Can you show the circuit?

5. Make a sketch of the circuit involved.

5. Using a voltmeter, you find the correct value of voltage on one side of the I.F. transformer primary. The other side, which goes to the plate of the I.F. tube, gives no reading. The negative prod of the voltmeter is held to ground for both tests. What may be wrong?

6. Why must the radio be *off,* when using the ohmmeter for tests?

7. A circuit of the parts involved will help you answer this question.

7. The screen grid of a tube receives its voltage through a two megohm resistor. The correct voltage for this screen grid is 100 volts. What voltage would you expect if the measurement is made with 1,000 ohms/volt meter? (Measurement between screen grid and ground.)

8. What two tests are usually made to determine whether a vacuum tube is in good operating condition?

9. Make a sketch of a simple analyzer of your own design. Include only an octal socket.

LESSON 19

Electronic Test Equipment

Audio Frequency Signal Generators. A vacuum tube oscillator may be constructed, with suitable values of inductance and capacity in the tuned circuits, to produce energy at audio frequencies. Audio oscillators, as such instruments are commonly called, produce frequencies between 30 and 15,000 cycles per second. The frequencies produced may be selected with the aid of a dial adjustment. The intensity of the output signal is also adjustable with an attenuator control.

To test stages which are designed to handle audio frequencies, an audio frequency signal generator is employed to produce the needed signals.

Courtesy Hickok Electrical Inst. Co.
Figure 276. A good quality R.F. signal generator incorporating a decibel meter for measuring the output signal level of a radio receiver.

Most R.F. signal generators incorporate an audio frequency generator for modulating the R.F. carrier. In some units, several audio frequencies are available and the percentage modulation (ratio of audio power to radio frequency power) may be controlled.

Oscillator circuits, similar to the R. F. types we have discussed, may be employed to produce audio frequencies. Of course, the L-C circuit must resonate at the required audio frequencies. Suitable inductors and capacitors would be quite large and could be made variable only with the greatest difficulty. However, it is possible to produce audio frequencies by *beating* (combining in a non-linear impedance) two radio frequencies differing in frequency by the number of cycles required to produce the audio frequency. In practice, two R.F. signal generators are built-in a single case. One produces a fixed R.F., while the second has its frequency variable and easily altered with a regular tuning condenser. If the frequencies of the two R.F. generators, for any one adjustment, differ (for example) by 800 cycles, then 800 cycle audio signal is produced. A few lately developed types of sine wave audio signal generators use circuits without any inductance. The required wave form is produced with novel R-C vacuum tube circuits.

Radio frequencies are considered above 100,000 cycles, while frequencies below 15,000 cycles are of the audio type.

R.F. GENERATOR TYPES

Since the R.F. signal generator needed for service work must produce a variety of frequencies, a crystal controlled oscillator will not do. However, for a single frequency adjustment, a crystal controlled oscillator may be used.

R. F. Signal Generators. An electron-coupled oscillator circuit is employed to produce adjustable radio frequencies. With this type of oscillator, the variations in the load have little effect upon the frequency. Tuning (adjustment of the frequency produced) is accomplished with a variable condenser. The control dial is carefully calibrated and is usually accurate to within 1%. The frequencies are generated with several different coils which are selected and connected to the tuning condenser of the circuit with a band-switch. A practical R.F. signal generator may cover frequencies from 100 KC. to 90 MC. This includes all I.F. frequencies used and the usually employed communications frequencies. The coverage may be obtained in six or seven steps. In most units, the higher frequencies are not actually generated as fundamentals, but are harmonics of the highest frequency band for which L-C is provided.

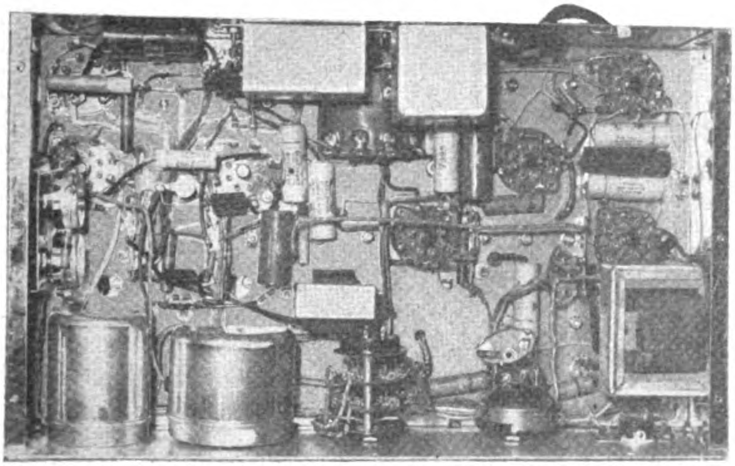
Figure 277. A signal generator can be used as an aid in testing the various stages of a radio receiver.

A small audio signal generator is usually included in the cabinet of the R.F. signal generator. The audio signal may be of a single frequency (400 cycles commonly used), or several different frequencies may be available for selection. The intensity of the audio signal superimposed on the R.F. carrier may be controlled. This is known as the percentage of modulation. The audio frequencies may be used separately if need arises.

These are the basic applications of a signal generator.

A signal generator may be used for locating faults in radio receivers and as an aid for properly aligning all types of sets. With a signal generator, you can produce a similar signal to the one which can be handled by any stage of the receiver. For example, you can generate a powerful audio signal to drive the output stage. Or you can produce a relatively weak I.F., of the correct frequency and with about 30% modulation, to excite the input of the first I.F. transformer. The signal is applied to any one stage, and if the output is present in the loudspeaker, this stage and the balance of stages leading to the speaker may be assumed to be operating.

By adjusting the signal generator to the I.F. frequency of the receiver, the I.F. transformers can be correctly peaked. It is best to feed the signal into the primary of each I.F. transformer and adjust the trimmers for maximum results. You may judge the results by the sound reproduced by the speaker, but it is better to have an output indicator. A cathode ray oscilloscope may be used for exacting results since it shows the exact response curve.



Courtesy Supreme Instruments Corp.

Figure 278. Under-chassis view of a combination A.F. and R.F. signal generator of good design.

In a manner similar to the alignment procedure explained in Lesson Fourteen, a signal generator may be used for alignment. Instead of tuning in a station of about 1,500 KC. and then one of 650 KC., these frequencies can be generated with the signal generator.

In aligning the circuits of the short-wave bands, the same procedure is followed. However, the frequencies used are located at the upper limit and at the lower end of the band to be aligned. Separate trimmers and padder condensers are provided for each band. The I.F. transformers, of course, need not be touched once they are adjusted for any one band.

Vacuum Tube Voltmeter. When a vacuum tube (triode or pentode) is operated over its *curved* characteristic, the D.C. plate current will depend on the voltage applied to the grid. It is possible, therefore, to calibrate a plate current meter in terms of the voltage which is applied to the grid. The zero-grid-voltage plate current is balanced out with another, separate circuit which passes current through the plate meter in reverse. The zero meter adjustment, required on all types of vacuum tube voltmeters (this instrument is abbreviated VTVM), is the adjustment for this balancing circuit. Since the input grid circuit of a negatively biased vacuum tube draws no current, zero current is taken from the circuit in which the measurement is being made by the VTVM. Since the circuit connected to the VTVM may not complete the grid to ground return (does not offer a D.C. path from grid to ground), a high valued resistor is placed in the circuit across the input terminals for this purpose. This resistor may be 10 or 20 megohms for the 10 volt scale. This makes the unit have the equivalent sensitivity

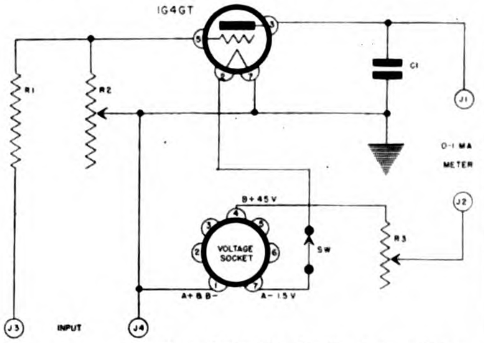
More about alignment with a signal generator will be given in a later lesson.

You probably realize that similar components and mechanical assembly are employed in radio receivers, test equipment, and electronic devices.

Courtesy Hickok Electrical Inst. Co.

Figure 279. A vacuum tube voltmeter incorporating a type 955 acorn tube in the probe to reduce the input inter-electrode capacity. Notice that the dial at the left is used for zero adjustment, the center dial for range selection, and the right hand knob for adjusting the circuit for either D.C. or A.C. operation.

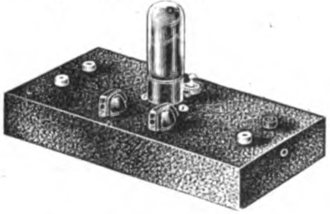
VACUUM TUBE VOLTMETER



Courtesy Lafayette Radio Corp., Chicago

A very simple, experimental type vacuum tube voltmeter. The circuit as illustrated may be employed to measure up to 6 volts. A standard 0-1 ma. meter is used and a calibration chart may be prepared to show the relationship between the measured voltages and the scale readings. An extra voltage divider can be incorporated in the input to increase the maximum voltage reading. The values of parts are:

R_1 = 500,000 ohms
R_2 = 1 megohm
R_3 = 1 megohm
C_1 = .003 mfd.



An illustration of the *Meissner Analyst* used for signal tracing type of servicing. A vacuum tube voltmeter is incorporated in this unit.

of one megohm per volt. For higher voltage readings, additional resistors are wired in a voltage divider circuit, and the same high sensitivity exists. From a practical point of view, a vacuum tube voltmeter takes no current from the circuit under test.

Courtesy General Radio Co.

Figure 280. Another excellent quality vacuum tube voltmeter. Although an acorn type tube is used in the probe, to reduce further the input capacity, the terminals may be removed, as shown.

The lead from the grid input terminal has a certain amount of capacity to the return terminal which is at ground potential. There is also capacity between the control grid and cathode of the tube employed. At ordinary frequencies (as high as one megacycle in good VTVM), this total capacity has extremely high capacitive reactance and may be ignored. However, at frequencies above the broadcast band, the capacity of the input practically shorts the signal to be measured and reduces the sensitivity of the instrument. Special precautions are taken to reduce the capacity of the input circuit. One method uses a tube of the "acorn" type having very low inter-electrode capacities.

The vacuum tube voltmeter will indicate peak values of voltage measured. If the voltage is a sine wave, the RMS value will be about 0.7 times the indicated value. Often, several scales are required to include the various voltages encountered in practical radio work. It is necessary to have several arcs on the scale of the meter used in the instrument, since the several ranges employed may not track accurately on a single calibrated arc.

Cathode Ray Tube. Cathode ray tubes are the basis of modern television reception and also are used extensively in visual analysis of electrical phenomenon. In its simplified form, the cathode ray tube consists of an electron gun to generate an electron beam of high velocity, a dual-set of perpendicular electrostatic or magnetic deflecting devices, and a fluorescent screen to make visual the actual path described by the end of this electron beam.

Figure 281. Most oscilloscopes employ three inch cathode ray tubes and have the required controls for adjustment to "see" signals of various types.
Courtesy Hickok Electrical Inst. Co.

In the figure below, the components of a basic cathode ray tube are enclosed inside the glass bulb (E), which also maintains a vacuum in the tube. The cathode (K) is employed for the production of free electrons; the electrode (H) accelerates the electrons; the focusing electrode (F) concentrates the electrons into a "cathode

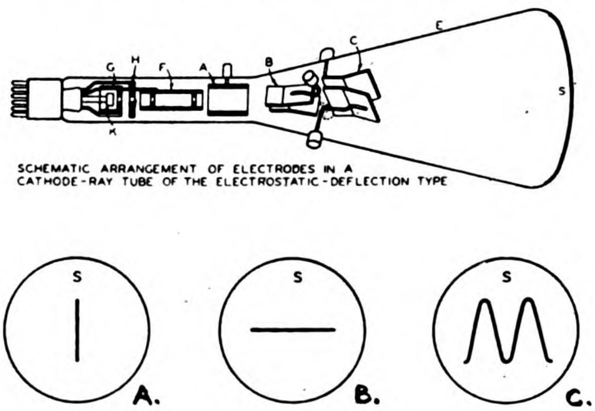


Figure 282. Position of electrodes inside of a cathode ray tube, and simple patterns obtained on the screen.

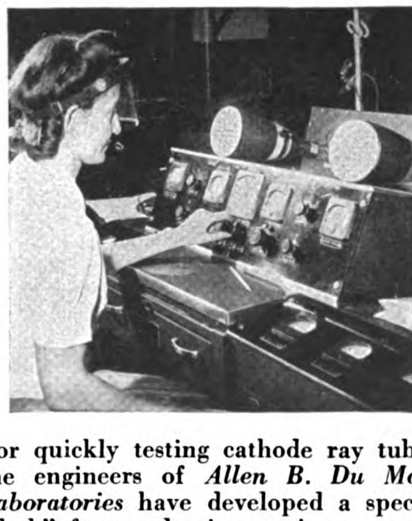
ray" or beam; the high-voltage anode further accelerates the electrons. The control grid (G) controls the beam current, increasing or decreasing the intensity of the beam. Two sets of electrostatic deflecting plates (B) and (C) are used for deflecting the electron beam. The screen (S) is coated on the inside surface of the enlarged end of the bulb. The screen is made of material which shows a fluorescent glow at the point of impact of the electron beam.

CONSTRUCTION OF A C.R. TUBE

The electron beam narrows down to a small point where it meets the screen. The fluorescent screen (inside front of tube) glows with *light* when the electron beam strikes it and continues to glow for a short time after the beam moves on to another spot.

Cathode ray tubes using electrostatic deflecting plates (most small C-R tubes are of this type) operate from the voltage impressed. To be influenced by current, the current to be measured must produce a voltage drop in an associated resistor.

Since there are many connections to a cathode ray tube, a twelve terminal socket may be used and additional connections may be brought out through the sides of the glass container.



For quickly testing cathode ray tubes, the engineers of *Allen B. Du Mont Laboratories* have developed a special "desk" for production testing.

OPERATION OF A C.R. TUBE

The focusing of the electron beam is similar to such processes used with light lenses.

The electron beam consists of rapidly moving electrons and is an actual electric current responding to both electrostatic and electromagnetic influences. The beam has negligible mass and inertia and responds instantly to electrical forces. Certain initial adjustments are made so that the end-spot of the beam strikes the screen exactly in the center. The control grid is adjusted to give the fluorescent glow, resulting from the electron beam impact, the required visibility. The tube is so placed in its socket, that the operator looks directly at the screen, and has one set of deflecting plates at the left and right (for horizontal sweep), while the second set of plates are above and below (to serve as the vertical sweep). Controlling voltages may be applied independently to either set of electrostatic plates. Let us study the effects on the electron beam pattern as these voltages are varied.

First, we will connect a battery to the two *vertical* plates. The plates act as a low capacity condenser as far as the voltage supply is concerned. The beam will be attracted (to some degree) towards the positive plate and repelled from the negative plate. The spot will move up (and stay there) if the upper plate is the one connected to the positive terminal of the battery. Now let us connect an alternating voltage (A.C.) to the vertical plates. The potential of the plates will increase and decrease periodically, and the plates will alternately become positive. The beam and the end-spot, therefore, will move up and down in accordance with these voltage variations. Since the screen retains the fluorescent glow for a short time, the many *moving* dots will form a straight line, as in the screen view A, of the illustrations included on the previous page.

This is true provided the frequency is high enough. In the usual unit, even 25 cycles per second will produce a *picture* of a straight line.

In a similar manner, various voltages could be applied to the horizontal plates, and the beam would move horizontally. Usually

OSCILLOSCOPE CIRCUIT

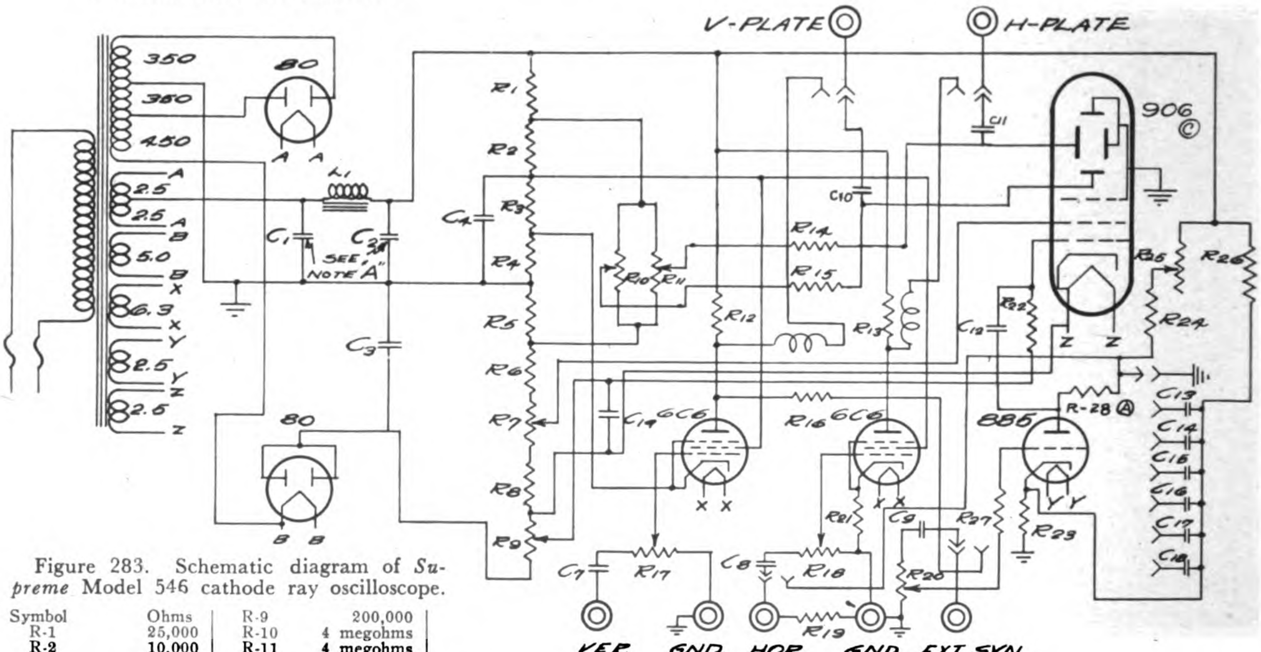


Figure 283. Schematic diagram of *Supreme* Model 546 cathode ray oscilloscope.

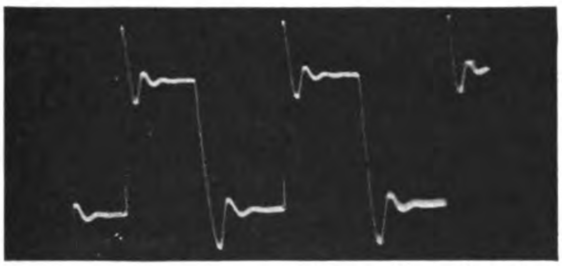
Symbol	Ohms						
R-1	25,000	R-9	200,000	R-18	4 megohms	R-23	1,000
R-2	10,000	R-10	4 megohms	R-19	1 megohm	R-24	1 megohm
R-3	10,000	R-11	4 megohms	R-20	15 megohms	R-25	4 megohms
R-4	220	R-12	50,000	R-21	1,000	R-26	100,000
R-5	250,000	R-13	100,000	R-22	500,000	R-27	100,000
R-6	750,000	R-14	1 megohm			R-28	500
R-7	500,000	R-15	500,000				
R-8	100,000	R-16	1 megohm				
		R-17	1 megohm				

Symbol	Mfd.	Symbol	Mfd.		
C-1	4.0	C-3	0.5	C-12	50 mmfd.
C-2	4.0	C-4	8.0	C-13	0.37
		C-7	0.1	C-14	0.04
		C-8	0.1	C-15	0.01
		C-9	0.05	C-16	0.0025
		C-10	0.5	C-17	600 mmfd.
		C-11	0.25	C-18	200 mmfd.
				C-19	0.5

the horizontal set of plates is employed with a special sweep circuit which moves the beam from left to right at a pre-selected uniform rate, and then quickly returns it to the starting position at the extreme left to repeat the movement. If the vertical plates are not excited, even this *saw-tooth* horizontal sweep will appear as a straight horizontal line, see B of the figure. By applying a signal voltage to the vertical plates, and employing the horizontal plates for the sweep action, various patterns can be reproduced on the screen of the cathode ray tube.

In figure C, we have the reproduction of a sine wave. The number of cycles appearing depends on the sweep frequency. This sweep frequency can be varied and locked in step with the signal applied to the vertical plates.

OSCILLOSCOPE CIRCUIT. An examination of the circuit schematic indicates the power supply at the left. The voltage outputs of the full-wave and half-wave rectifiers are combined to serve the cathode ray tube, amplifier tubes, and the type 885 thyratron sweep generator. The voltage input to the vertical and horizontal plates may be amplified. Ordinarily, however, the horizontal plates are used in conjunction with the sweep circuit which is locked in step with the incoming signal to be observed and applied to the vertical plates.



Courtesy Hewlett-Packard Co.

Figures 285 and 286. The distortion produced in the square wave, which is injected in a piece of radio equipment, serves to illustrate the possible faults. Top illustration indicates poor response at both the low and high frequencies. Bottom pattern indicates peak amplification at a frequency nine times the square wave frequency.

HOW TO OPERATE THE OSCILLOSCOPE. The circuit supplying the voltage to be observed is usually connected to the vertical amplifier input. The unit is turned *on* by advancing the *intensity* control. Keep both amplifier gain controls in the *off* position. Advance the *intensity* control until the spot is just visible. Using the *horizontal* and *vertical position* controls, center the spot. Adjust the *focus* control for maximum clearness of the spot. Carry out these operations quickly. Do not permit the spot to remain in a single position for any period of time. Keep the brilliance down while making adjustments.

You will be using *internal synchronization* and the *internal sweep,* so keep the toggle switches in the position illustrated to obtain this operation. Adjust the *sweep frequency* control to the value closest

OSCILLOSCOPE CIRCUIT

The return sweep is performed so quickly that the electron beam does not leave any visible trace on the fluorescent screen.

The speed of the sweep across, from left to right and the quick return, is locked in step with the voltage applied to the vertical plates and which is *reproduced* on the screen.

This circuit of a complete 3-inch oscilloscope is shown on page 252.

Thyratron tubes are described in greater detail in a lesson of Volume 3.

The oscilloscope is used for design, service, adjustment, and production testing of electronic equipment and as the indicating instrument in industrial test equipment.

This is a small illustration of the *Supreme* oscilloscope described in the text and also shown in Figure 284.

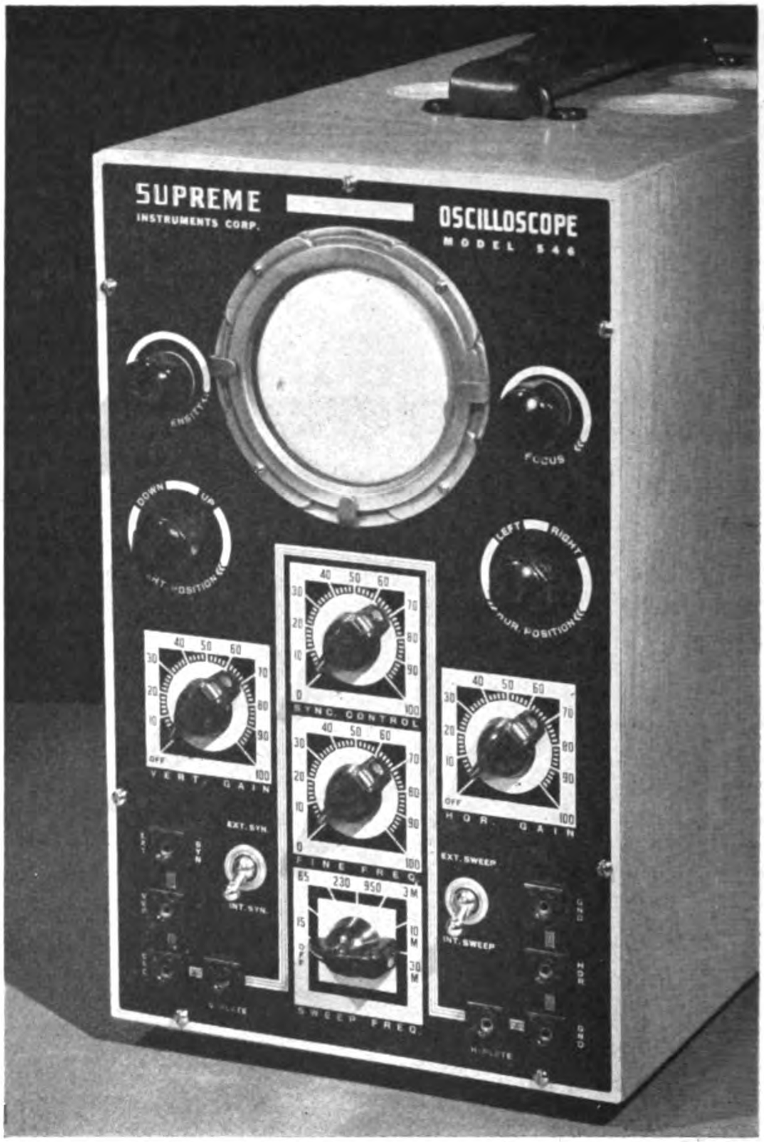


Figure 284. Front-panel view of the *Supreme* Model 546 oscilloscope. The various controls are explained in the text.

A ruled celluloid screen may be placed in front of the cathode ray tube to judge the size of patterns obtained. Holding brackets are a part of the round escutcheon.

The function of these controls is explained in the text.

It is possible to cause the trace to go off the screen by applying excessive voltages to the deflecting plates.

to the frequency of the signal to be observed. Advance the *horizontal gain* control until the spot is moving across (forms a horizontal line) almost the entire screen of the cathode ray tube. Now advance the *vertical gain* control until the spot moves up and down, keeping within the confines of the screen. The intensity may be advanced to make the pattern clearer. Now adjust the *fine frequency* control until the pattern appears as stationary as possible. The *synchronizing control* may be used now to stop all motion.

The patterns obtained tell a story of the signal existing in the circuit. Modern visual signal tracing equipment uses cathode ray oscilloscopes and more will be said about the meaning of patterns in explaining the use of this equipment.

Signal Tracing Equipment. The radio signal exists in all stages of a properly operating radio receiver. The signal may undergo many changes as it proceeds from the antenna to the loudspeaker,

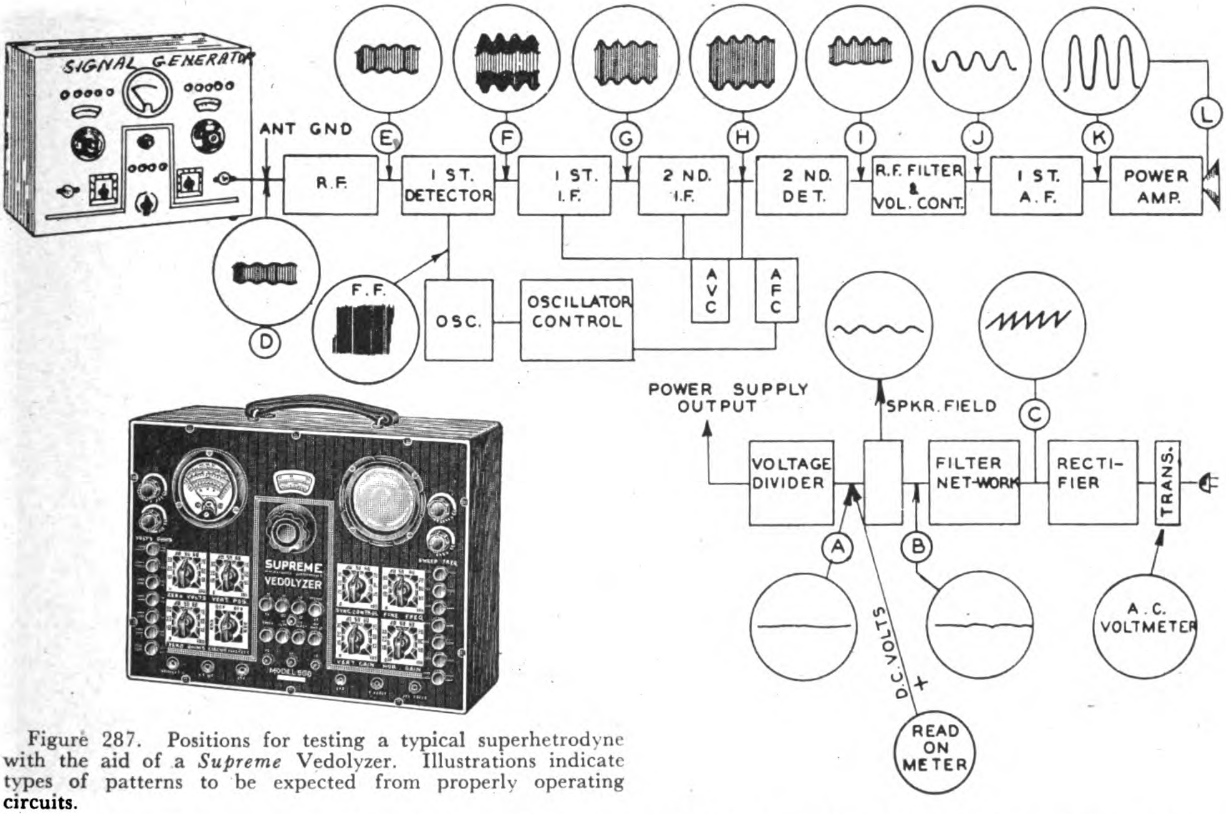


Figure 287. Positions for testing a typical superhetrodyne with the aid of a *Supreme* Vedolyzer. Illustrations indicate types of patterns to be expected from properly operating circuits.

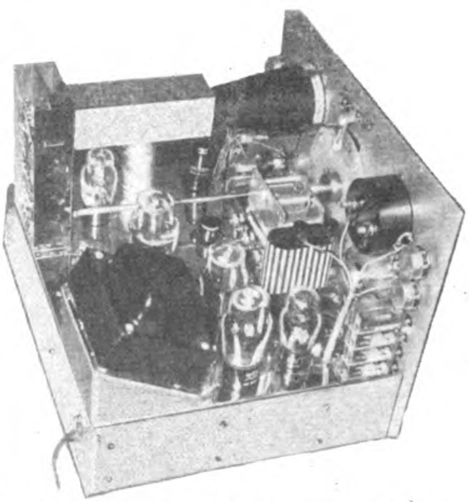
but it is present in every stage. The power supply is not considered an actual stage and may be tested with the usual voltmeter method. A logical method of servicing (detecting the existence of a fault) is to examine the actual signal in its progress through the radio. The observation of an unexpected form of signal at any point will point to the fault lying in one of the preceding stages. In this manner, the function of the equipment can be examined and the fault discovered. The usual signal tracing unit combines circuits for testing R.F., I.F., oscillator, and audio stages. Since vacuum tube voltmeters or oscilloscopes are employed as indicating devices, *no* current is taken from the stage under test and the equipment continues to function in the same manner after the signal tracing unit is connected.

Servicing with Visual Equipment. The radio receiver to be tested is excited with a radio frequency signal which is modulated with a definite frequency audio signal. The signal is examined with the aid of a cathode ray oscilloscope which is built-in and is a part of the signal-tracer. The vertical amplifier should be adjusted to compensate for the changes in the signal intensity as it progresses through the radio. The sweep frequency and synchronizing control also will need adjustment for the tests in various stages. The detailed drawings will suggest locations for the tests and the types of patterns obtained from properly operating equipment.

Review Questions and Problems. 1. Name and describe the three methods commonly used for producing audio frequencies in signal generators.

2. Explain the reason for modulating a R.F. signal generator which must be used for aligning a radio receiver.

The *Vedolyzer* illustrated combines a cathode ray unit, volt-ohm-milliameter, and a tuning unit of the type employed in signal tracing testers.



An inside view of the *Supreme Vedolyzer.*

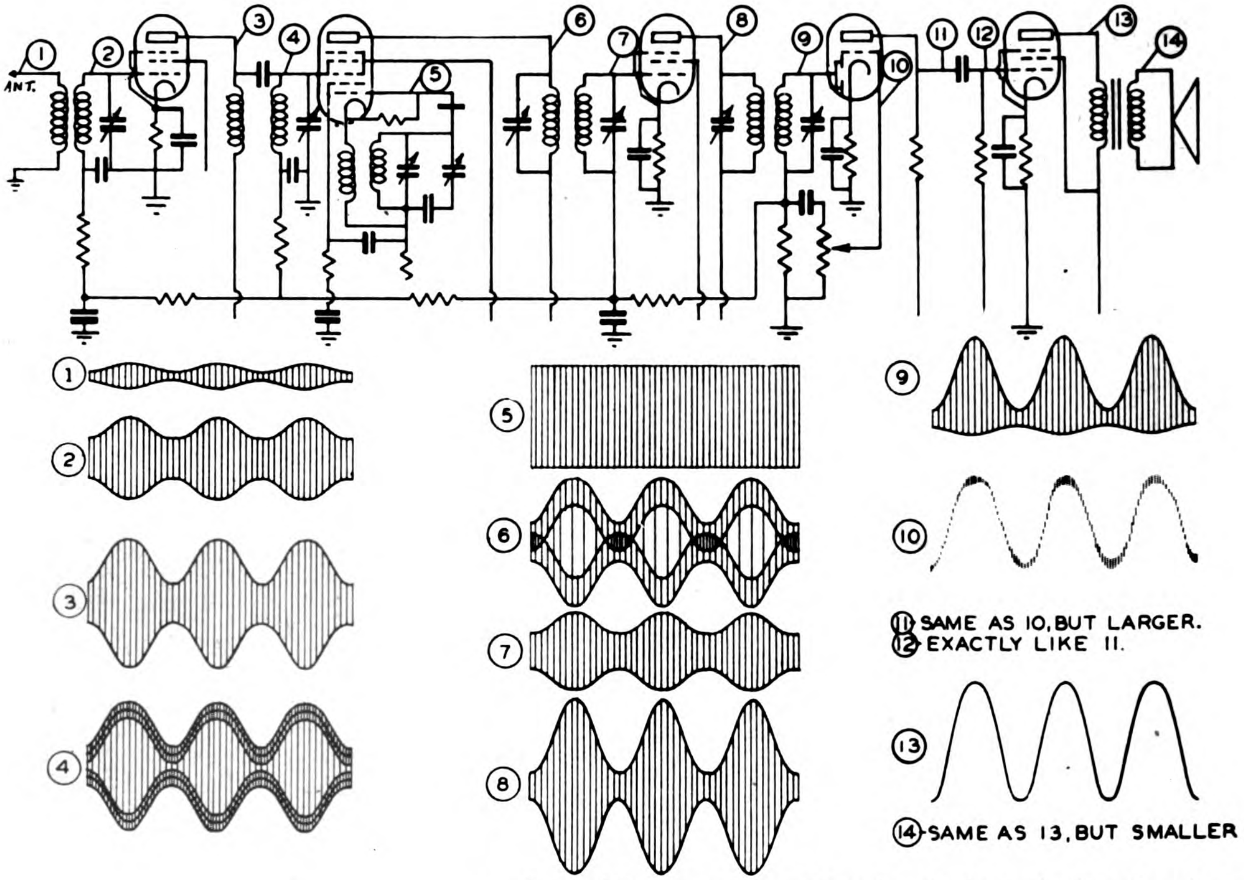


Figure 288. Suggested positions for visual examination of a simple superhetrodyne receiver. Probable patterns for each point indicated, are illustrated.

3. Tell what adjustments would be turned in what order and what effect these adjustments will have on the operation of the circuit.

7. Make up more problems of this type. Try to see an oscilloscope in operation at a local service shop, in a radio school laboratory, or at your radio jobber.

8. Refer to Figure 283. These controls are potentiometers — look for them.

3. Explain in detail the process of aligning one of the superhet receivers described in Lesson Fourteen.

4. Make a schematic diagram of a simple vacuum tube voltmeter to be operated from batteries.

5. What effect does frequency have upon the sensitivity of a vacuum tube voltmeter?

6. Refer to the schematic diagram of the cathode ray oscilloscope and label the elements which correspond to the ones described in the text.

7. Sketch the patterns resulting when the following signals are applied to the plates of the oscilloscope:

Vertical Plates	*Horizontal Plates*
60 cycle A.C.	60 cycle A.C. in phase with Ver. Pl.
60 cycle A.C.	60 cycle A.C. 180° out of phase with Ver. Pl.
60 cycles A.C.	120 cycle A.C. in phase

8. State the part numbers of the components in the schematic diagram which correspond to the following controls of the oscilloscope: *a.* Intensity, *b.* Focus, *c.* Vertical position, *d.* Horizontal position, *e.* Vertical gain amplifier, *f.* Horizontal gain amplifier, *g.* Synchronizing control, *h.* Fine frequency adjustment, *i.* Sweep frequency adjustment.

LESSON 20

Automatic Frequency Control

In a limited number of radio sets using push button tuning, automatic frequency control (AFC) has been incorporated. This circuit permits proper reception of a station even when the radio is not tuned properly.

In any superhet receiver, the station frequency combines with the oscillator frequency to produce the I.F. If the set is not tuned properly, the station's frequency will be present in reduced intensity, but the oscillator will produce a different frequency than that required. Whether the detuning is above or below the station will make little difference. In each case, the oscillator will produce either a higher or a lower frequency than needed to combine with the station frequency for the I.F. And you know, if the I.F. frequency is off, the intermediate frequency stages will not permit the signal to go through.

If a radio is incorrectly tuned, the above described facts will occur and the voltage (of the signal) in the I.F. stages will be reduced. But it will be reduced in a similar manner whether the error in tuning happens to be in one direction or another.

AFC is used with push-button type superhets. Improvements in mechanical design permit automatic push-button tuning to adjust the tuning condenser very accurately. Because of these improvements, AFC was used but for a short time in broadcast radio receivers. The principles of AFC, however, are important since they are applied in frequency modulation detection and in some electronic circuits.

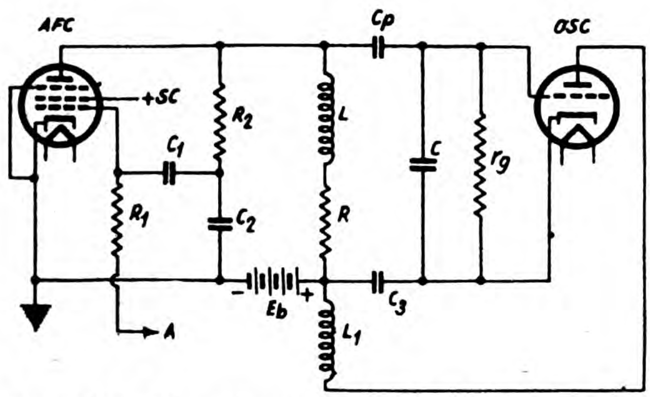


Figure 289. The oscillator of the receiver is so connected to the AFC tube that this tube is able to change the value of the inductance of the oscillator tuned circuit. The AFC tube, in turn, is controlled by the voltage generated in the discriminator.

A vacuum tube amplifier shifts the phase between the grid voltage and plate current by 180°. The AFC tube is so arranged that the equivalent phase shift influences the L-C of the oscillator, detuning it by the required amount.

In the lesson on combined circuits we talked about phase difference and this is what saves the day. The phase differs in detuning above or below the proper point. In AFC circuits a discriminator is used to produce a voltage in accordance with the amount of detuning of the radio. This circuit also takes into account in which direction the detuning is made.

The basic discriminator circuit is shown in Figure 290.

Now we must come back to our story of the superhet circuit action. If the set is detuned a little, the station's frequency will get through but will be a little reduced in intensity. However, the set will not work because the oscillator frequency will be wrong (because of the detuning) to produce the right I.F. If we could change

DISCRIMINATOR ACTION

at this time the oscillator frequency to be different by the required amount to combine with the station frequency and produce the proper I.F., all would be well.

The detuning may be due to imperfect automatic setting of the tuning condenser with the push-button operation.

This change, of course, can be made by turning the padder condenser, but we want this action to take place automatically. You remember we have a voltage which depends on how far the set is detuned, or (what is the same thing) on how much the oscillator will have to change its frequency to permit the set to work.

And this voltage from the discriminator (usually a diode tube like the 6H6) is just what is used for this purpose. But the voltage first must be changed to act like an inductance or capacity.

This circuit (in basic form) is shown on page 257.

Radio tubes shift the phase by a definite amount and in this respect act as inductances. The amount of shift can be made to depend on the bias voltage. By connecting a tube in a proper manner to the oscillator circuit of the superhet, and by controlling the bias of this tube from the voltage of the discriminator, we can realize automatic frequency control.

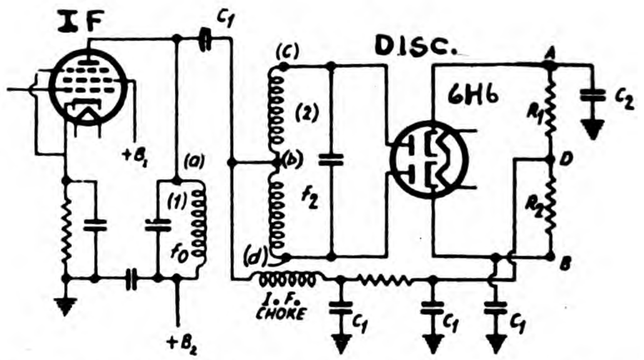


Figure 290. A discriminator circuit in which two resonant circuits, both tuned to the signal frequency, are used. The discrimination in this case is obtained by adding (vector addition) the voltage across the primary to the two *half-voltages* of the secondary.

In examining the above circuit of the discriminator, you will notice that the I.F. tube feeds a special split-secondary transformer. This unit with the diode circuit develops a voltage across points A-B, depending on the amount of detuning and having a relationship with the direction of detuning. This voltage is applied to the circuit of a special AFC tube and usually controls the grid voltage of this tube. This tube acts as shunt inductance with the oscillator coil and has an effect on the oscillator frequency. Please notice that if the set is tuned correctly, the voltage developed is zero and the oscillator operates at the normal correct frequency.

A detailed analysis of this action requires the knowledge vector diagrams.

AFC is far from the perfection to make the radio work just as well when detuned. The AFC circuit never makes a perfect correction and the AVC must make the set more sensitive to make up for the detuning.

REVIEW QESTIONS AND PROBLEMS. 1. Why is AFC used?

2. How is the needed phase shift obtained in an AFC circuit?

3. What type of tube may be used in the AFC circuit? What tube for the discriminator?

4. What would you guess must be done to a set with AFC when alignment work is to be performed?

LESSON 21

Frequency Modulation

TYPES OF MODULATION. Radio transmission which is frequency modulated presents certain advantages over amplitude modulation which was presented in earlier lessons. A number of broadcasting stations using this form of modulation are already in operation and considerable extension of this form of radio broadcasting is expected in the near future. Let us learn how this system of modulation is produced, how it compares with more commonly employed amplitude modulation, and what receiving circuits are needed.

An excellent paper on this subject was presented by the Engineering Staff of Aerovox Corporation, and published in the *Aerovox Research Worker* for February, 1940. We will reproduce much of this material in this lesson and extend due credit to the source.

Much of the future broadcasting, especially in the larger urban areas, will be of the frequency modulated type. Permissible wider audio band and freedom from certain types of noise are but two of the advantages. Some of the present day Army transmitters use FM.

SIDE BANDS. In explaining amplitude modulation, we have mentioned the presence of two side bands. At any one instance, if the transmitter is amplitude modulated with a single frequency sine wave at the moment, the energy radiated is made up of the carrier frequency and the two side bands. The frequencies of the side bands shift together and these side bands are always apart from the carrier frequency by an equal number of cycles. Since the side bands have their frequencies equal to the carrier frequency plus the modulating audio frequency for one and the carrier minus the audio frequency for the other, the frequencies of the two side bands shift together from moment to moment as the modulating audio frequency changes.

For example, in amplitude modulation, when a carrier of 1,000 KC. is modulated with an audio tone of 400 cycles, there results two side bands of 1,000,400 cycles and 999,600 cycles.

These side bands and the carrier have a definite phase relation. At the moment when the upper and lower side bands are in phase, they are either in phase or exactly 180 degrees out of phase with the carrier wave.

Now suppose we have a carrier which is frequency modulated. It is possible to *swing* the frequency by different amounts. The amount of frequency shift will determine the amplitude of the audio signal at the detector, while its "rate of change" or *speed* determines the audio frequency. Such a signal can be shown to consist of a carrier plus an infinite number of side bands. The side bands are in pairs, symmetrically placed with respect to the carrier and they are separated by the amount of the modulating frequency. A carrier of 1,000 KC. being frequency modulated at 1,000 cycles would have side bands at 1,001, 1,002, 1,003, etc., as well as at 999, 998, 997 KC. When the carrier is being swung, for instance 10 KC. to either side, the side bands situated between 990 KC. and 1,010 KC. only are of importance, the others becoming very weak. Therefore, the practical band-width of a frequency-modulated signal is equal to twice the frequency deviation employed and has no connection with the audio frequency.

Remember that the amplitude causes frequency shift. The larger the amplitude, the larger the frequency shift from the carrier frequency. The number of times per second the side bands *shift* out and back to the carrier is a function of the modulating audio frequency.

The side bands again have a definite phase relationship with the carrier. When the upper and lower side bands are in phase, they are 90 degrees out of phase with the carrier.

ADVANTAGES OF F. M.

Noise Reduction. It was shown by Major Armstrong that frequency modulation could be used for noise-free high-fidelity transmission when the frequency was swung wide, a limiter being employed, and the signal was at least twice as strong as the noise.

If the signal and noise are of the very same nature, one cannot be separated from the other and both must remain or be eliminated together.

If one is to eliminate noise from the transmitted signal, it is first necessary to find characteristics wherein these two differ. Then, it is possible to make a device which will discriminate between the two. Most types of interference: static, man-made static, tube hiss and thermal agitation are similar to amplitude modulated signals. Therefore, they might be eliminated by a system of frequency modulation if the receiving system is made insensitive to amplitude modulation. This is accomplished by the *limiter,* a tube in the I.F. amplifier which is adjusted so the signal will overload it. The voltages of all waves are limited to the same maximum size, removing all amplitude modulation, if the signal exceeds a certain minimum.

These noises are similar to amplitude modulated signals, but do differ from frequency modulated signals.

Armstrong showed the following properties of noise in sharp and broad-tuning receivers. In amplitude modulation receivers, the noise at the detector is proportional to the band-width of the receiver as long as no carrier is being received. As soon as a carrier appears, the various noise components beat with the carrier only and not with each other. The noise is then proportional to the band width up to a 32 KC. band-width. Any further broadening of the receiver will have no audible effect.

In a frequency-modulated system, in the presence of a limiter, the noise is inversely proportional to the band width. Thus a system with a frequency deviation of 100 KC. each side of the carrier would have one-tenth of the noise of a system employing only 10 KC. frequency deviation each side of the carrier.

These facts were presented in highly technical papers; for example, an article by E. H. Armstrong, "A Method of Reducing Disturbances in Radio Signalling by a System of Frequency Modulation," published in *Proceedings of the Institute of Radio Engineers,* May, 1936.

Due to the wide band required, frequency modulated signals have to be restricted to the high frequency channels. At present there are some stations near 40 MC., just below the television band. There is also an experimental station on 110 MC.

General Receiver Considerations. Since the present transmitters employ a frequency deviation of 80 KC., the receivers are superheterodynes with a band width of 200 KC. so that there will be some leeway for possible fluctuation of the signal frequency or the local oscillator frequency due to heat or voltage variation.

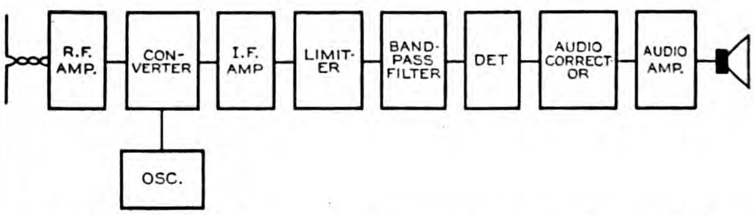


Figure 291. Block diagram of a frequency modulation receiver. Compare this with a block diagram of a regular A.M. superhet (see Figure 193, page 178).

The receiver is shown in block diagram form. There is an oscillator and a converter with or without an R.F. stage. This is followed by a 200 KC. wide I.F. amplifier usually at about 3 MC. Then there is the limiter followed by another set of bandpass circuits so as to cut out the harmonics created. Next comes the detector and an audio corrector circuit. This audio corrector is needed because the stations are using a speech amplifier with a rising characteristic at the high frequency end so as to get a better signal to noise ratio at this frequency. The corrector, a type of tone control, reduces these excessive high frequencies to normal. This tuner is followed by a high-fidelity audio amplifier and a good speaker.

Since the R.F. end of the receiver is no different from that of an amplitude modulation receiver of the same range, it may be dismissed briefly, with this additional observation: the range of the receiver is usually from 39 to 44 MC. When the oscillator frequency is chosen above the signal frequency, it will fall within the television band. It has proven to blot out completely the image on a neighboring television receiver. It is better, therefore, to select the oscillator frequency below the signal frequency and keep the oscillations out of the television band.

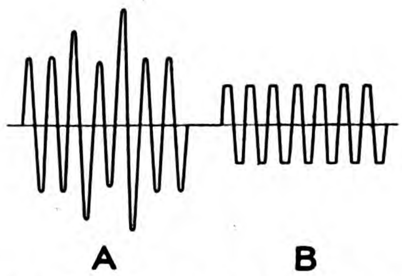
The oscillator sets up actual radiation at its own frequency and this signal may be picked up by other equipment.

I.F. Amplifier. The intermediate frequency seems to be little standardized. It is roughly between 1,500 KC. and 5 MC. At these frequencies, it is rather simple to obtain the required band-width since a 200 KC. width at 4 MC. corresponds to a 20 KC. width at 400 KC. The I.F. coils are now commercially available. They could also be made from standard 3 MC. variable selectivity coils by setting them for the required *width* and connecting a resistor of 15,000 ohms across the tuned circuits.

Connecting this resistor lowers the Q, and increases the band-width.

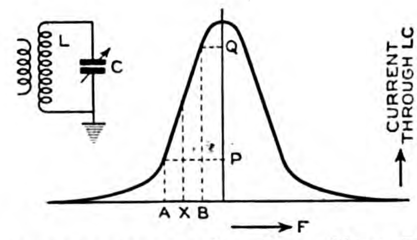
The Limiter Action. This device consists of a sharp cut-off pentode of the 6J7 type, with a low plate and screen voltage, while the bias is provided by a grid leak as shown in the figure. There will be a voltage drop across the grid leak and this may be used as A.V.C. for the preceding I.F. stages. The action of the limiter is illustrated by figures A and B. Figure A shows how the signal looks before it enters the limiter, and B shows how it appears in the plate circuit.

Refer to Figure 292.



In (A) is the form of the voltage wave entering the limiter of a FM receiver. The output wave-form from the limiter is shown in (B).

F.M. Detection. There are several detectors for frequency modulated waves. The old system consisted in changing the frequency modulation to amplitude modulation by means of a "slope filter" and then detecting it with circuits we have already studied. The slope filter can be a tuned circuit which is slightly out of tune with the incoming carrier. In the figure below, such a circuit is shown with its resonance curve. If the circuit is tuned so that the carrier falls at X, a frequency variation of the carrier between A and B will cause the current in the circuit (and the voltage drop across C) to vary between P and Q. So the signal now is also amplitude modulated. There are several disadvantages to this type of detector. If there is to be no distortion, the frequency can be varied only over the range where the side of the resonance curve is approximately straight. Also, a frequency-modulated signal results in less than 100 per cent amplitude modulation which gives best results.



A response curve of a slope filter. The carrier frequency corresponds to the point X. As the frequency swings between points A and B, the amplitude of the resulting signal shifts between the points P and Q.

The detector now generally employed for frequency modulation produces an audio frequency directly without first changing the signal into an amplitude modulated one. The circuit is the old familiar "discriminator" of A.F.C. systems. A description of this detector was given in Lesson 20.

There are two diodes which are so connected to the special transformer that their diode currents are equal when the carrier is at its normal frequency. When the carrier frequency deviates in one direction, the current in diode A is larger than in diode B (see schematic diagram), while if the frequency deviates the other way, the current of second diode B is larger. The two equal load

DETECTOR FOR F. M.

This explanation refers to the diagram of Figure 292, below.

resistances are so connected that their voltage drops buck each other. So, the voltage drop between point P and the chassis is equal to the difference between the voltage drops across the two diode loads. When the carrier is at its normal frequency, there is no potential difference between P and the chassis while a frequency modulated signal will cause the voltage at P to vary in accordance with the frequency modulation.

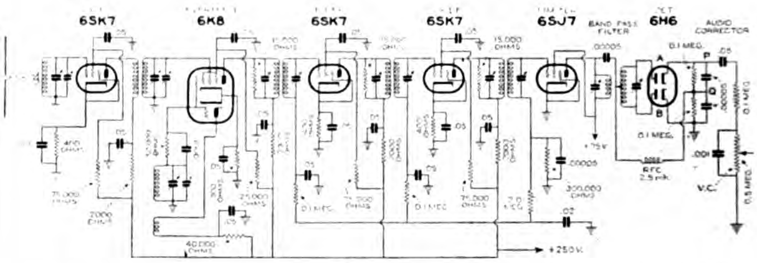
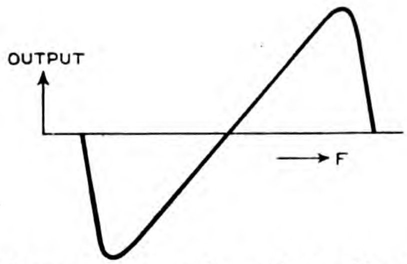


Figure 292. A schematic diagram of a complete F.M. receiver with the exception of the audio stages.



This curve shows the relationship between detector voltage output and frequency.

The output voltage at P is proportional to the frequency deviation as well as to the strength of the signal in the previous transformer. Since the limiter cuts all signals down to the same size, the output at the detector is practically independent of the strength of the incoming signal as long as it is above a cetain minimum level. The characteristic of frequency-versus-output of this detector is shown. To avoid distortion, the sloping middle part of the curve should be straight and long enough to accommodate the 200 KC. swing. The curve should also be symmetrical.

The separation of the two peaks or the length of the sloping part depends on the Q of the tuned circuits. In order to have a wide enough curve, it may be necessary to employ resistance loading. The symmetry depends on the correct adjustment of tuned circuits.

Shown in the schematic above.

Audio Frequency Corrector. The transmitters are being designed to emphasize the high notes so that there may be a better signal-to-noise ratio at these frequencies. It is necessary to employ a corrector circuit to neutralize this effect. It is a rather simple resistance-capacity network consisting of two resistors and one condenser. This resembles an ordinary tone control of fixed adjustment.

Audio Amplifier for F.M. The circuit does not show the audio amplifier since it can be of conventional design. In order to take advantage of the high fidelity possibilities, the best audio amplifier is none too good. The output stage should be preferably a set of triodes such as type 6A3 or 6A5-G. If pentodes or beam tetrodes are employed, inverse feedback should be used. The speaker and its mounting should also be designed for best fidelity.

Review Questions and Problems. 1. The amplitude of the signal has what effect on the behavior of FM signals?

2. Can FM be transmitted on the regular American broadcast band? Is this possible? Is this practical?

3. What is the action of the limiter in a FM receiver?

LESSON 22

Fundamentals of Television

FUNDAMENTAL PROCESSES OF TELEVISION. The transmission of a visual scene by electrical (radio) means requires two fundamental processes of changing the light rays reflected from the item to be televised, to corresponding electrical energy and subdividing the image into many small elements.

The conversion of light energy to electrical current is performed by photo active materials—the intensity of light varying the current produced. If the light from an entire scene is *televised* by a single photo-cell, the current produced will vary with the average light present. Light from all parts of the image will fall on the photo-cell and will exercise its influence.

For intelligent television transmission it is essential to separate the image into many small elements and transmit these in a regular order. Since various parts of an object being televised reflect different amounts of light, if each one's light is permitted to act separately, a series of current variations will be produced in accordance with the light intensity of the elements scanned. A definite order of scanning these elements must be carried out, so that the image can be reconstructed later at the receiver.

In sound broadcasting, voice or music must be changed to corresponding electrical energy to be handled by radio transmitting and receiving equipment. In television, light reflected from an image to be televised must be changed to electrical energy. An object is visible because it reflects light to the eye.

SCANNING DISC TELEVISION. The process of television (no longer used) is shown below. A man's head is located in a strongly illuminated field served by projector lamp L. The revolving Nipkow disc D, permits one element of the image, at a time, to

This television process is explained because it is easy to understand and serves as an introduction to more modern television methods.

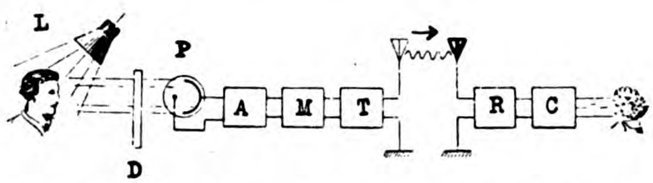


Figure 293. Simplified, block diagram illustration of a scanning disc type television transmitter and receiver.

reflect its light to the photo-cell P. The current in the photo-cell will vary in accord with the rays. If dark elements, maybe corresponding to sections of the hair, are scanned, low current will be created. If the light elements are scanned, much light will be reflected and the photo-cell current will increase. These small variations can be amplified in a pre-amplifier A, and modulator M, and then placed on the radio carrier produced in transmitter T.

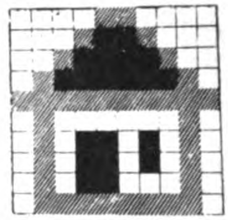
Colors become shades of gray. Red reproduces as black, for example.

These radio waves, modulated with the electrical variations corresponding to the scanned picture, may be received by a special radio (television) receiver and used to recreate the picture with a special neon glow tube and synchronized scanning to remain in step with the transmitter. The light intensity of any element produced will correspond to the signal strength at that moment.

NUMBER OF ELEMENTS

A very simple subject (a block diagram of a house) has been selected to make the explanation easier to understand.

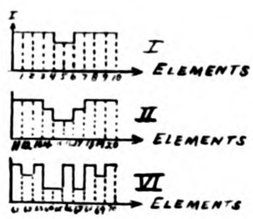
Scanning Process and Quality. If a block diagram of a house is to be televised by means of 100 elements, we can assume that the illustration is superimposed upon ten horizontal lines each having ten elements. The scanning may be performed horizontally from line to line, or vertically from row to row. Horizontal method is preferred. If the scanning process is started at the upper left hand corner, the first four elements (1, 2, 3, and 4) will produce maximum current. These elements are white and will reflect a

Figures 294 and 295. A picture of a simple black and white house placed upon a television screen of 100 elements. At the right is the televized view of the same house.

maximum of light. Elements 5 and 6 will reflect less light, being partially covered with the dark roof of the picture. While these elements are scanned less current will be generated by the photo-cell. Again, elements 7 to 10 of the first line, will produce a strong current. These changes are illustrated graphically. Follow the changes occurring as the other elements are scanned and check your results for the 2nd and 6th lines which are shown below.

Make a similar sketch for a few other elements.



Figures 296 and 297. The current produced in the photo-cell by the different elements. Refer to Figure 294, above. At the right is a view of the same house as televized using 900 elements.

The photo-cell current may pass through a resistor and produce a voltage drop which in turn may be amplified.

These changes in the photo-cell current may be amplified and used to amplitude modulate the transmitter carrier. At the receiver these amplitude changes will produce visual effects along similar 100 elements. Many details will be lost because of the small number of elements employed. Notice that when a change of shade occurs in a single elemental area, this change does not appear at the receiver but simply influences the tone of the entire element. Using 900 elements better definition is obtained as shown in the last illustration above.

The word *Iconoscope* is used by R.C.A. Other manufacturers use the word *Camera Tube*, or similar name.

How the Iconoscope Works. In modern television, a cathode ray tube is used for pickup and the scanning is performed automatically. A mosaic is a mica plate having many thousands of photo active globules insulated from each other and from the back conducting plate. Each globule forms a tiny condenser with this back plate; the mica serving as the dielectric. The scene to be televised is projected upon the mosaic. Light sections of the image cause high electron emission from the photo active globules. The globules in the dark parts of the image emit very few electrons.

The mosaic is mounted in the tube as shown. The scene is focused on the mosaic by means of a lens system in the same manner used in photography. An electron gun emitting a stream of electrons is made to scan the mosaic in a regular order. The electron spot falling on the mosaic covers a large number of globules and, in some Iconoscopes, measures 1/50 of an inch in diameter. The beam may be made to cover the surface of the mosaic in any predetermined order, but at present 441 line scans are used, double interlaced so that the odd lines are scanned first and then the even, the complete image being scanned 30 times per second.

This scanning process first covers the odd lines of the 441 horizontal divisions, then the even sections are covered in order. This completes the scan of the entire image, and this process is repeated 30 times every second.

The mosaic takes the place of the photographic film of a regular camera.

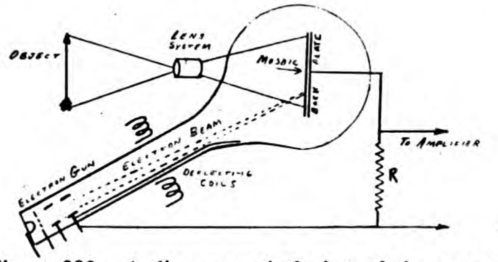


Figure 298. A diagrammatical view of the operation of an Iconoscope. The electron beam scans the mosiac in a regular order. The voltage developed across resistor R, depends on the amount of light present on the globules being scanned at the moment.

Now you will recall that light causes the photo active globules to emit electrons which form a space charge around the corresponding globules. Since each globule is actually one plate of a small condenser (the metal deposit on the back of the mica serving as the other plate), the small condenser so formed will become charged.

The electron stream sweeps over these charged "condensers" covering a number at a time and discharges the accumulated electrons through resistance R. The voltage across this resistance, therefore, will depend on the charge of the globules covered by the beam during the corresponding instant. Since the charge, in turn, depends on the light intensity of the image, the signal voltage produced will be in exact accord with the light of the elements covered.

Since any one elemental mosaic area is receiving light while the remaining sections are being scanned, the charge is cumulative and excessive amplification is not needed.

Television Transmission. You will see from the diagramatical illustration given (reprinted from the Proceedings of the Institute of Radio Engineers) how the synchronizing signals are applied to the pickup tube and are also transmitted to serve at the receiver. These synchronizing signals of all present American stations follow the R.M.A. standards.

Figure 299, next page.

The actual deflection at the cathode ray tubes is accomplished by means of magnetic deflecting coils (electro-static plates may also be used). Two pairs of coils are employed mounted at right angles to each other. The beam will be deflected as a varying current is applied to the magnetic yokes, and, since electrons have infinitesimal mass, the deflections will be instantaneous.

Only one set of coils is shown in Figure 298.

Ultra high frequencies are used for transmission of television signals. This is essential because of the extremely high frequency of the side bands. The first television channel is from 44 to 50 MC., and the others are at still higher frequencies.

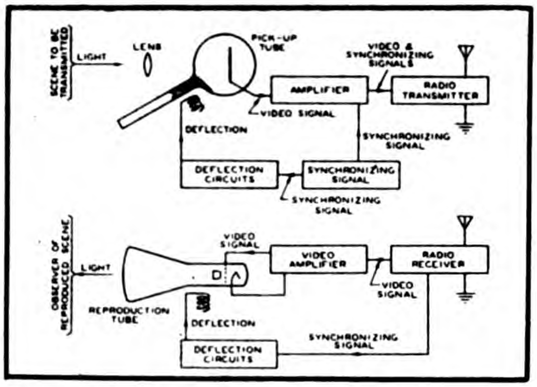


Figure 299. Simplified, block diagram of a modern television transmitter and receiver.

Video frequencies in a television receiver correspond (in relationship) to audio frequencies in regular broadcast receivers. However, video frequencies run up to 4½ megacycles and special wide-band amplifiers must be designed to handle these frequencies.

Television Receivers. To the practical man, the actual function and repair of a television receiver is of prime importance. By dividing the receiver into sections, the problem of servicing is greatly simplified. The television receiver may be of the TRF or

If your work or special interests lie in the television field, we suggest you purchase from the publishers a booklet, *Cyclopedia of Television Facts,* which will give you more information and suggestions for servicing television receivers.

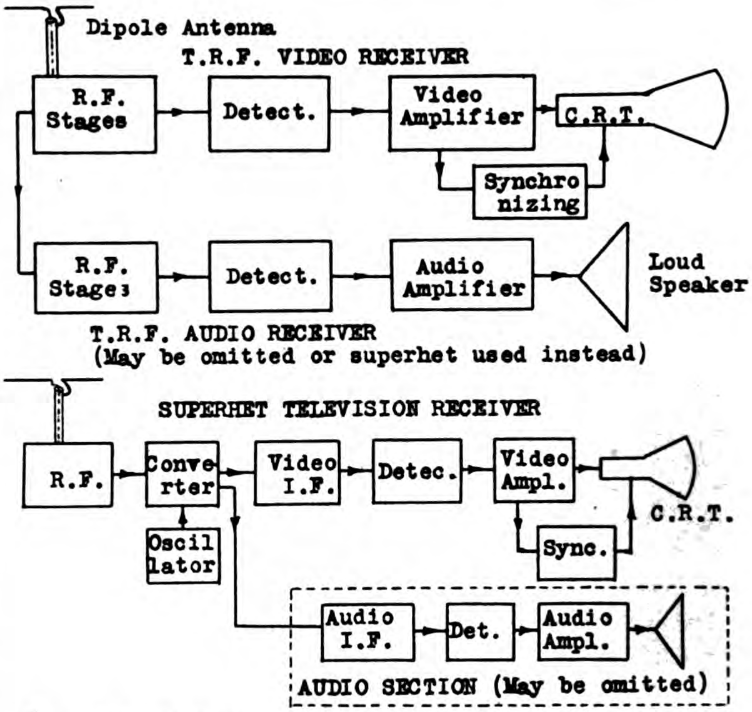


Figure 300. Block diagrams of television receivers.

The synchronizing pulses are transmitted along with the television signals and are amplified with the signals in the different stages of the receiver. Special circuits are used to separate these synchronizing pulses from the signal and use them to control the sweep circuits of the cathode ray tube.

superhet type, may or may not have the audio channel receiver included. In the TRF type unit, an entirely separate receiver is used for audio although the controls may be combined. In the superhet type, the R.F. pre-selector and converter-oscillator are common to video and audio channels. If audio is not included,

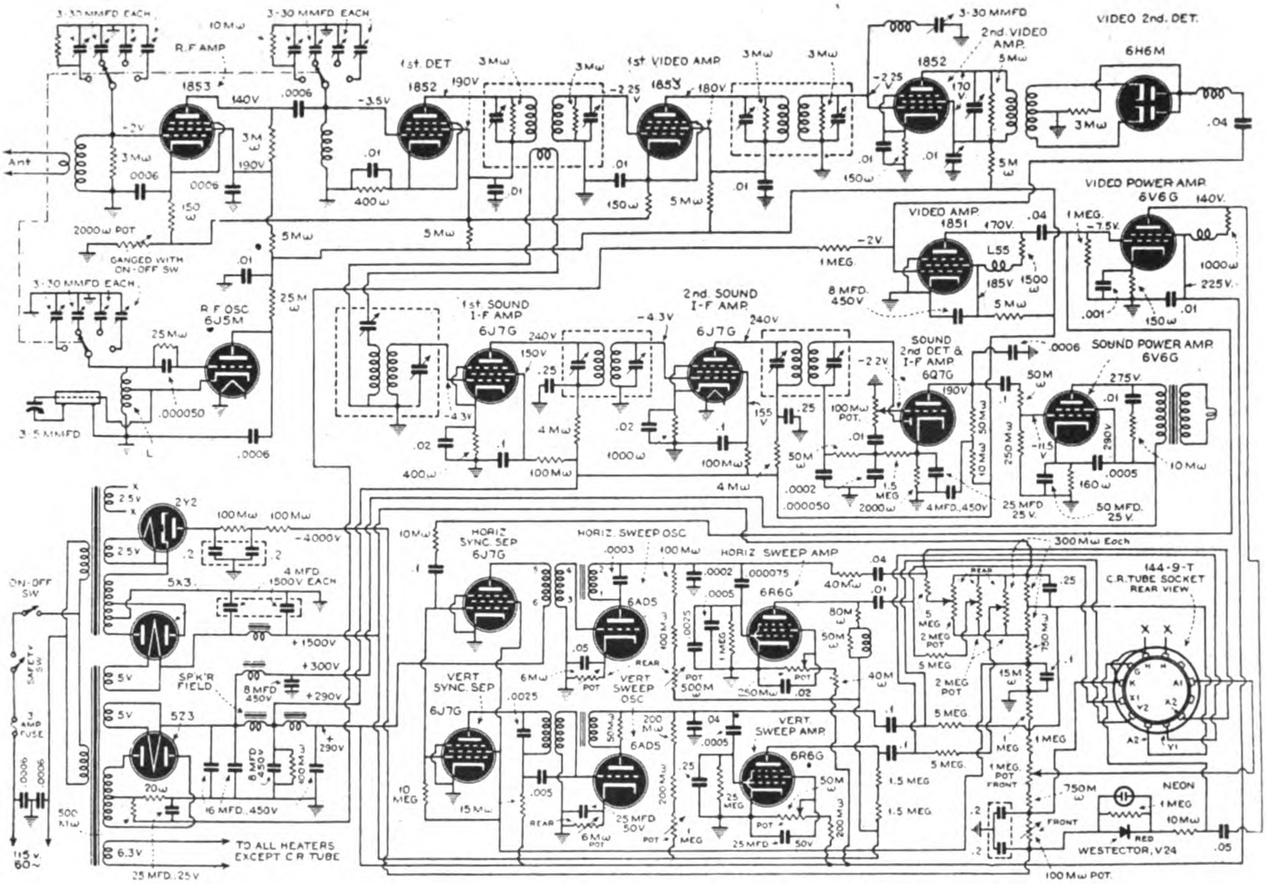


Figure 301. A complete schematic diagram of a modern television receiver. Reception for four channels is provided. The audio channel is transmitted at one end of the television band used and is handled by the same R.F. preamplifier and mixer (1st detector) as used for the video signals. However, in beating with the oscillator frequency, the audio and video produce different frequencies and have separate I.F. amplifiers.

simplification of these first stages results and the audio channel I.F., detector, and audio frequency amplifiers are omitted.

Since the majority of present day television receivers combine video and audio and are of the superhet type, we will use this type of set as the basis for our discussion. The Du Mont, Model 180, schematic illustrated is an excellent example.

Starting at the antenna input you will notice that the secondary is loaded with a 3,000 ohm resistor to flatten the response curve. The process of loading inductances is used in television equipment to permit the passage of extremely wide side-band. Tuning is accomplished by means of pre-set trimmers connected to a push-button switch. The local oscillations produced by the 6J5 tube, beat with both the video and audio carriers producing two different useful I.F. frequencies. One is used for the video I.F., while the other corresponds to the audio I.F. frequency. There are two stages of I.F. in each channel. Ordinary receiving type tubes are employed in the audio section, but special low inter-electrode capacity tubes must be employed in the video I.F. channel. The balance of the audio signal receiving equipment is similar to the type used in regular radio sets.

In the video section also, a second detector is used followed by a videa amplifier. After the first video stage part of the signal is tapped off and serves the horizontal and vertical sweep circuits. The synchronizing signal received simply controls the local vertical and horizontal oscillators and locks them in step.

Your basic studies are now complete. In the next volume, you will apply these facts to practical electronics and to radio and electronic servicing.

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