CHAPTER 7

RADIO RECEPTION

102. Reception

Receivers perform the function of intercepting a tiny part of the radio-wave energy radiated by transmitters and of recovering the information contained in it. This information can be in the form of radiotelegraphy code signals, consisting of periodic interruptions of the radio-frequency carrier, or in the form of modulation of the amplitude or some other characteristic of the r-f carrier. Only receivers for continuous waves and for amplitude modulation are discussed here. Both types must contain the necessary circuits for performing the following six functions (fig. 154) : signal reception, signal selection, r-f amplification, detection, a-f amplification, sound reproduction. These are sufficient for a-m reception, but for c-w reception an additional circuit in the form of a beat-frequency oscillator is required.

a. Signal Interception. The *receiving antenna* intercepts a small portion of the passing radio waves. The signal power extracted by ordinary receiving antennas is only a few microwatts, which is sufficient for subsequent amplification as long as the noise energy intercepted by the antenna is substantially less than this.

b. Signal Selection. The physical dimensions of the antenna generally favor its response for a specific frequency band within the total radio-frequency spectrum. Within this given frequency band, some means must be provided to select the desired signal from all of the r-f carriers intercepted by the antenna. Signal selection is achieved by tuned I-C (inductance-capacitance). These respond best at their resonant frequency, as explained previously, and respond very little or not at all at other frequencies. Several tuned circuits

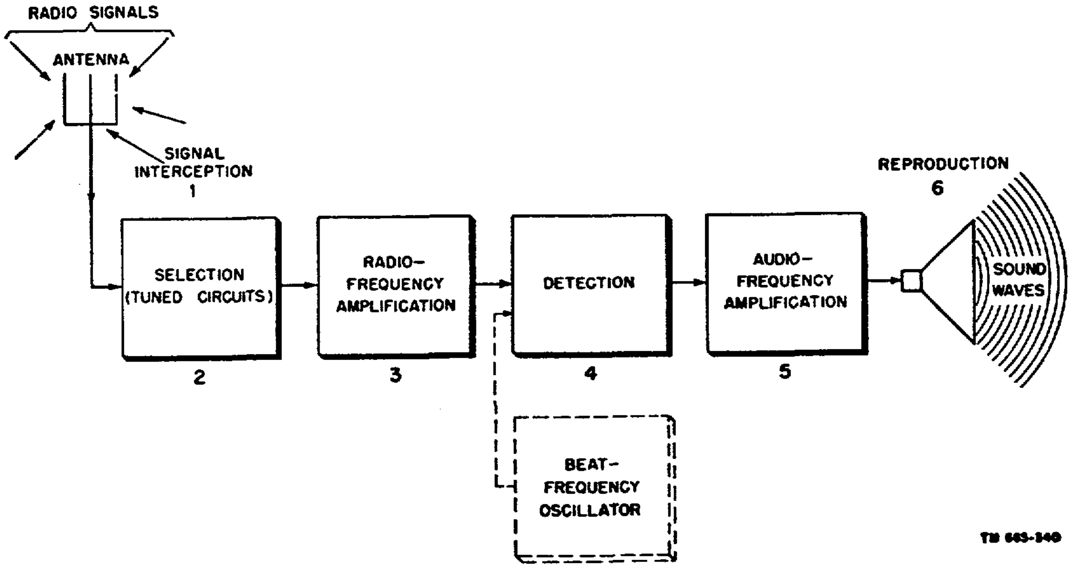

Figure 154. Essentials of radio reception.

usually are necessary to differentiate sufficiently between the desired signal frequency and all other frequencies.

c. R-F Amplification. The weak signals intercepted by the antenna usually must be amplified considerably before the intelligence contained in them can be recovered. One or more r-f amplifiers serve to increase the signal to the required level. A selective tuned circuit in the input of each r-f amplifier makes sure that only the desired signal is amplified. If amplification is carired out only at the carrier frequency of the signal, the receiving system is known as a *trf* (*tuned radio-frequency*) receiver.

d. Detection (Demodulation).

(1) If the signal is amplitude-modulated, the original intelligence must be recovered from it by separating the modulation signal from the r-f carrier. The circuit which separates the audio-frequency signal variations from the r-f carrier is called the *detector* or *demodulator.* Most detectors do not operate well at very low signal levels, and this is one of the reasons why radio-frequency amplification usually is required ahead of the detector.

(2) In the case of c-w (radiotelegraphy) reception, a beat-frequency oscillator is used in the receiver circuit (shown by dotted lines in figure 154). The bfo provides an r-f signal which *beats* or *heterodynes* against the frequency that is injected into the detector. The resultant frequency is an audio frequency which can be heard in the headset or loudspeaker at the output of the receiver. In some cases, the bfo is combined with the detector stage.

e. A-F Amplification. The signal frequency present in the output of the detector stage generally is too weak to operate a headset or loudspeaker. Therefore, one or more stages of audio-frequency amplification are required to strengthen the audio output of the detector to a level sufficient to operate the headset or loudspeaker.

f. Sound Reproduction. The amplified audio-frequency signal is applied to an electromechanical reproducing device, such as a loudspeaker or headset, which translates the electrical audio-frequency variations into corresponding sound waves. For a-m, the sound output of the reproducer is a close replica of the original audio tones at the transmitter. For c-w, the sound output is a tone the frequency of which depends upon the frequency of the local oscillator. This tone is heard whenever the key is depressed at the transmitter, and, consequently, it reproduces the interruptions of the radio carrier in accordance with the telegraphic code.

103. Types of Receivers

a. In the development of radio, the circuits and components necessary to perform all of the functions outlined above came into existence gradually. In the early days of radio, little was known about antennas, tuning, and amplification. A *receiver* in the early 1900's, for example, consisfed of a very inefficient detector and a telephone headset. Such a receiver could be used only at a very short distance from the transmitter and did not permit selection of transmitted signals. Years later, the range of reception was considerably increased by the addition of the elevated antenna and the ground connection, resonant tuning circuits, and the discovery of the more sensitive crystal detector.

b. The invention of the triode vacuum tube by Lee de Forest made possible the development of simple *triode detector receivers* having increased sensitivity and stability over the crystal set. Various refinements were made to increase the amplification and hence the sensitivity of the simple one tube receiver. The most important among these was the invention of the regenerative and the superregenerative detector circuits by Armstrong. These will be discussed later. Although these detectors were highly sensitive, they were none too stable and had poor fidelity. The regenerative detector still is used for the detection of c-w, and the superregenerative detector for voice signals. It was found that a-m reception could be improved substantially by adding separate stages of tuned radio-frequency amplification and audio-frequency amplification to the simple triode detector. These trf receivers have excellent fidelity and fairly good sensitivity and consequently are still used in many applications to this day. However, unless many tuned circuits are used, the trf receiver does not have good selectivity. Selectivity is the ability to differentiate between desired and unwanted signals.

c. The invention of the superheterodyne receiver by Armstrong, during World War I, removed the chief deficiencies of the trf receiver. Superheterodyne receivers are in almost universal use at the present time because they have excellent sensitivity, selectivity, and fidelity (ch. 8). In this receiver, signal amplification is carried on in steps, partly at the carrier frequency and partly at a lower intermediate frequency to which the received signal is converted.

104. Simple Crystal Receiver

a. Circuit. In the elementary type of crystal receiver shown in A of figure 155 the basic parts are an antenna, a tuned *L-C* tank circuit, a crystal which is the detector, and a headset bypassed by capacitor C_b. The signal intercepted by the antenna is coupled to the *L-C* circuit through the r-f transformer, *T*. If a step-up ratio is used between the primary antenna winding and the secondary tank coil winding, some amplification exists. Certain mineral crystals, such as galena, silicon, and carborundum, have the property of allowing current to flow through them much more readily in one direction than in the opposite direction. Therefore, they act as rectifiers of alternating current. Galena crystals are used in most crystal receivers. The headset serves to translate the audio-frequency variations in its input to corresponding sound waves. C_b is an r-f bypass *capacitor to keep radio-frequency currents out of* the headset.

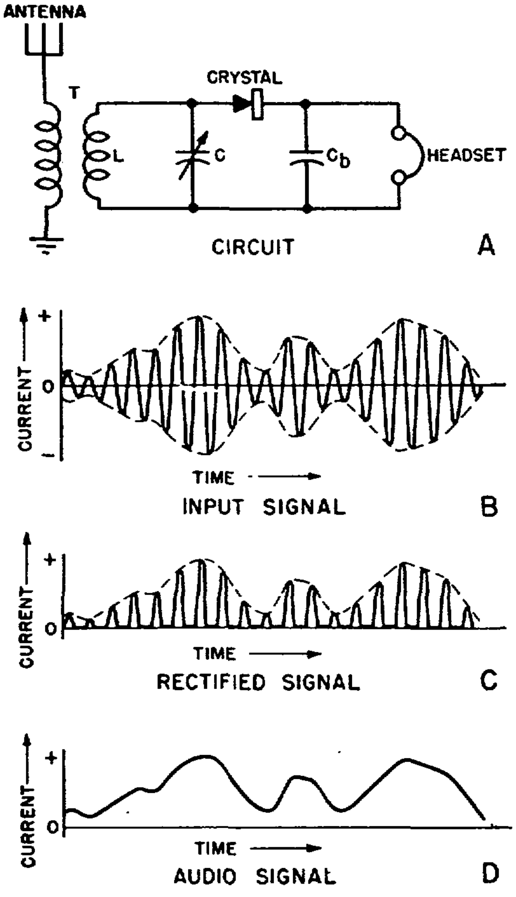

Figure 155. Crystal receiver and waveshapes.

b. Operation. Assume that the *L-C* tank circuit is tuned to one of the modulated radio-frequency signals intercepted by the antenna. The initially weak signal is coupled to the resonant tank circuit through the r-f transformer, being slightly stepped up in the process. The still small signal current is considerably amplified by the principle of resonance. The tank circuit strengthens the r-f current of the frequency to which it is tuned, while discriminating against r-f currents of all other frequencies. The ability of the tank to select just one frequency depends on the sharpness of resonance, which in turn is determined by the losses in the tank circuit. B shows the modulated r-f signal selected by the tank circuit. This signal oscillates at a rate determined by the carrier frequency. The strength or amplitude of the signal varies at an audio rate determined by the modulating signal frequency. The headphones are incapable of responding to the extremely rapid carrier-frequency oscillations, but they can reproduce the slower audio-frequency variations of the modulation, which contain the intelligence. Consequently, it becomes necessary to separate the modulating signal frequencies from the r-f carrier. This process is carried out in two steps.

(1) The first step in the *rectification* of the r-f carrier by means of the crystal. Since the crystal can respond only to current flowing in one direction, it eliminates the negative portions of the modulating signal and carrier below the zero axis. The resulting wave-form is shown in C of figure 155. The current through the circuit never reverses in polarity, but it still pulsates at the rate of the r-f carrier. It is necessary to smooth out these pulsations before the modulation can be re-

produced by the headset, since the headset cannot respond to radio frequencies.

(2) The second step is the smoothing or *filtering action* achieved with the bypass capacitor, C_b. The value of this capacitor is so chosen that it has a low reactance at radio frequencies an da relatively high reactance at audio frequencies. As a result, the r-f is shunted around the headset, and the audio-frequency variations of the carrier pass through it. In C, the current is passing through C_b and in D the current is passing through the headset. The audio reproduced as sound by the headset corresponds to the original audio at the transmitter.

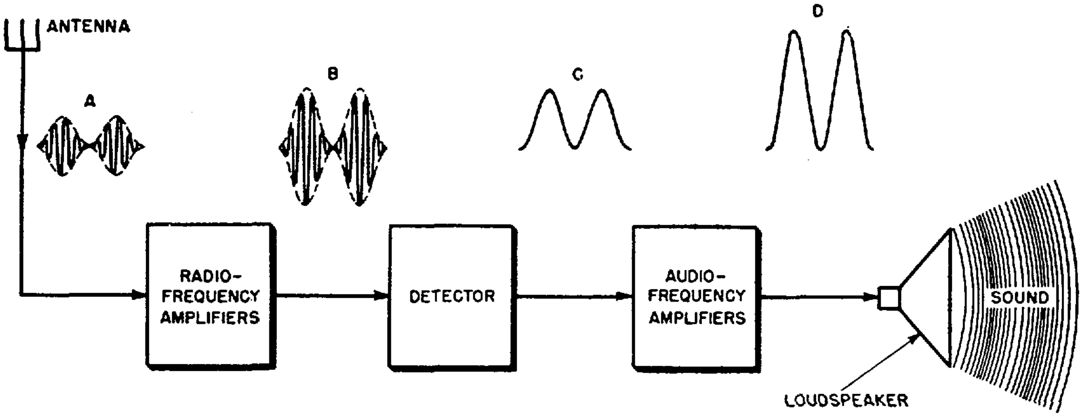

Figure 156. Block diagram of trf receiver.

105. Tuned Radio-Frequency Receiver

The tuned radio-frequency receiver shown in figure 156 consists of one or more stages of r-f amplification with tuned circuits in the input of each stage, a detector stage, and one or more stages of audio amplification, driving a loudspeaker. The inputs and outputs of each stage are shown in the block diagram. The signal intercepted by the antenna is portrayed as an r-f carrier modulated by two cycles of an audio-frequency tone (waveshape A). It is selected and amplified by the trf amplifiers. The amplified output (waveshape B) is applied to the detector stage, where it is detected. The output of the detector which is shown as waveshape C consists only of the audio-frequency variation of the carrier. The a-f signal is strengthened by one or more stages of audio amplification until its amplitude is of sufficient value to drive the loudspeaker, as in waveshape D.

106. Tuned R-F Amplifiers

a. Operation. In figure 157, the signal input from the antenna or a preceding r-f amplifier is coupled to the tuned-grid tank circuit through r-f transformer $T1$. The tank circuit augments the input signal frequency to which it is tuned by $C1$, but at least partially suppresses all other frequencies. The signal selected by the $L1C1$ tank circuit is applied to the control grid of tube $V1$ and appears amplified in the plate circuit of the tube. Although a triode is shown for illustration, pentodes commonly are used. The output of $V1$ is coupled through transformer $T2$ to the input of the next stage, which can be another r-f amplifier or the detector. $L2C2$ is tuned to the same frequency as $L1C1$ for a maximum transfer of energy from $V1$ stage to the next stage. R-f amplifiers in receivers are operated class A so that they present a minimum of distortion to the modulated signal. Resistor $R1$ in the cathode circuit of the tube provides the required negative bias for class A operation. The r-f is bypassed around the bias resistor by capacitor $C3$, which is in parallel with it.

b. Selectivity.

(1) It has been pointed out that the reason for using a tuned tank circuit in an r-f

amplifier is its ability to differentiate between the desired signal frequency and undesired frequencies, whether they are unwanted signals, noise, or other disturbances. The extent to which a receiver has this ability is called *selectivity.* The greater the number of tuned circuits in a receiver, the greater is its over-all selectivity. The selectivity of each individual tuned circuit is determined by the sharpness of its resonance. The sharpness of resonance, in turn, depends on the resistive losses in the tank circuit, or equivalently, on its effective Q.

(2) A of figure 158, shows resonance curves of a typical tuned circuit for various values of Q. When the Q is low (graph for Q=50), the gain or response of the circuit is broad, as indicated by the wide resonance peak. Since the relative response falls off very slowly when the circuit is detuned from resonance in either direction, it cannot discriminate well between the desired resonance frequency and unwanted (off-resonance) frequencies. Therefore, the selectivity is poor. For $Q=100$, the resonance peak is much sharper, and the selectivity is considerably improved. For a Q of 150, the resonance curve is very narrow and the selectivity is excellent. In addition, this high value of Q increases the relative voltage gain of the tuned circuit at resonance.

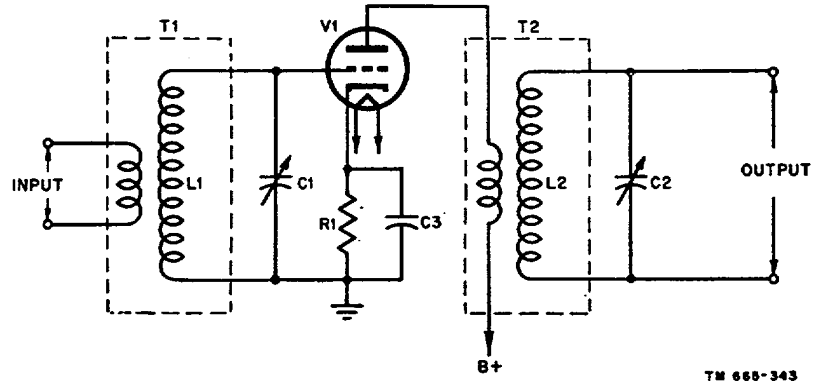

Figure 157. Tuned r-f stage of trf receiver.

(3) To illustrate the effect of tank circuit Q on the selectivity of each stage, consider two signal voltages of equal strength, which are intercepted by the antenna and applied to the grid tank circuit of the first r-f stage. The tank is tuned to the desired signal frequency of 1,000 kc. The frequency of the unwanted signal is 980 kc, as shown in A. For a $Q=150$, the relative gain of the tank for the desired 1,000-kc signal is arbitrarily taken as 100. The unwanted 980-kc signal is -20 kc off resonance, and the corresponding relative response of the tank is seen to be 20. Therefore, at the output of the tank the relative gain of the 980-kc signal is only $20/100=1/5$, or 20 percent of the gain of the desired 1,000-kc signal. However, if tank circuit Q is only 50, the relative voltage response of the 1,000-kc signal is 35, and that of the 980-kc signal is about 20. Consequently, the relative response of the undesired 980-kc signal in this case is $20/35=4/7$ or about 57 percent of that of the desired 1,000-kc signal. An unwanted signal more than one-half as strong as the desired signal would be very disturbing at the output of the receiver. Therefore, a high-Q tank circuit in each stage of the receiver is essential for selectivity.

(4) The over-all selectivity of a receiver can be increased greatly over that of a single stage by *cascading* (putting in series) a

number of tuned r-f amplifier stages. The greater the number of r-f stages, the greater the number of tank circuits. The manner in which the selectivity of a receiver goes up in direct proportion to the number of tuned r-f circuits used is illustrated in B. The following is the result when a 1,000-kc signal and a 980-kc signal of equal strength are applied to the input of the resonant grid tank circuit of the first r-f amplifier in a receiver. To emphasize the effect of many tuned stages, broad tuning low-Q tank circuits have been chosen for plotting B. The output of the first tuned circuit for the 980-kc signal is 50 percent or one-half of that for the desired 1,000-kc signal. The ratio of the desired signal (1,000-kc) to the undesired signal (980-kc), therefore, is 2 to 1, after passing through the first tuned circuit.

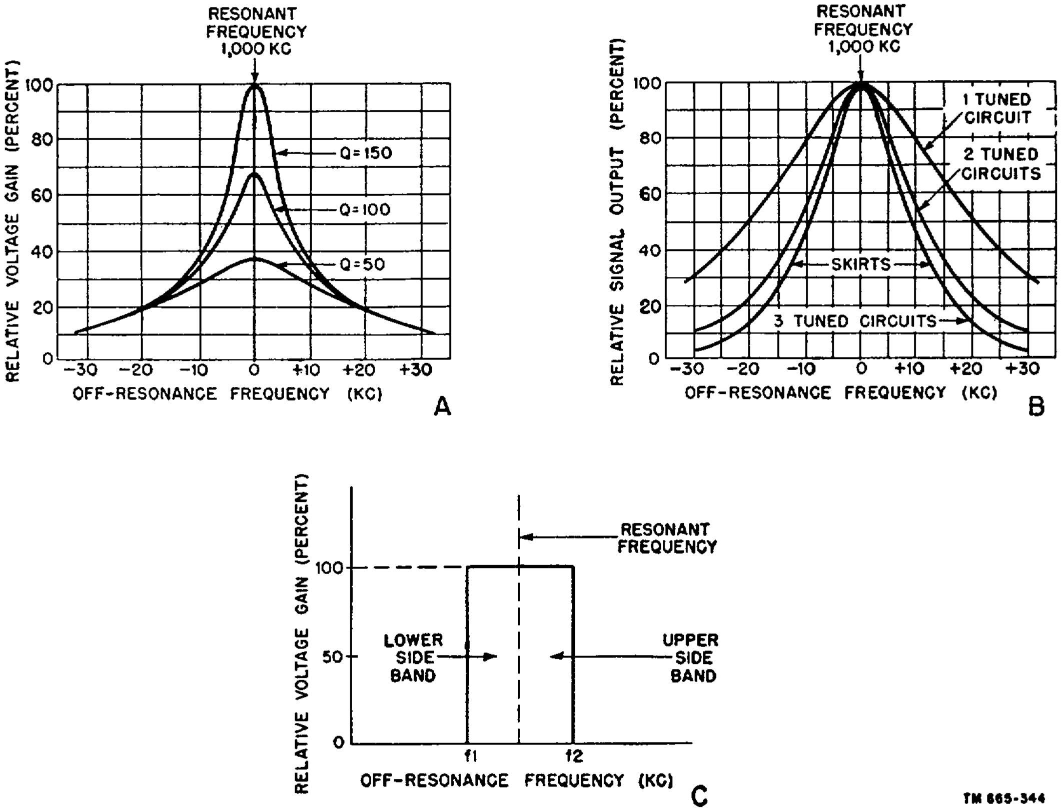

Figure 158. Selectivity of trf receiver.

(5) The first r-f tube amplifies these signals equally so that the ratio of the two voltages applied to the input tank circuit of the next stage is still 2 to 1. The ratio of the two signal voltages in the output tank circuit of the second stage is 2 times 2 to 1, or 4 to 1. The amplitude of the 980-kc signal, after passing through two tuned circuits, therefore, is one-fourth or 25 percent of that of the desired 1,000-kc signal, as in (B of fig. 158). If the signals are passed through another tuned stage of similar characteristics, the ratio of desired to undesired signal will be 2 times 4 to 1 or 8 to 1 in the output of the third tuned circuit. The amplitude of the 980-kc signal then will be one-eighth of

12.5 percent of that of the 1,000-kc signal, as indicated. To make the 980-kc signal negligible compared to the desired 1,000-kc signal, a fourth tuned circuit is required, or else the Q of each individual stage must be improved. *Cascading* affects chiefly the *skirts* or sides of the resonance curve, but does not change materially the sharpness or *nose*.

c. *Fidelity.*

(1) The selectivity or sharpness of the resonance curve of an individual tuned circuit cannot be improved indefinitely by increasing the Q. If the resonance peak is made so sharp that it cuts off part of the upper and lower side bands of the modulated carrier, the bandwidth will be impaired and the signal becomes distorted. Since there are two side bands, the tuned circuit must pass a bandwidth twice that of the highest modulating frequency. Consequently, if an audio tone of 5,000 cps is to be passed, the bandwidth is 2 times 5,000=10,000 cps, or 10 kc. If the carrier is, say 1,000 kc, the tuned circuit must pass 5 kc on either side of its resonant frequency of 1,000 kc, or from 995 kc to 1,005 kc. Ideally, it should pass all frequencies within this 10-kc band with equal amplitude, while completely rejecting all frequencies outside of this band. This necessitates the *flat top* resonance curve shown in C. Frequencies $f1$ and $f2$ represent the lowest and highest frequencies of the resonance curve, respectively. Such a curve cannot be attained in practice, but it can be approximated through special *band-pass* circuits.

(2) The extent to which the tuned and other circuits of the receiver are capable of reproducing accurately all of the frequencies present in the input is known as *fidelity*. For c-w reception, side bands are confined within a very small region in the neighborhood of the carrier frequency, and fidelity is of no consequence. For c-w, therefore, the selectivity of the tuned circuits is made as great as possible. For radiotelephone service, a channel of 5 kc on each side of the carrier generally is sufficient, and the fidelity of the receiver is relatively unimportant. It is, however, of vital importance in a-m, and f-m, and television broadcast receivers, where relatively large bandwidths must be passed by each tuned circuit.

d. *Sensitivity.* The sensitivity of a receiver is defined as the minimum signal input voltage that will deliver a standard signal output power. This is a convenient definition, since the output power ordinarily is fixed by the type of receiver. Standard values varying from .05- to 1-watt output power are in use, depending on the type of receiver. The sensitivity usually is expressed in microvolts input to the antenna for the standard watt output. In addition to the definition of sensitivity as expressed in microvolts input for a standard output, a further quantity is specified in that the previous relation must exist for a given signal-to-noise ratio. The signal-to-noise ratio in itself is discussed below. The over-all voltage gain of the r-f and a-f amplifier stages determines directly the sensitivity achieved by a particular receiver. In a trf receiver, the number of tuned r-f stages is the most important factor contributing to the over-all gain.

e. *Signal-To-Noise Ratio.*

(1) It would seem that unlimited sensitivity could be obtained in a receiver by adding progressively more stages of amplification, and thus increasing the over-all gain almost indefinitely. Although more stages do give more gain, this is not the only factor determining the sensitivity, the other factor being *noise*.

(2) The term *noise* in radio reception applies to any form of undesired electrical disturbance occurring within the useful frequency band. The source of noise may be external or within the receiver itself. External noises are picked up by the antenna along with the desired signal, and both are equally amplified by the receiver, the noise tending to *mask* the signal. The most common externally produced noises are atmospheric disturbances and man-made interference. Atmospheric disturbances, often called *static*, are caused by electrical discharges which take place within the atmosphere, such as lightning and electrical storms.

(3) Man-made electrical noise can be caused by a great variety of electrical and electromechanical devices. Any device that produces electric sparks is a source of electromagnetic radiation, and, therefore, of noise. Common spark producers are electric bells, electric motors and generators, interruptors, and distributors and spark plugs in automobile engines. Direct radiators, such as diathermy machines, are another common cause of man-made interference. Most externally produced noises have the form of transient disturbances, called *impulses*. These vary in amplitude and their energy is distributed over an extremely wide range of frequencies. Impulse noise interferes directly with a-m reception at practically all useful frequencies of transmission. Special circuits are incorporated into communication receivers to eliminate or reduce at least a portion of externally produced impulse noise.

(4) Noise produced by the receiver itself results from three main causes: tube noise (also called *shot effect*), thermal agitation, and hum. Shot effect is generated within vacuum tubes by random fluctuations occurring in the electron flow from cathode to plate. These fluctuations are produced as a result of small variations in the rate of emission of electrons from the cathode, and they are independent of the signal at the grid. The fluctuations are amplified along with the useful signal and they result in a noise. Triodes, because of their simple structure, are always inherently less noisy than multigrid tubes such as pentodes. Shot effect can be minimized to some degree by operating the tube with a sufficiently high filament temperature to cause copious emission of electrons.

(5) *Thermal agitation* is a form of random noise caused by temperature differences between the terminals of resistors and other components. These differences produce random motions of the free electrons in the conductors or resistors, which are superimposed as additional noise currents upon the normal conduction current. The higher the resistance, the greater is the equivalent thermal noise voltage produced across its terminals. Proper placement of the components reduces these temperature differentials, and hence the thermal noise voltage.

(6) Resistor noise sometimes is a source of trouble. Certain composition resistors composed of carbon granules generate noise, often considerably in excess of thermal agitation noise, and when such resistors are discovered they must be removed from the circuit and replaced with an equivalent resistor which is not noisy.

(7) *Hum* often is present in a-c line-operated receivers, usually because of improperly filtered power supplies. Inductive stray pick-up from nearby coils and transformers also can produce hum. Proper filtering of the power supply, careful placement of the components, and shielding help to minimize hum.

(8) Noise is particularly troublesome when produced in the *input* stage of the receiver, which consists of the antenna, the coupling circuit, and the first r-f amplifier tube. This noise generated is subject to the full amplification of the receiver, and thus tends to mask the received signal. This imposes a limit upon the weakest signal which can still be received. Noise voltages contributed by subsequent stages of the receiver are of minor importance compared with that produced in the input stage.

(9) It is not the absolute value of the signal strength at the input of a receiver, therefore, that determines the usable sensitivity, but rather the ratio of that signal strength to the strength of all interfering noise (internal and external) that appears along with the signal. This ratio of signal strength to noise at the input of a receiver is called the *signal-to-noise ratio*. It is this ratio that limits the maximum sensitivity of a receiver. Since noise is distributed more or less uniformly over the entire frequency spectrum, the signal-to-noise ratio is dependent on the bandwidth which must be passed by the receiver. The signal-to-

noise ratio is improved when the bandwidth is cut down to the minimum necessary for acceptable intelligibility.

f. Reradiation Suppression. Another important function of the r-f amplifier stage in receivers is the suppression of radiation of electromagnetic energy occurring in subsequent stages of the receiver. It will be seen later that the regenerative detector circuits frequently used in trf receivers are capable of radiating appreciable energy. If such an oscillating detector were connected directly to the antenna in the input of the receiver, it would radiate a fairly strong signal via the antenna which acts as its load. With the r-f stage interposed between the antenna and detector, this cannot happen, and the stage functions as an *isolating* or *buffer* amplifier. Direct radiation from the oscillating detector is prevented further by shielding the entire receiver.

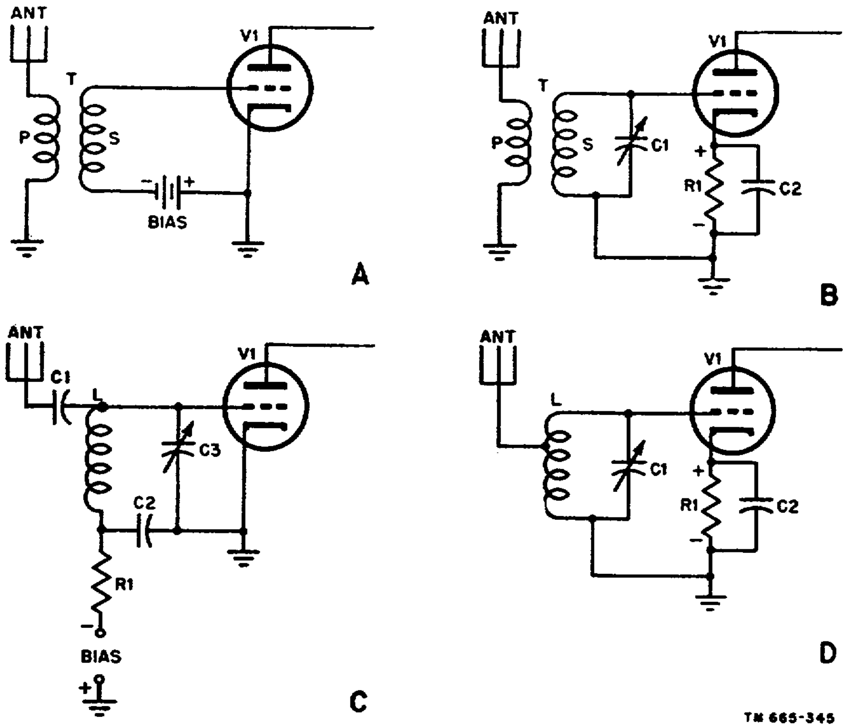

Figure 159. Typical antenna-coupling circuits.

107. Antenna Coupling

The antenna-coupling system (fig. 159) transfers the signal intercepted by the antenna to the grid of the first amplifier tube in the receiver. Since the antenna input in general has a low impedance, and the grid circuit of the amplifier tube has a very high impedance, the antenna-coupling system serves also as an impedance-matching device to produce efficient energy transfer.

a. An *untuned* transformer-coupling arrangement is shown in A of figure 159. This arrangement, if properly designed, has a fairly good frequency response over the entire frequency range of the receiver. However, compared with the tuned r-f transformer, it has poor selectivity and considerably less sensitivity. Resistance-capacitance coupling is used occasionally, instead of the transformer, T, with a consequent improvement in uniform response of the receiver over the frequency range.

b. By far the most common antenna-coupling arrangement is the conventional tuned r-f transformer, shown in B. The secondary windings of transformer *T* are tuned to the desired signal frequency with variable capacitor *C*1, whereas the primary usually is untuned. Because of circuit resonance, this results in improved selectivity and sensitivity. In addition, a voltage step-up of approximately 6 to 8 is possible between the primary and secondary coil of the transformer. The bias voltage for *V1* is developed across resistor *R1*. *C2* is an r-f bypass capacitor.

c. If the signal intercepted by the antenna is weak, greater coupling may be desirable between the antenna and grid. This can be accomplished by the capacitive and direct input coupling arrangements shown in C and D, respectively. In C, the amount of coupling between the antenna and the tank circuit is determined by the ratio of the reactances of coupling capacitors *C1* and *C2*, which form an a-c voltage divider. In D, the same result is achieved by connecting the antenna directly to a tap on tank circuit coil L. Although having good sensitivity, both circuits have poor selectivity. Another variation of direct coupling is the *loop antenna*, which is sometimes used because of its directional effect. Here, a coil of wire making up a loop comprises the inductance of the first tuned circuit in the receiver.

108. Interstage Coupling

Three basic types of coupling are in use between r-f amplifier stages—transformer coupling, impedance coupling, and resistance-capacitance coupling (fig. 160).

a. The conventional transformer-coupled circuit is illustrated in A; this is the most widely used arrangement. The untuned primary of transformer *T* in the plate circuit of *V1* is coupled to its tuned secondary in the grid circuit of the next r-f stage, *V2*. The information given concerning the voltage step-up and selectivity of the tuned transformer-coupled antenna arrangement, in B, applies here also. Transformer coupling is the sim-

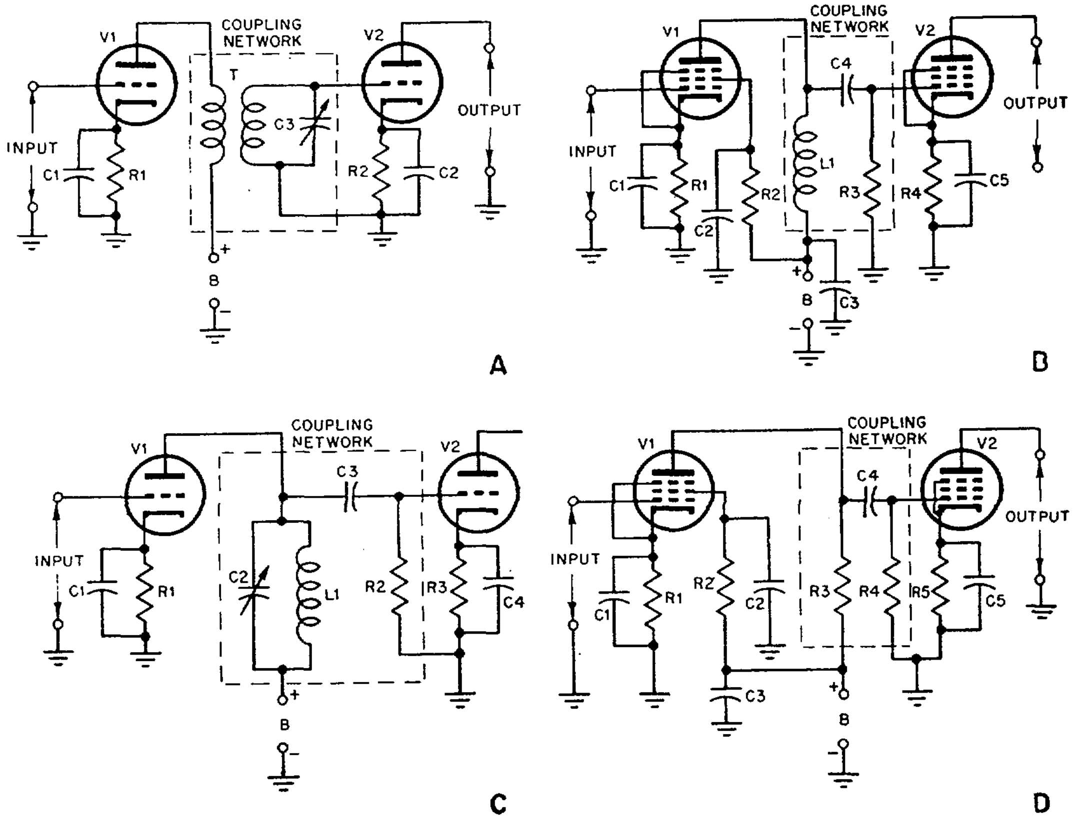

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Figure 160. Interstage coupling circuits.

plest, and, in general, the most satisfactory arrangement.

b. Impedance coupling is used occasionally between r-f amplifier tubes, especially with pentodes. In B, *L*1 represents an r-f choke which is the plate load of *V*1. The voltage developed across *L*1 is coupled through capacitor *C*4 to the grid input resistance *R*3 of the next stage, *V*2. Since *L*1 is untuned, the gain of the stages should be fairly uniform over the entire tuning range of the receiver. In practice, uniform amplification cannot be achieved, since the choke resonates at some frequency with the distributed capacitance of the coil and the input capacitance of *V*2. The result is a reduction in gain above and below the resonant frequency of the choke. In the tuned impedance coupling circuit, in C, the tuned circuit, *C*2*L*1, is the plate load of amplifier *V*1. Maximum signal voltage is developed across the load when *C*2 is adjusted so that the tank circuit resonates at the frequency of the desired signal. This signal voltage is coupled to the grid of *V*2 through coupling capacitor *C*3 which has a low reactance to the signal frequency but blocks the d-c. The grid signal voltage of *V*2 is developed across input resistor *R*2. In some practical examples, a fixed tuning capacitor is used for *C*2, and tuning is accomplished by a molded iron dust magnetic core which can be moved in and out of coil *L*1. This method is known as *permeability* or *slug tuning.* Excellent *Q*'s for the tank circuit can be obtained even at fairly high frequencies with specially developed iron-dust magnetic cores. Permeability tuning often is used in connection with push button fixed-channel tuning.

c. An untuned resistance-capacitance coupled circuit is shown in D. Pentodes are used instead of triodes to produce a large voltage gain. The signal variations at the output of *V*1 are reproduced across the plate load resistor *R*3. This signal voltage is coupled to the grid of *V*2 through coupling capacitor *C*4 which also blocks the d-c voltage from the grid of *V*2. The grid return circuit of *V*2 is completed through *R*4. A resistance-coupled stage sometimes is incorporated into a trf receiver as an inexpensive means of boosting amplification.

109. Shielding

a. The necessity for shielding certain parts of a receiver to prevent radiation has been discussed above (par. 106*f*). An even more important function of shielding is to prevent regenerative feedback of energy and parasitic oscillation. Feedback and possible oscillations can occur because of stray electromagnetic and electrostatic fields generated by a circuit operating at a relatively high signal level. These may be coupled to a circuit tuned to the same frequency operating at a low signal level in the proper phase to produce oscillation through or around the path completed by this stray coupling. Interstage feedback between the coils in tuned circuits of the receiver is kept to a minimum by using small r-f coils, properly oriented in respect to each other, and shielded in metal inclosures. The tuning capacitors for the various stages are shielded from each other by metal plates to minimize electrostatic coupling. Critical leads in the plate and grid circuits carrying high signal voltages are kept as short as possible and are aften surrounded by shielding braid. Complete stages of the receiver may be placed in metal inclosures to prevent internal and external coupling.

b. In general, the problem of reducing interstage feed-back and external stray coupling resolves itself into careful electrical and physical design of components, correct mechanical layout, and sufficient shielding. Iron commonly is used for shielding audio-frequency circuits, and copper, aluminum, or brass is used for r-f circuits. All shields are connected to the chassis of the receiver, which serves usually as common ground for all connections. Since shields placed around tubes and coils change the resonant frequency of the tuned circuits with which they are associated, all tuning and alinement adjustments must be made with the shields in place.

110. Band Selection Methods

a. Single Control Tuning. Most trf receivers have two or three r-f stages ahead of the detector, all tuned to the same signal frequency. It is convenient to tune all r-f stages together by means of a multiple-section tuning capacitor. On such a ganged variable capacitor, the rotor plates of the individual capacitors are turned with a single tuning knob to the same relative positions in respect to the stationary (stator) plates, so that they all have the same capacitance. If the tuning coils and capacitors are identical, the resonant frequencies of the tuned circuits are the same.

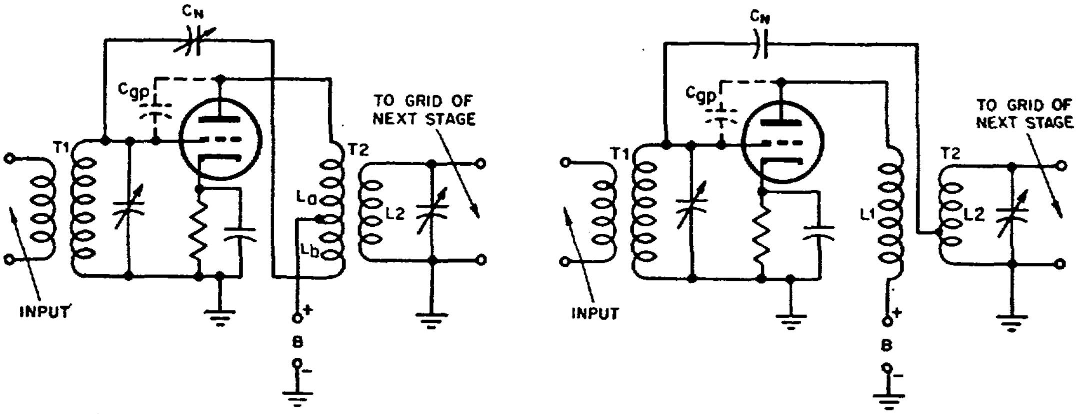
b. Tracking. Because of mechanical difficulties in making the coils and capacitors of the same value, and because of stray circuit capacitances, it is found in practice that the circuits cannot all be tuned to exactly the same frequency for a particular dial setting. To compensate for these irregularities, small *trimmer capacitors* are connected in parallel with each tuned circuit. In receivers having only one frequency band, these trimmers usually are connected in parallel with the ganged capacitor, one for each section. In receivers with several bands, the trimmers are mounted on the individual coils. The trimmers are adjusted or alined at specific frequencies, so that all tuned circuits are in resonance at these frequencies and thus have maximum output. To insure that the tuned circuits remain in alinement at all dial settings, and not only at the particular alining frequencies, additional adjustments are necessary. In some receivers these are provided by means of slotted rotor end plates in the tuning capacitors. Any portion of these slotted plates can be bent closer to or farther away from the stator plates, thus permitting adjustment of the capacitance to obtain correct tuning throughout the frequency range. When all stages of the receiver tune to identical frequencies at all dial settings, they are said to be *tracking.*

c. Band Switching. Each tuned circuit of the receiver is designed to cover a certain frequency range by means of its variable capacitor. Design difficulties limit the maximum frequency range that can be covered with a particular combination of coil and variable capacitor. If a greater frequency range is to be covered by the receiver, the tuned circuits must be modified. This usually is accomplished by substituting another coil in parallel with the same variable tuning capacitor. In some receivers, this substitution is accomplished by using a set of plug-in coils for each desired frequency band. In the great majority of receivers, however, the various coils for different frequency bands are mounted inside the receiver. The leads from each coil are brought out to a multicontact rotary switch, called a band switch. By turning the band switch, any desired frequency band may be selected. In both methods of band selection, the same tuning capacitors are used for all tuning ranges. Tracking or alinement must be carried out separately for each frequency band.

d. Band Spread. To permit separation of many stations which are crowded together on a small portion of the tuning dial, some receivers are provided with *band spread* arrangements. These spread out a small sector of the main tuning dial over the entire scale of a separate tuning dial. Band spread can be electrical or mechanical. In electrical band spread, a small tuning capacitor is connected in parallel with the main tuning capacitor of the tuned circuit. The tuning range of this band spread capacitor is a fraction of that of the main tuning capacitor. Thus, one complete revolution of the band spread capacitor modifies the total capacitance and therefore the resonant frequency of the tuned circuit by only a small amount. In mechanical band spread, a gear train is used between the band spread dial and the main tuning dial. One complete revolution of the band spread dial moves the main tuning dial and capacitor over a small fraction of its range, thus permitting precise tuning.

111. Triode R-F Amplifiers

a. Need for Neutralization. Despite their inherently low gain, triode tubes sometimes are used as r-f amplifiers in trf receivers. Because of their low gain, several r-f amplifier stages must be used to achieve the required sensitivity. It has been found in practice, however, that several triode amplifier stages in cascade tend to be unstable and produce oscillations. The reason for this is the cumulative effect of the feedback of energy from the plate circuit of each triode stage to its grid circuit through the relatively large grid-to-plate capacitance present in the triode tubes. It has been pointed out in the analysis of the tuned plate tuned grid oscillator (ch. 3) that the phase of this feedback depends on the plate-circuit impedance. If the plate circuit is resistive, the feedback energy is out of phase with the grid voltage (degenerative feedback exists), and consequently the gain of each stage is reduced. If the plate circuit is inductive, as is usual, the feedback energy is in phase with the applied grid voltage and regeneration takes place. This increases the gain of the stage by overcoming some of the losses in the grid circuit. If the regeneration is sufficient to overcome all losses in the grid circuit, the effective circuit resistance becomes zero, and oscillation takes place. In most cases, both degeneration and regeneration are undesirable and methods must be used to neutralize the feedback between the plate and grid circuits.

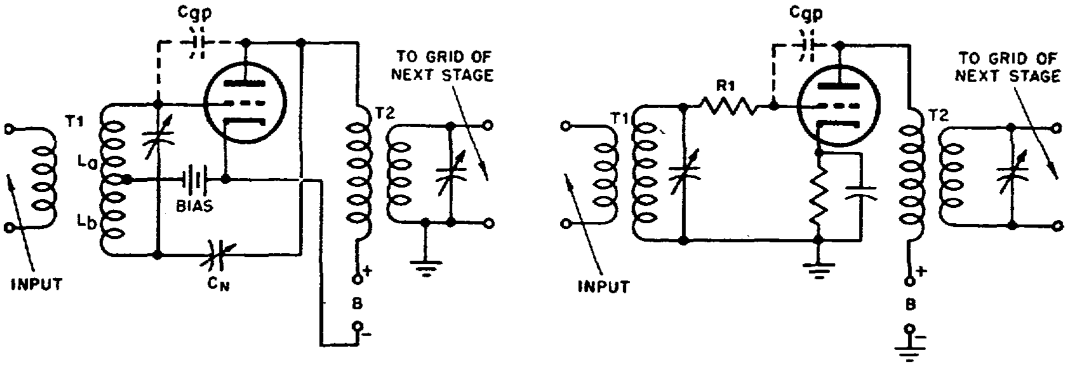


NEUTRODYNE OR HAZELTINE

A

MODIFIED NEUTRODYNE

B



RICE SYSTEM

C

"LOSSER" RESISTOR TO PREVENT OSCILLATION

D

TM 665-347

Figure 161. Typical neutralizing circuits.

b. Neutralization Methods. For effective neutralization, the neutralizing circuit must provide to the grid circuit of each stage a signal voltage from the plate circuit which is equal in magnitude and opposite in phase to the feedback voltage, in order to cancel it completely (fig. 161).

(1) The *neutrodyne* or *Hazeltine* circuit, shown in A, is one of the most frequently used neutralizing circuits. Here, the primary coil of output transformer *T2* is tapped so that the voltage at the lower end of L_b, which is connected to C_N, is 180° out of phase with the plate end of L_a. The energy fed back through neutralizing capacitor C_N is, therefore, out of phase with that fed back from the plate to the grid through C_{gp}. With the proper size of C_N, the neutralizing voltage is equal in magnitude and 180° out of phase with the feedback voltage, and cancels it completely. A modification of the neutrodyne circuit is illustrated in B. Here, the secondary coil, *L2*, of output transformer *T2* is tapped, and a phase reversal takes place between primary coil *L1* and secondary coil *L2*. The neutralizing voltage can be made equal in magnitude and 180° out of phase with

the voltage fed back through C_{gp} by adjusting the tap on $L2$.

(2) In the *Rice system* of neutralization, in C, the neutralizing capacitor, C_N, has a value such that the current flowing through it as a result of the plate circuit voltage equals that flowing through the grid-to-plate capacitance, C_{gp}. Since the the secondary of $T1$ is tapped, the currents through C_{gp} and C_N are in phase opposition and so neutralize each other.

(3) The circuit shown in D is designed to prevent oscillation by absorbing some of the energy fed back through C_{gp} in a *losser* resistor, $R1$, but it does not neutralize this energy. The ohmic value of $R1$ is a few hundred ohms and is connected in series with the control grid. Normally, the grid is biased negatively and no current flows through the losser resistor in the absence of oscillations; consequently, no loss in gain or selectivity takes place. If oscillation takes place, however, the grid is driven positive, and a current flows through the grid resistor. The presence of the resistor directly in series with the oscillating circuit causes electrical losses which tend to damp out the oscillations. The resistor, while not canceling out the feedback energy, tends to hold it below the level of regeneration required for oscillation. The grid resistor also tends to keep the gain over the frequency band more uniform, by absorbing more energy at the higher frequencies.

112. Advantages of Pentodes

The development of the tetrode tube, with the screen grid acting as a shield between the plate and control grid, has made neutralizing circuits in trf receivers unnecessary. It also raises the gain for each stage of the receiver, and thus permits the use of fewer amplifier stages for the same over-all sensitivity. Further improvement in the performance of r-f amplifiers is provided by modern high-gain pentodes. These provide greater gain per stage than any other type of r-f amplifier tube. The grid-to-plate capacitance of pentodes is reduced to a negligible value by the action of the screen and suppressor grids. R-f pentode amplifiers provide very high usable stage gains without regenerative feedback or oscillation. The majority of r-f pentodes in receivers are of the *variable-mu* or *remote cutoff* type, a feature which permits the use of avc (automatic volume control) with little distortion.

113. Detection

Detection is the process of extracting the transmitted intelligence from the modulated carrier wave. The detection or demodulation process consists of separating the audio-frequency variations from the radio-frequency carrier, and then discarding the carrier. In amplitude modulation, this is accomplished by first rectifying the modulated radio signal to obtain a pulsating direct current varying in magnitude in accordance with the original signal. These pulsations are then smoothed out with a filter, and the r-f carrier is discarded. The detector circuit combines these functions in a single stage. This action has been discussed in connection with the crystal receiver. Depending on their use and operation, detectors, in general, are characterized by such terms as *power*, *square-law*, and *linear*. A power detector is designed to rectify relatively large r-f signal voltages; a weak-signal detector is intended for a small r-f signal input. A linear detector develops a rectified output proportional to the amplitude of the r-f input voltage, whereas the output of a square-law detector is proportional to the square of the amplitude. Weak signal detectors are always of the square-law type, and power detectors usually are linear. Various types of detectors have been developed, each having certain advantages and limitations, depending on application. The most important and most frequently used types are the grid leak detector, the plate or bias detector, the infinite-impedance detector, and the diode detector.

a. Grid Leak Detector.

(1) In figure 162, which illustrates the circuit of the grid leak detector, A and B show a triode and pentode circuit, respectively. The action of both circuits is the same, but the pentode provides more amplification. In both, detection of the modulated signal takes place in the control grid-to-cathode portion of the tube, and amplification is achieved in the grid-to-plate portion. To illustrate the different possibilities, A shows an L-C filter and transformer coupling, and B uses an R-C filter and resist-

ance-capacitance coupling. Either method of filtering is feasible.

(2) In A, the triode grid and cathode are operated like a diode rectifier. The grid leak resistor, R_g, represents the load for the rectifier; grid capacitor C_g acts as a bypass for r-f. Assume that an r-f signal voltage, as in C, is present at the primary of $T1$ and is applied through C_g between the grid and cathode of tube $V1$. Initially, the tube has zero bias. When the signal input voltage drives it positive, the grid draws current. The grid current, which flows from the control grid through R_g, the secondary of $T1$, and back to the cathode, produces a negative voltage drop across the combination of R_g and C_g, as shown. This voltage drop is the bias for the tube. The relatively high capacitive value of grid capacitor C_g holds its negative charge during the negative half cycles of the signal voltage when no grid current flows. This action is cumulative and tends to bias the tube near cut-off. Consequently, plate current flows during the positive half cycles of the r-f signal and not during the negative half cycles.

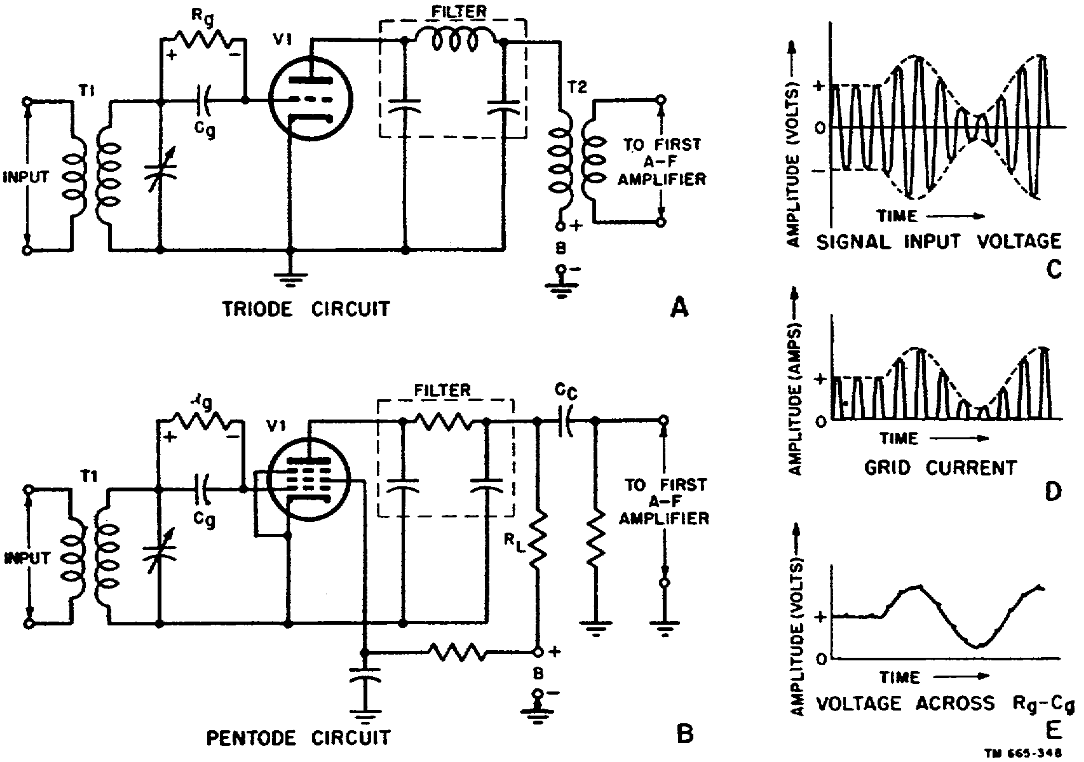


Figure 162. Grid leak detector.

(3) During the positive half cycles of the signal, grid current flows as in D. This pulsating d-c grid current produces a varying voltage across R_gC_g and consequently a varying negative bias. Because of the r-f filtering action of R_gC_g, however, this bias varies at the audio frequency of the modulation rather than at the frequency of the r-f carrier. The time constant (R_g times C_g) is chosen so that the charge on C_g leaks off very slowly through R_g and, therefore, cannot follow the rapid variations of the r-f carrier. However, it is capable of following the slower a-f variations of the modulation. Consequently, the voltage across C_g re-

produces only the *peaks* of the r-f carrier, as shown in E. Since the amplitude of these peaks varies as the a-f modulation, the voltage across C_g and, therefore, the bias also follow the modulation. This varying bias, or modulation, on the grid of the tube appears in amplified form in the plate circuit. An increase in bias decreases the plate current, and a decrease in bias increases the plate current. The r-f component of grid voltage also is amplified and appears at the plate. The a-f modulation component of the plate current, therefore, must be separated from the r-f component by a suitable *R-C* (resistance-capacitance) or *L-C* filter in the plate circuit. Freed of the r-f, the audio component then is coupled to the grid of the first a-f amplifier tube.

(4) As a weak signal or square law detector, the tube is operated at a low plate voltage and R_g is chosen between 1 and 5 megohms, with C_g having a value between 100 and 300 $\mu\mu$f. In this application, the grid leak detector is extremely sensitive for weak signals. Because of square law operation, however, the output is considerably distorted. With strong signals, the positive grid current overloads the tube, and additional distortion results. Also, since current is drawn from the tuned imput grid circuit for rectification, the selectivity of the tuned circuit usually is low.

(5) Less distortion of strong signals occurs if the circuit is operated as a grid leak power detector. For this application, the tube is operated at a higher plate voltage, R_g is reduced to approximately 100,000 to 500,000 ohms, and C_g is from 50 to 100 $\mu\mu$f.

b. *Plate Detector.*

(1) In a plate detector (fig. 163), rectification of the modulated r-f signal takes place in the plate circuit of the tube. A shows a typical circuit, with its principle of operation illustrated in B. The cathode bias resistor, R_k, is made sufficiently large to bias the tube near cut-off in the absence of a signal. This places the operating point in the lower bend of its i_p–e_g characteristic. The bypass capacitor, C_k, does not respond to r-f or a-f and therefore holds the bias at a constant value. The effect of applying an r-f signal to the grid of the tube under these conditions is as shown in B. The negative half cycles of the signal voltage drive the tube completely to plate current cut-off. These half cycles, therefore, are eliminated for the most part in the output of the tube. The positive half cycles of the signal drive the tube above the cut-off value, so that plate current flows throughout these half cycles. *In effect, therefore, when* the tube is operating near plate current cut-off, rectification of the r-f signal takes place. Because of the characteristics of the tube, amplification of the positive half cycles also occurs.

(2) The average value of the plate current pulses (shown by heavy solid lines) varies in accordance with a-f modulation of the signal. An r-f filter in the plate circuit removes the remaining r-f carrier component of the signal but permits free passage of the audio modulation, as represented by the average plate current. The a-f output signal then is either resistance- or transformer-coupled to the grid of the first a-f amplifier stage.

(3) For weak signals, the plate detector operates essentially in the curved square law portion of the i_p–e_g characteristic. As a result, considerable distortion of the output waveform occurs. For strong input signals, operation takes place over the more linear portion of the characteristic, and less distortion occurs in the output. The maximum signal-handling ability of the plate detector is limited, however, since the signal voltage must be below the value that would cause the grid to draw current. If grid current is drawn, the sensitivity and the selectivity of the detector are lowered. Another disadvantage of the plate detector is that it does not provide directly a voltage for avc. Pentodes usually are preferred as plate detectors because they provide a larger audio-output voltage triodes.

c. *Infinite-Impedance Detector.*

(1) The infinite-impedance detector circuit (fig. 164) is so-named because its grid in-

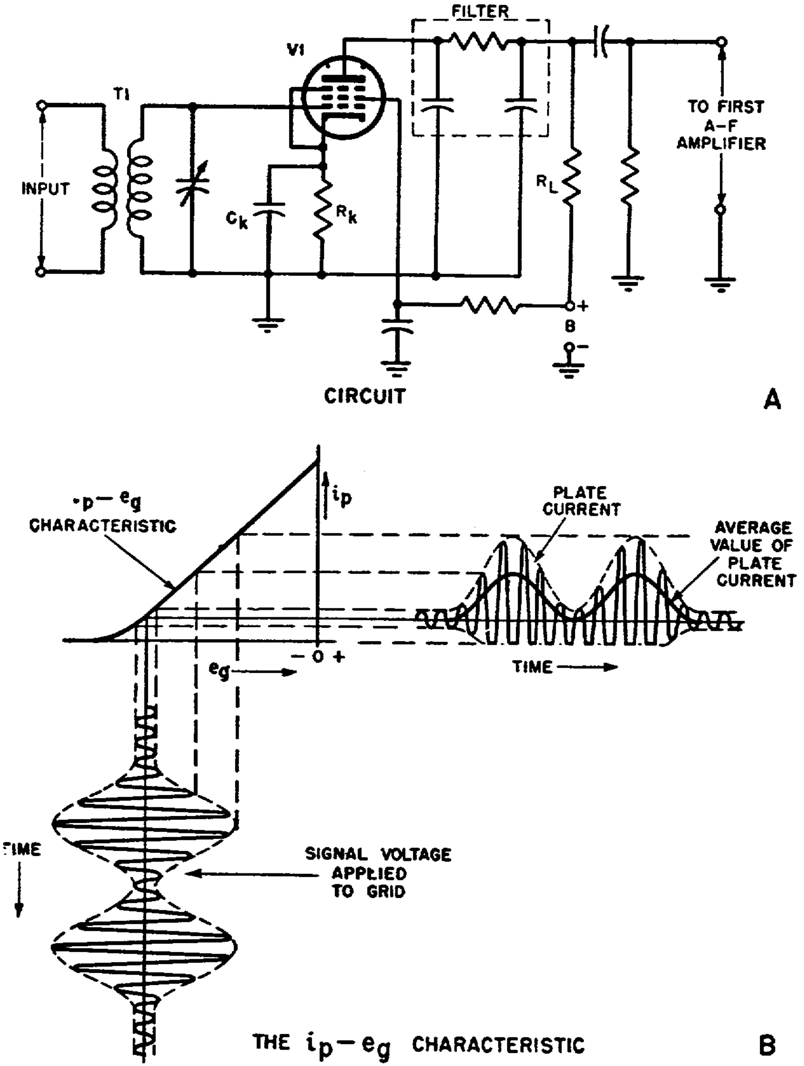


Figure 163. Plate detector.

put has theoretically infinite impedance, since the grid cannot be driven positive, regardless of signal strength, and consequently no grid current is ever drawn. As a result, the selectivity of the circuit is excellent. A further characteristic of the infinite-impedance detector is its good linearity (low distortion), and its ability to handle high signal input voltages.

(2) The circuit resembles that of the plate detector, except that the audio load resistor, *R*1, is connected between the cathode and ground and thus is common to both grid and plate circuits of the tube. Therefore, negative feedback from plate to grid circuit takes place at audio frequencies, which further improves linearity and reduces distortion at all signal levels. Since the output is taken from the cathode circuit, no amplification takes place, and the sensitivity of the circuit, therefore, is low. This is of little im-

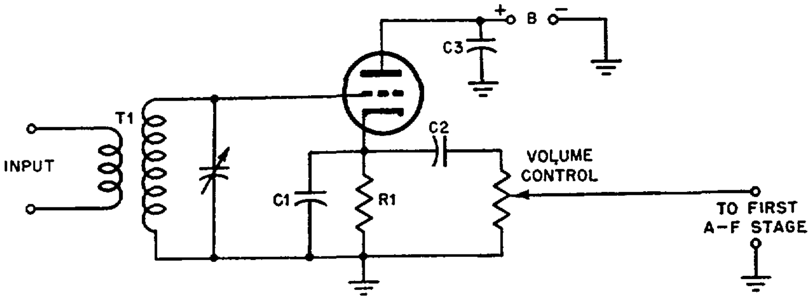


Figure 164. Infinite-impedance detector.

portance in trf receivers using high gain r-f amplifiers ahead of the detector.

(3) The cathode load resistor, *R*1, serves two purposes: It acts as load for the rectified audio signal and it provides automatic bias near plate current cut-off of the tube. As in the plate detector, therefore, the negative half cycles of the signal are cut off, and rectification takes place. The rectified voltage appears across *R*1, and *C*1 filters out the r-f component. The capacitive value of *C*1 is chosen so that it bypasses the r-f fluctuations to ground but does not shunt out the audio-frequency signal appearing across *R*1. The plate is bypassed to ground for both audio and radio frequencies by *C*3. The audio voltage across *R*1 is coupled through *C*2 and the volume control to the grid of the first a-f amplifier stage.

(4) As in the case of the plate detector, the average plate current increases with the amplitude of the signal voltage. With increasing plate current, the voltage drop across *R*1 and consequently the bias also increase. The grid bias, therefore, adjusts itself automatically to the r-f input signal and the grid cannot be driven positive for any value of the signal. This is the reason for the high selectivity and excellent linearity of the circuit, even for very large signal voltages. The chief disadvantage of the infinite-impedance detector, in addition to low sensitivity, is its inability to supply a voltage for conventional automatic volume control circuits. A further disadvantage of the infinite-impedance detector is the fact that when the received signal is so weak that only a low value of signal is applied at the grid of the detector circuit, distortion will occur.

d. Diode Detector. Although having excellent linearity characteristics, diode detectors need a strong signal voltage for efficient operation and have low sensitivity. Their use is confined chiefly to the highly sensitive superheterodyne receivers, where large amplification takes place before demodulation. Diode detectors are discussed in the next chapter.

114. Volume Control

a. Volume or *gain controls* are provided in receivers to permit variation in the receiver sensitivity. This is necessary to compensate for differences in the strength of incoming signals. Volume control can be manual or automatic. The majority of trf receivers use manual volume control, since their gain is low. Automatic volume control is used universally in superheterodyne receivers, and is discussed later.

b. Two basic methods of manual volume control are in use. In one method, the volume of the audio signal is varied by changing the gain of one or more of the r-f amplifier tubes used in the receiver. This is accomplished by changing one of the controlling potentials applied to the tube, such as the grid bias, plate, or screen voltages. In the other method, the gain of the amplifiers themselves is not changed, but the signal is attenuated at some convenient point in the receiver by use of a variable shunt resistor or by tapping a portion of the signal voltage from a potentiometer-voltage-divider arrangement.

c. Figure 165 shows a few commonly used volume control systems. A shows a variable resistor, *R*, connected in parallel with the primary winding of the antenna transformer, *T*1. The lower the value of this resistor, the greater is the shunting effect and the lower the volume of the receiver. The disadvantage of this arrangement is that by shunting the primary of *T*1, the *Q* and, therefore, the selectivity of the first tuned circuit are lowered.

d. In B, the variable resistor, *R*, permits changing the bias and consequently the gain of the r-f amplifier stage. A remote cut-off (variable-mu) pentode is used for this application. Varying the grid bias of variable-mu tubes causes the amplification factor and the gain of the tube to change smoothly. The limiting bias resistor, R_c, prevents the bias of the r-f amplifier stage from being zero when *R* is adjusted to a minimum value. By increasing *R*, the bias is increased and the amplification is reduced. When using this method, the bias voltages of all r-f amplifier stages usually are controlled together. This is achieved by tying the cathodes of the amplifier tubes together.

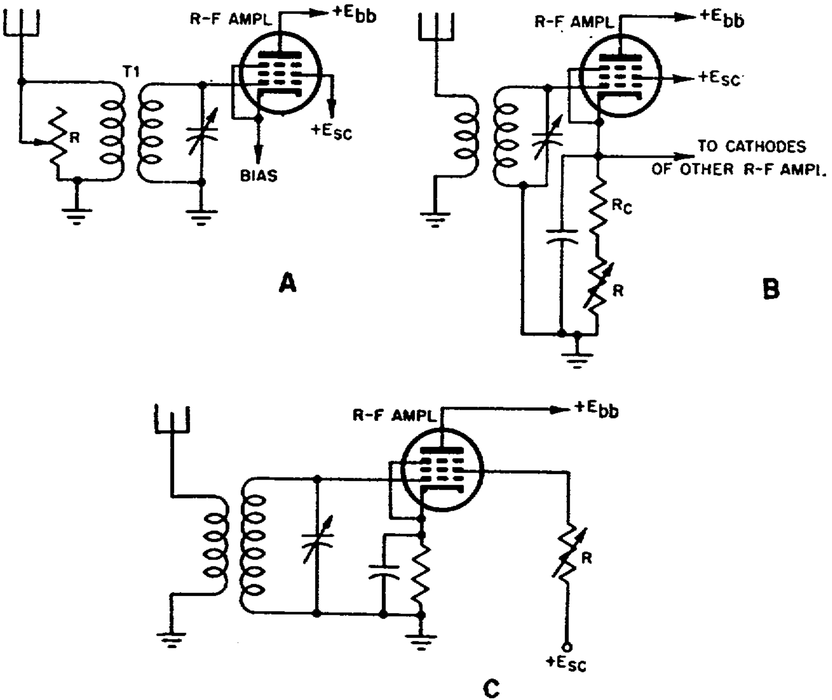


Figure 165. Methods of volume control.

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e. In C, the gain of the r-f amplifier stage is controlled by varying the screen grid current and thus the screen grid voltage. This is accomplished by varying the variable screen resistor, *R*. The same effect can be produced by placing *R* in series with the plate.

115. Audio-Frequency Amplification

After a modulated signal has been detected, the audio-frequency variations usually must be amplified before they can be applied to drive a reproducer. In general, this involves one or more a-f voltage amplifiers and a power amplifier with sufficient output to drive the reproducer. These stages may be combined into a single a-f stage inserted between the detector and reproducer, particularly if a headset is used since it necessitates little audio power. Audio amplifiers and reproducers that are used in trf receivers are of the same type as those used in superheterodyne receivers. They are discussed in the next chapter.

116. Typical Trf Receiver

a. The basic elements of the typical five tube trf receiver (fig. 166) already have been discussed in

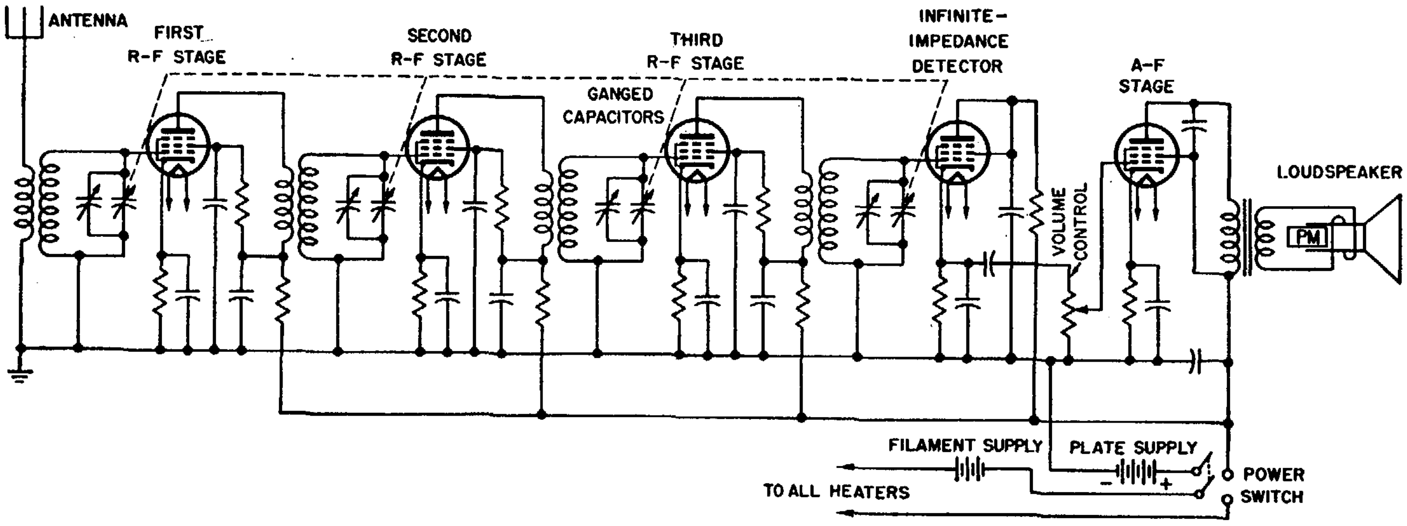

Figure 166. Battery type trf receiver.

CHAPTER 8

SUPERHETERODYNE RECEIVERS

122. Superheterodyne Principles

a. In the trf receivers studied in the last chapter, r-f amplification takes place at the frequency of the incoming r-f signal, and all tuned circuits are adjusted to this frequency. The superheterodyne receiver differs essentially from the trf receiver in that it *changes* the frequency of the received signal to a *fixed* value at which the tuned amplifying circuits can operate with maximum stability, selectivity, and sensitivity. The conversion of the received signal frequency into a lower (i-f) frequency in the superheterodyne receiver is based on the *heterodyne*, or beam, *effect.*

b. It has been pointed out (par. 117) that the trf receiver suffers from several disadvantages inherent in its operation. Since all its r-f stages function at the same frequency, stray coupling between output and input circuits may provide sufficient feedback to cause instability or oscillation. Furthermore, it is difficult to achieve uniform amplification of the r-f stages over the entire frequency range of the receiver. At the higher frequencies, the gain of each stage tends to fall off, and therefore the sensitivity of the receiver is reduced. Finally, the most serious drawback of the trf receiver is that the selectivity of the tuned circuits cannot be kept uniform over the frequency range. At the high-frequency end of the tuning range, the selectivity of the trf receiver decreases markedly. This lack of selectivity can become serious at the higher frequencies generally used in Signal Corps communication systems.

c. The inherent difficulties of the trf receiver are overcome to a large degree in the superheterodyne circuit by conversion of the signal frequency to a lower *intermediate frequency.* This frequency usually has a value below the carrier frequency of the incoming signal. Regardless of the value of the received signal frequency, the signal with its audio modulation is always converted to this fixed intermediate frequency. Then it can be amplified to the desired degree in a fixed-frequency i-f amplifier. This amplifier can be designed to have much higher and more uniform amplification and selectivity per stage over the tuning range of the receiver than is possible with a variable-frequency amplifier.

d. At the lower frequency of the i-f amplifier, it is possible to obtain more amplification than in the trf amplifier without the trf difficulties of feedback and oscillation. Furthermore, the selectivity of an i-f amplifier is considerably greater than that of an r-f amplifier operating at higher signal frequencies. Summing up, the superheterodyne circuit is superior to the trf receiver, because it is more selective, and has higher gain per stage and uniform selectivity and sensitivity. In addition to these advantages, it has fewer variable-tuned circuits and is more easily adapted to multiband reception. For these reasons, superheterodynes have replaced trf receivers in practically all applications.

123. Beat Frequencies

The production of beat frequencies can best be understood by considering first a similar effect with sound waves.

a. When two notes close in pitch (frequency) are sounded at the same time, a throbbing or pulsating sound is heard. These pulsations, or beats, occur at a frequency equal to the frequency *difference* between the two notes and are caused by interference between their sound waves. This effect often is observed when two notes in the lower registers of a pipe organ are sounded together, or when two tuning forks which differ slightly in pitch are struck.

b. The production of a beat note is illustrated in figure 169. Assume that two tuning forks are struck at the same time, one with a pitch of 90 cps,

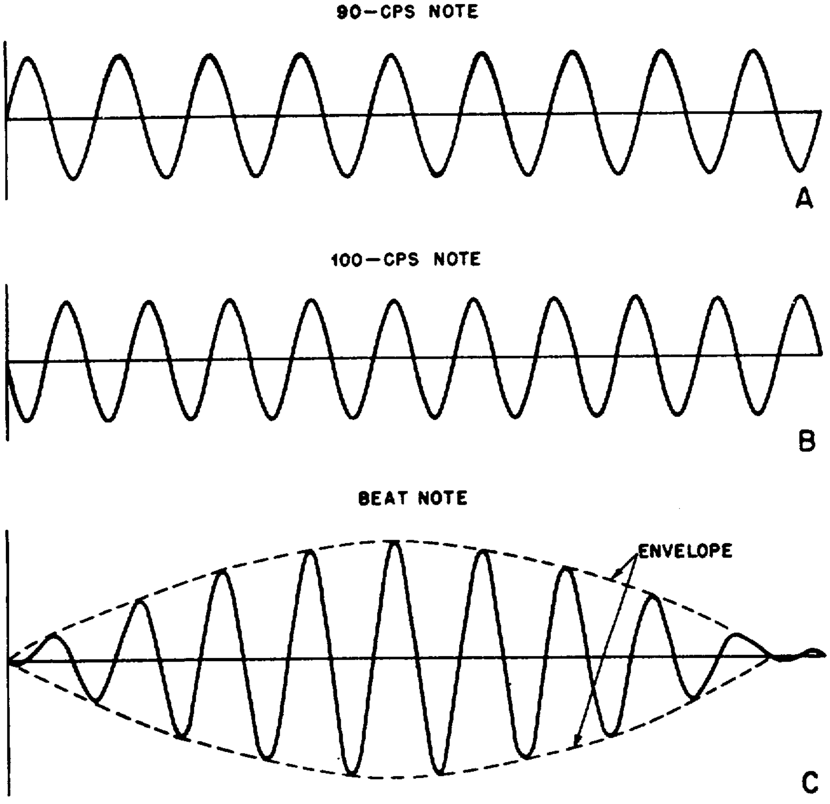

Figure 169. Production of beat frequency.

as in A, the other, in B, with a pitch of 100 cps. The two tones are represented graphically by sine waves; 9 cycles of the 90-cps tuning fork and 10 cycles of the 100-cps fork are given. It is found that the two sound waves interact with each other. Sometimes they are vibrating together (in phase); at other times they are completely opposed to each other (out of phase). Whenever the two waves are in phase with each other, their amplitudes add, and they reinforce each other. Whenever the waves are in opposition, their amplitudes subtract from each other, and the sound waves interfere with each other.

c. In between these two extremes the waves reinforce or interfere with each other in varying degrees. This is clearly brought out in part C. Here the amplitudes of the two tones have been added algebraically to obtain the resultant waveform. Initially, the two notes are in opposition, and their resultant amplitude is zero. After approximately 5 cycles have passed, the forks vibrate in phase, and the resultant amplitude is the addition of the amplitudes of both waves. After approximately 10 cycles, the two notes are again out of phase and the resultant amplitude is zero.

d. As a result of this alternate reinforcement and interference, the two notes will at times swell in volume, and at other times they will be almost inaudible, thus producing beats. As seen from the figure, the frequency of these beats is equal to the frequency *difference* between the two tones. One cycle of the beat note is indicated in C by the contour or *envelope* connecting the peaks of the resultant wave. Actually, with the 90-cps and 100-cps tuning forks, a beat frequency equal to the difference, or 10 cps, is obtained.

e. The principle of beats also applies to alternating currents of different frequency. Two alternating currents can be combined in such a manner as to produce a beat or difference frequency between them. If the beat frequency is within the range of hearing (16 to 16,000 cps, approximately), it can be made audible by transforming it into sound waves, As an example, assume that an unmodulated 1,000-kc radio wave is received in a radio set, and that this signal is mixed with the output of an oscillator operating at a frequency of 1,001 kc. In figure 170, the r-f signal is at A and the oscillator output frequency at B. The resultant waveform is shown at C. It is generated by alternate reinforcement and cancellation as in the case of the two sound waves. The beat note, which is 1,001 kc minus 1,000 kc=1 kc, or 1,000 cps, is represented by the envelope of the resultant signal. If this signal is rectified as in D, and the r-f pulses are filtered out, only the 1,000-cps beat note remains, as in E. The electrical beat frequency then is passed through a loudspeaker or headphone, and becomes audible as a 1,000-cps tone. In principle, this is the process which takes place when a regenerative detector is used in the reception of c-w.

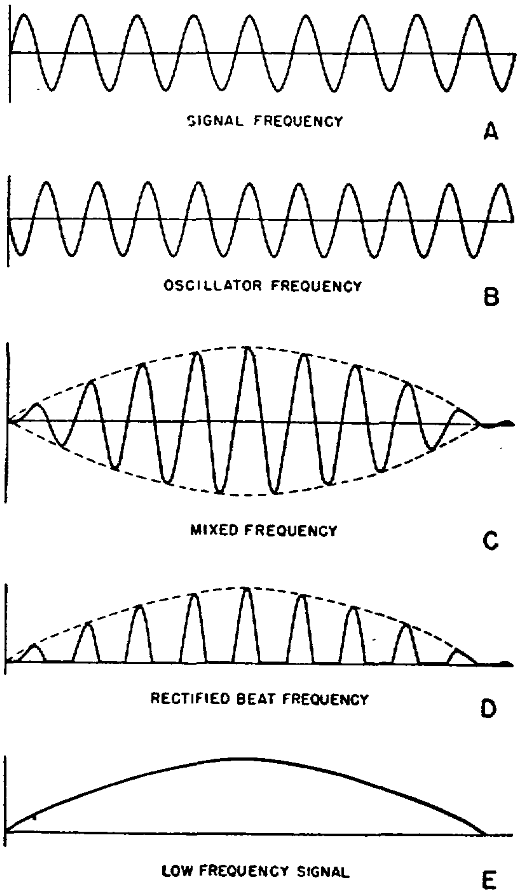

Figure 170. Superheterodyne reception of unmodulated (c-w) signal.

f. The reception of a modulated r-f signal in a superheterodyne receiver takes place essentially in the manner described above (fig. 171). A typi-

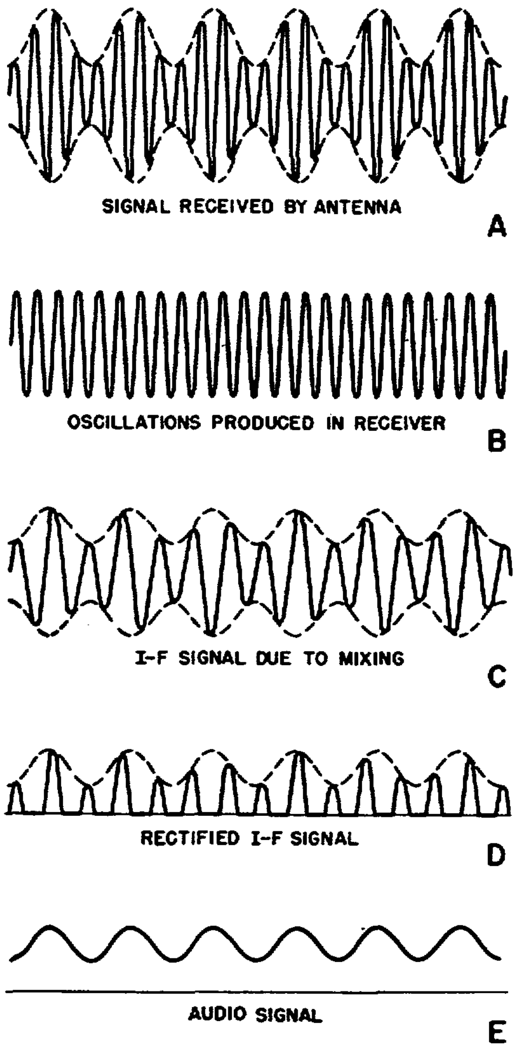

Figure 171. Superheterodyne reception of modulated r-f signal.

cal modulated r-f signal, intercepted by the receiver antenna shown in A, is amplified to a useful level with an r-f amplifier. In B, it is mixed with the output of a local oscillator which is a continuous wave of a frequency differing from the incoming signal frequency by an amount equal to the desired difference, or intermediate, frequency. It does not matter whether the frequency of the local oscillator is higher or lower than the r-f signal frequency, so long as the difference between the two is equal to the correct intermediate frequency.

g. For example, if the frequency of the incoming signal is 1,500 kc and the desired intermediate frequency is 455 kc, a common value, then the frequency of the local oscillator can be either 1,500 plus 455=1,955 kc, or 1,500 minus 455=1,045 kc. In either case, an i-f equal to the difference of 455 kc is produced. The intermediate frequency always is chosen well above the highest audio-frequency component in the desired signal, since otherwise considerable distortion of the desired intelligence would result. The result of mixing the modulated r-f signal with the output of the local oscillator is shown in C. An intermediate difference, or beat, frequency is generated as before. The amplitude of the beats, however, varies in this case as the amplitude of the modulated wave. In other words, the *envelope of the i-f (intermediate-frequency) signal reproduces the modulation of the received r-f signal.*

h. The higher-frequency modulated radio signal has been converted into a lower-frequency signal which carries the original modulation. The stage of the receiver which accomplishes this result is known as the *mixer* or *first* detector. The modulated i-f signal then can be amplified to the required level by one or more stages of i-f amplification. It is rectified and filtered in a conventional detector, as in D, sometimes called the *second* detector, so that only the audio modulation corresponding to the envelope of the rectified i-f signal remains, as in E.

124. Characteristic of Mixer

a. Two alternating currents of different frequency produce a beat frequency when they are combined in a suitable mixer. If two alternating currents differing in frequency are fed into a resistance load, *no resultant beat frequency is produced.* The two currents combine in a complex wave, but this wave has no new additional frequencies. As far as the resistance is concerned, each current is separate, and no interaction takes place because a resistance is a *linear* device; that is, the current flowing through it is directly proportional to the voltage across it (Ohm's law). The voltage-current characteristic of any linear device can be represented by a straight line, as in A of figure 172. The slope of the line is equal to E/I, or R.

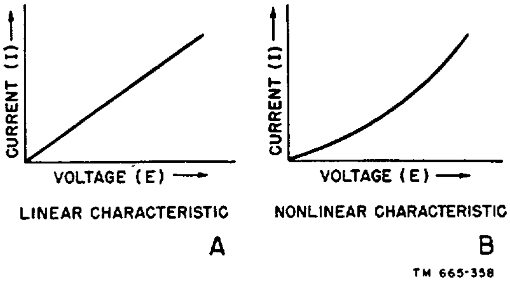

Figure 172. Required mixer characteristic

b. It is a fundamental fact that a device with a linear characteristic produces no interaction between currents of different frequency, and, therefore, no beat frequencies. Mathematical analysis shows that a *nonlinear* voltage-current characteristic, shown in B, leads to production of new frequencies in the output which are not present in the input. If two alternating currents of different frequency are impressed on a nonlinear device, they interact to produce a beat or difference frequency in the output. This is not the only additional frequency produced in the output of a nonlinear device. For example, if the output current of a device varies as the *square* of the applied voltage (such as in a square-law detector), the following prominent frequencies are produced as a result of applying two sine waves at different frequencies:

(1) The original frequencies of the applied alternating currents.
(2) Frequencies twice the value of the applied frequencies.
(3) A frequency equal to the *sum* of the original applied frequencies.
(4) A frequency equal to the *difference* of the two applied frequencies.

c. If the nonlinear device follows a more complex relationship between input and output, many additional frequencies also will be present in the output. For superheterodyne reception, only the sum or difference frequency is of interest, and all other frequencies in the output of the mixer must be filtered out. Many devices have a nonlinear voltage-current characteristic. One of the simplest is the ordinary vacuum tube when operated along the curved part of its characteristic curve.

125. Selectivity

a. The superheterodyne receiver provides much greater selectivity than any other type of receiver. The heterodyne principle assures a sufficient relative frequency separation, even for very closely spaced adjacent carriers. For example, assume that a desired signal of 4,000 kc and an undesired signal of 4,040 kc are both present in the input of the receiver. The actual separation between these signals is 40 kc, and the percentage of frequency separation is 4/400 times 100=1 percent. The tuned circuits of a trf receiver would have great difficulty in separating two signals with only a 1-percent relative frequency separation, and interference should be expected.

b. In a superheterodyne receiver, the situation is entirely different. Assume that the receiver has an intermediate frequency of 455 kc. To produce this difference frequency for an incoming signal of 4,000 kc, the local oscillator must be tuned to a frequency of 4,000 plus 455=4,455 kc. After mixing the two signals, the difference frequency, or i-f, is then 455 kc. The undesired signal of 4,040 kc also beats with the local oscillator to produce a difference frequency of 4,455 minus 4,040=415 kc. At the input to the i-f amplifier, which is tuned to 455 kc, both the 415-kc and the 455-kc beat frequencies are present. The *numerical* separation between these signals is still 40 kc (455 minus 415), but the percentage of frequency separation is now 40/455 times 100, or about 9 percent. The relative frequency separation between the two signals and the selectivity of the receiver, therefore, have been greatly increased.

c. It must be remembered that this relative improvement in selectivity is in addition to the gain in selectivity achieved by circuit improvements, which are discussed in a later paragraph. At the lower intermediate frequency, the losses in the tuned circuits of the superheterodyne are substantially lower than in a trf receiver. The resonance curve, therefore, is sharper, and the selectivity also is increased by this factor.

126. Basic Superheterodyne Receiver
(fig. 173)

a. In the order in which a signal passes through the receiver, the basic stages for a-m superheterodyne reception are:

(1) An antenna for intercepting the signals from a transmitter.

(2) A variable-tuned r-f amplifier stage for selecting the desired signal. The r-f amplifier is not absolutely essential for superheterodyne reception, but its presence improves the signal-to-noise ratio and adds other desirable characteristics that will be discussed.

(3) A mixer in which the r-f signal is combined with the output of a local oscillator to generate an intermediate-frequency signal.

(4) A local oscillator for generating the signal which beats with the r-f signal. This can be any one of the conventional oscillators discussed in chapter 3.

(5) An i-f amplifier section consisting of one or more stages for amplifying the i-f signal from the mixer.

(6) A detector circuit for demodulating the i-f signal.

(7) An a-f power amplifier consisting of one or more stages for amplifying the audio-frequency output of the detector to a value sufficient to drive a loudspeaker or headphones.

(8) A loudspeaker or headphones for converting the electrical audio-frequency variations into sound waves corresponding to the original audio energy which modulated the r-f signal at the transmitter.

b. The fundamental operation of the superheterodyne receiver for the reception of a-m signals is as follows (fig. 173):

(1) Modulated r-f signals from many transmitters are intercepted by the antenna. They are coupled through an antenna input transformer to the first stage of the receiver, usually a variable-tuned r-f amplifier.

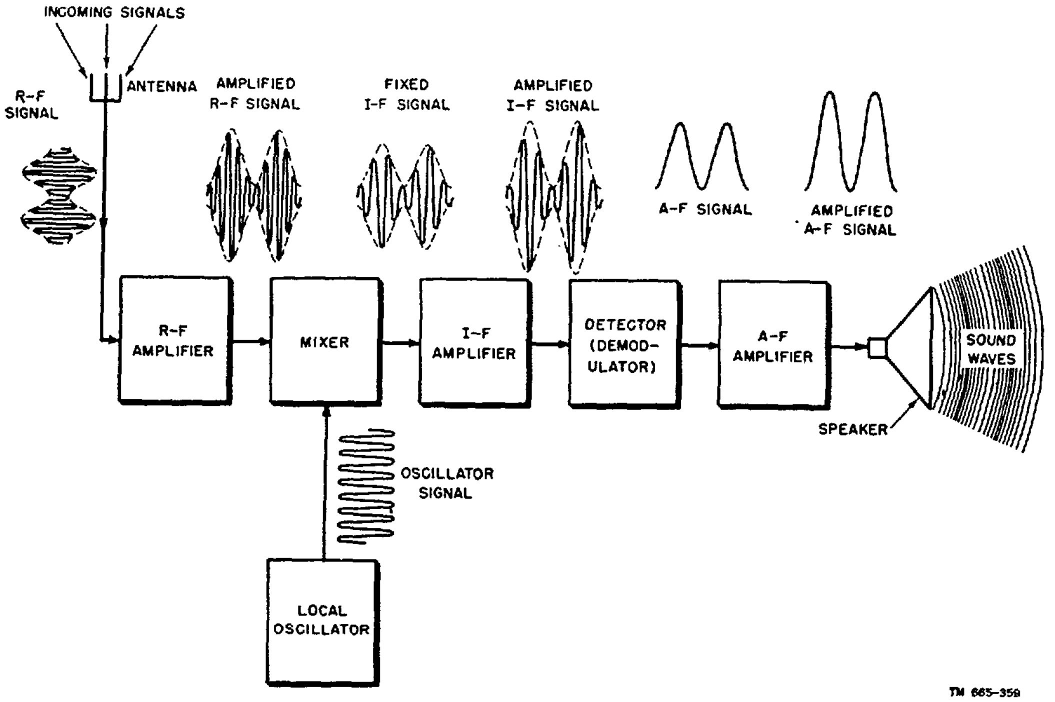

Figure 173. Block diagram of basic superheterodyne receiver.

(2) The desired r-f signal is selected by the tuned circuit of the r-f amplifier. This signal is amplified, and all other signals are rejected to some degree.

(3) The amplified r-f signal is coupled to the input of the mixer stage, where it is combined with the output of the local oscillator. In this process of heterodyning, a beat frequency equal to the difference between the r-f signal and local oscillator frequencies is produced. The frequency of the local oscillations is chosen either above or below (usually above) the r-f signal frequency by the required amount, so that the difference frequency is the desired i-f. The resulting i-f signal contains the *same modulation* as the original r-f signal.

(4) The i-f signal is amplified in the fixed-tuned i-f amplifier stages and is coupled to the input of the detector.

(5) The detector stage removes the audio modulation contained in the i-f signal and filters out the i-f carrier, which is no longer needed.

(6) The resulting audio signal is amplified to the level required for energizing an electromechanical reproducer.

(7) The electrical audio variations are converted into the corresponding sound waves by the reproducer (loudspeaker or headphones).

127. Frequency Conversion

a. General.

(1) The oscillator and mixer circuits together achieve the frequency conversion of an r-f signal to an intermediate frequency. Various methods and circuits exist for accomplishing this. All these arrangements are similar in that they use the nonlinear characteristic of a vacuum tube for mixing the r-f signal and local-oscillator frequencies. The plate current of the mixer tube is varied to produce a voltage of the desired intermediate frequency across the primary of a tuned i-f transformer. The secondary of this transformer is coupled to the grid of the first

i-f amplifier stage. The methods for frequency conversion differ chiefly in the types of tubes used and in the manner in which the signal and oscillator voltages are injected into the mixer tubes.

(2) Two methods are used to produce the desired frequency conversion. In one, a separate oscillator tube (usually a triode) is used to produce the local oscillations. The output of this tube is injected into another tube by some means of coupling. The incoming r-f signal also is injected into this second tube along with the local oscillations. The two signals can be injected into the second tube at the same point or at different points, where they combine to produce the intermediate frequency (among others) in the output. The tube in which the two signals are combined is called the *mixer*. The distinguishing feature of this method is that *two* separate tubes are used.

(3) In the second method only *one* tube, known as a *converter*, is used. The oscillator and mixer tubes are combined into a single tube which performs both functions. In the usual arrangement, the r-f signal is injected at one electrode, the local-oscillator signal being injected at some other electrode. There are also converter-tube types in which both signals are injected at the same electrode. The advantage of this method is that only one tube is necessary.

b. Terms.

(1) Certain characteristics are referred to when describing the performances of mixers and converters in frequency-conversion systems. One of these is the *conversion transconductance*, G_c, which is defined as the ratio between the i-f current in the output of the frequency converter and the r-f signal voltage,

$$G_c = \frac{i\text{-}f \text{ output current}}{r\text{-}f \text{ input voltage}}.$$

where G_c is in mhos (reciprocal of ohms) when the current is in amperes and the voltage in volts. G_c usually is in micromhos, which is mhos divided by 1,000,000. Representative values range from 300 to 950 micromhos. The conversion transconductance is an important quantity because the gain of the stage depends on the value of G_c; the higher this value the greater the gain.

(2) The amplification achieved in the frequency converter is called the *conversion gain*, or translation gain. It is defined as the ratio of the i-f output voltage to the r-f input voltage,

$$\text{Conversion gain} = \frac{i\text{-}f \text{ output voltage}}{r\text{-}f \text{ input voltage}}$$

This gain must be high in order to have amplified output from the tube. The conversion gain also can be shown to equal the conversion transconductance multiplied by the total load impedance on the tube. In order to have high gain, a tube with a sharp cut-off characteristic must be used.

(3) Another feature desired in frequency converters is control of amplification by means of a remote, or gradual, cut-off characteristic. This is in conflict with the need to have a sharp cut-off characteristic for high conversion gain. Therefore, either a compromise must be made, *or* a specially designed tube used which incorporates both remote and sharp cut-off characteristics.

(4) A high signal-to-noise ratio is another important desired characteristic. All frequency converters introduce a certain amount of noise, reducing the over-all signal-to-noise ratio of the receiver. Tube noise usually is measured in terms of equivalent grid resistance. The higher the noise produced, the higher the resistance. Tubes operated as converters have higher equivalent grid resistance than when the same tubes are operated as ordinary amplifiers.

(5) A highly desirable characteristic in frequency converters is that there be a minimum of interaction between the local-oscillator and r-f signal circuits. This interaction results in a change in oscillator frequency, called *pulling*, under certain conditions. In order that the local oscillator have maximum frequency stability, it is necessary to isolate it from the r-f signal circuits.

(6) Other desirable characteristics in frequency converters are low input conductance at high frequencies, high plate resistance, and minimum amount of space-charge coupling. All of these terms are discussed in connection with specific circuits for frequency conversion.

128. Simple Converter
(fig. 174)

a. Before the development of modern pentagrid converters, separate mixers and oscillators were used universally. Ordinary triodes and pentodes make excellent mixers, especially at high frequencies, and they still are used to a considerable extent.

b. The mixer tube functions as an ordinary plate detector biased approximately to cut-off. The tank circuit at the input of the mixer is tuned to the frequency of the incoming r-f signal. The oscillator grid tank circuit is tuned above (or below) the r-f signal frequency by an amount equal to the intermediate frequency. The i-f transformer in the plate circuit of the mixer is tuned to the desired difference frequency. The oscillator and mixer tuning capacitors are ganged together to permit single-control tuning.

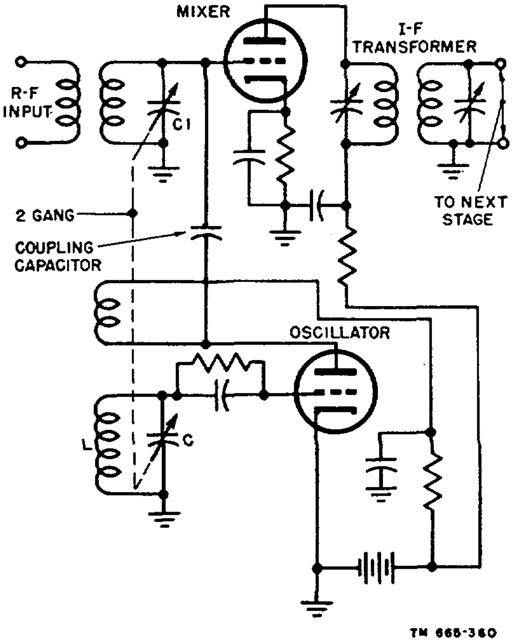

Figure 174. Triode oscillator and triode mixer.

c. A conventional tickler feedback oscillator is used in this frequency-converter circuit. Any other type also can be used as a local oscillator. For a properly designed mixer, very little power is drawn from the local oscillator. Oscillations from the plate circuit of the oscillator are coupled to the grid of the mixer by means of a coupling capacitor, a method known as *grid injection.* The oscillator voltage applied to the grid of the mixer tube should be as large as possible for maximum conversion gain. However, to avoid overloading, the sum of the oscillator and signal voltages impressed on the mixer grid should not exceed the grid bias. If the mixer is overloaded by driving the grid positive, both the gain and the input selectivity of the stage are reduced.

d. Any convenient means can be used to couple the oscillator voltage to the grid of the mixer tube. The amount of coupling should remain approximately constant as the oscillator frequency is varied so that the voltage injected at the mixer grid remains about the same over the frequency range. In figure 175, A and B illustrate two alternate coupling methods frequently used. In A, the oscillator output is inductively coupled to the cathode of the mixer. *Cathode injection* is very popular, because complete modulation of the mixer plate current is easily attained in this way. Both the oscillator signal coupled into the cathode circuit and the r-f signal injected into the grid circuit cause variations in the mixer plate current. The two different frequency components of the plate current beat together and generate the difference frequency (i-f). Interaction between the mixer and oscillator portions is somewhat less when cathode injection is used as compared with grid injection.

e. Inductive coupling between the oscillator and mixer is illustrated in B. The tank coil of a Hartley oscillator is directly coupled to the tank circuit in the input of the mixer. The method is equivalent to the capacitive grid injection in figure 174. If the oscillator coil is located too far from the mixer input, link coupling can be provided.

f. The simple plate-detector type of mixer performs very well and has the advantage of low cost. Its almost universal use in the early days of superheterodyne radios led to the name *first detector* for the mixer stage, a name still used occasionally to describe other types of mixers also. Mixers using triodes or pentodes are characterized by high conversion gain and good signal-to-noise ratio.

Their relatively low noise level makes them suitable for use at high frequencies. The chief disadvantage of triode or pentode converter circuits is the undesirable interaction caused by coupling between the mixer and oscillator portions. A strong interfering signal at the mixer input, whose frequency is close to the oscillator frequency, tends to make the oscillator synchronize, or *lock in*, with the interference, producing frequency instability. Pulling is especially annoying at higher frequencies where the local oscillator and signal frequencies differ by only a small percentage. The desire to isolate the local oscillator and r-f signal-input circuits from each other led to the development of *pentagrid* mixer and converter tubes.

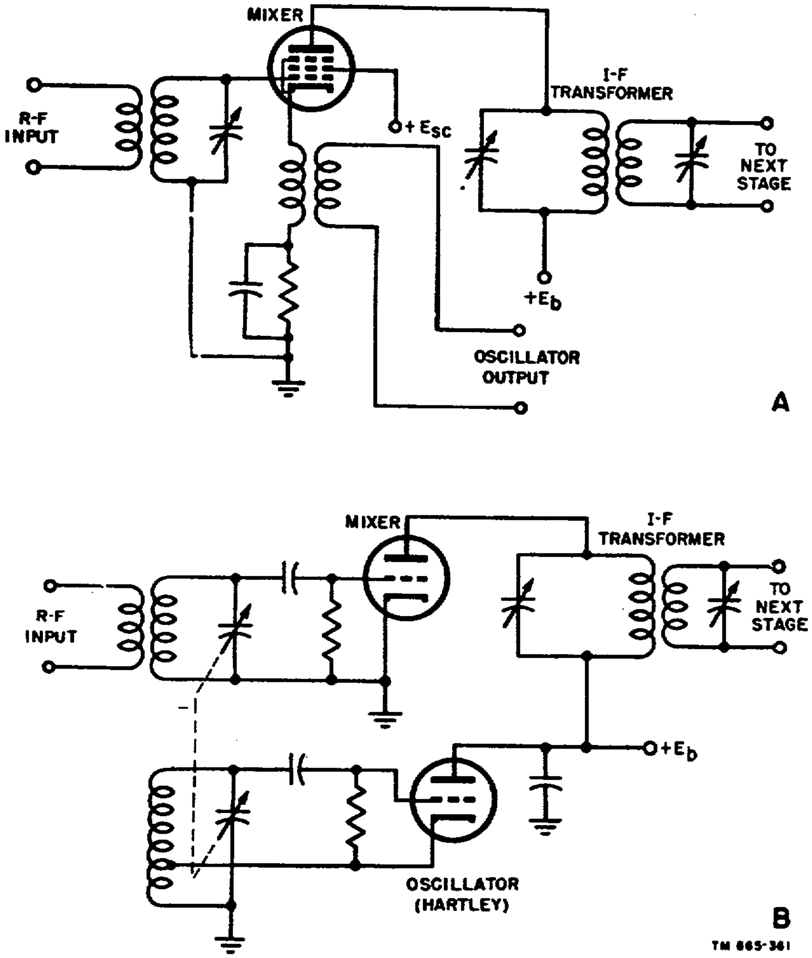

Figure 175. Simple frequency converters (showing different injection methods).

129. Pentagrid Mixer

a. Isolation of the local oscillator from the r-f input circuit is achieved in the *pentagrid mixer*, which is provided with *two* independent control grids, one for the r-f signal and one for the local oscillator signal (fig. 176). The tube contains a heater cathode, five grids, and a plate. Grids 1 and 3 are the control grids to which the r-f signal and oscillator voltages are applied, respectively. Grid 1, known as the *inner* grid, has remote cut-off (variable-mu) characteristic. Grid 3 is an injection grid used for modulating the electron stream in the tube. It has a sharp cut-off characteristic and produces a comparatively large effect on the plate current for a small amount of oscillator voltage. Grids 2 and 4 are screen grids which are connected internally. Their function is to accelerate the electron stream and shield grid 3 (oscillator signal grid) from the other electrodes. Grid 5 is a suppressor grid connected to the cathode, just as in ordinary pentodes.

b. The plate current of the pentagrid mixer is varied by the combined effect of the r-f and local oscillator signals. The r-f signal on grid 1 affects the electron stream as in an ordinary pentode. After being accelerated by grid 2, the electron stream is modulated by the oscillator voltage on grid 3. The arrangement is essentially the same as that of a suppressor-grid modulated amplifier (ch. 5). Excellent isolation of the oscillator section is achieved by the use of electron coupling and the two screen grids around the injection grid. Consequently, the r-f signal circuit has little effect on the oscillator frequency, and pulling is negligible. The addition of screen grid 4 and suppressor grid 5 also helps to increase the plate resistance and gain of the tube to a value similar to that of an ordinary pentode. With grid 3 biased approximately to cut-off in the absence of a signal voltage and an oscillator voltage sufficiently high to drive this grid positive, the conversion transconductance of the tube is about 300 micromhos, only a little less than for other types of converters. The d-c bias for grid 3 generally is obtained by a grid-leak resistance, whereas a cathode resistance is used to bias the signal grid 1.

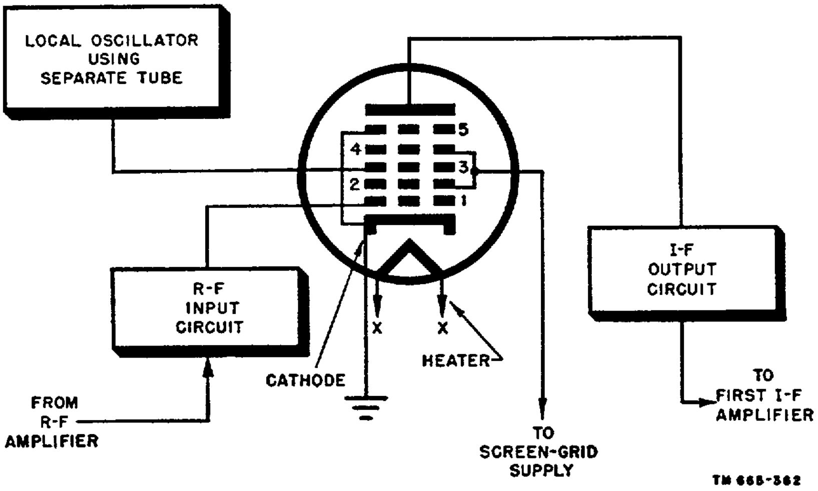

Figure 176. Pentagrid mixer.

c. Figure 177 shows a typical circuit of a pentagrid mixer with separate local oscillator excitation. The mixer input circuit is tuned to the frequency of the r-f signal, whereas the i-f transformer in the plate circuit is tuned to the difference frequency between the r-f signal and local oscillator frequencies. The local oscillator tuning capacitor is ganged with that of the signal input circuit so that the frequency difference between them always remains the same. The output of the oscillator is taken from the grid circuit and is applied to injection grid 3 of the pentagrid mixer through a coupling capacitor. This circuit frequently is used in the frequency stages of multiband and high-frequency superheterodyne receivers.

130. Triode Heptode

(fig. 178)

Some of the advantages of a separate oscillator and pentagrid mixer can be realized by a *triode-heptode* converter tube, which combines both in one envelope. An ordinary pentagrid mixer (heptode section) is built into the same envelope with a separate triode oscillator. The two sections share a common central cathode. The oscillator

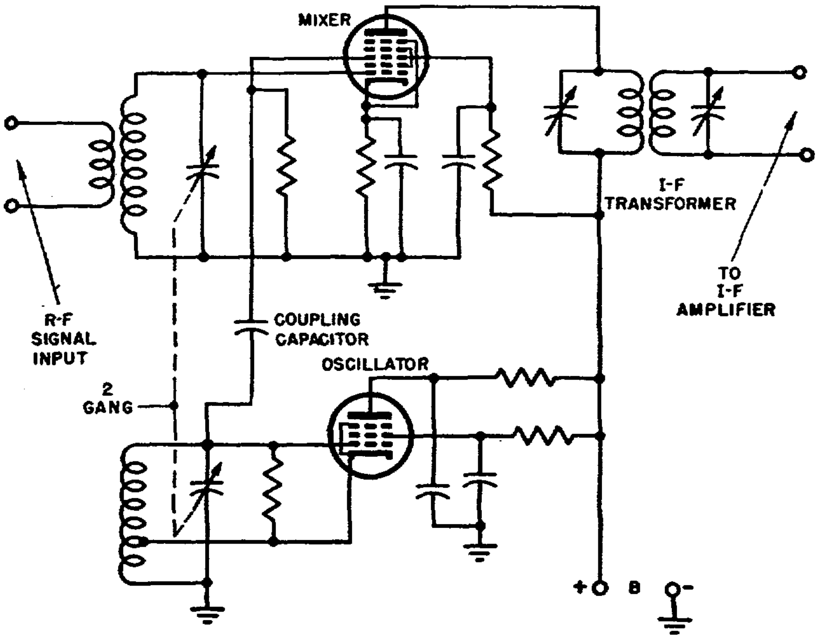

Figure 177. Pentagrid mixer circuit.

grid is connected internally to the mixer injection grid 3. The oscillator section of the tube is mounted either above or below the mixer section. Because the oscillator uses a small portion of the cathode, its transconductance cannot be made high, and it does not function very efficiently. Other constructional limitations are present also. Triode-heptodes are used principally for compact portable receivers, where space is limited.

131. Triode Hexode

(fig. 179)

a. The constructional deficiencies of the triode heptode are largely overcome in *triode-hexode* converter tubes, which contain a triode oscillator and a hexode (four-grid) mixer in one envelope. The schematic representation and the actual electrode structure of triode hexodes are shown in A and B, respectively. The tube utilizes a special design and arrangement of the electrodes to provide an entirely separate electron stream for the mixer and oscillator sections, so overcoming the cathode-area limitation of triode heptodes. The cathode, triode grid, and triode plate form the oscillator section of the tube. The mixer unit consists of the cathode, hexode injection (triode) grid, hexode double screen grids, hexode signal grid, and the hexode mixer plate.

b. Grid 1 completely surrounds the cathode. The side toward the triode oscillator plate acts as the oscillator control grid, whereas the side facing

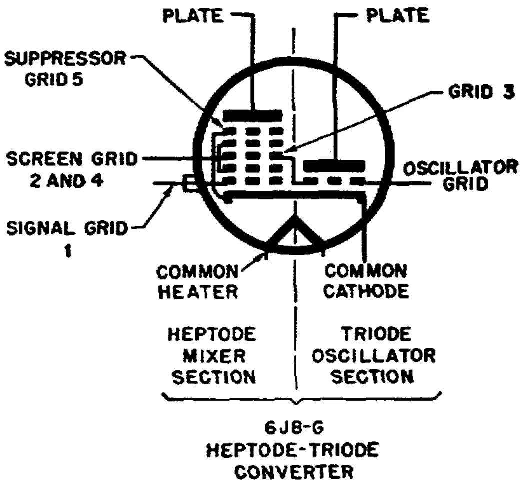

Figure 178. Triode-heptode frequency converter.

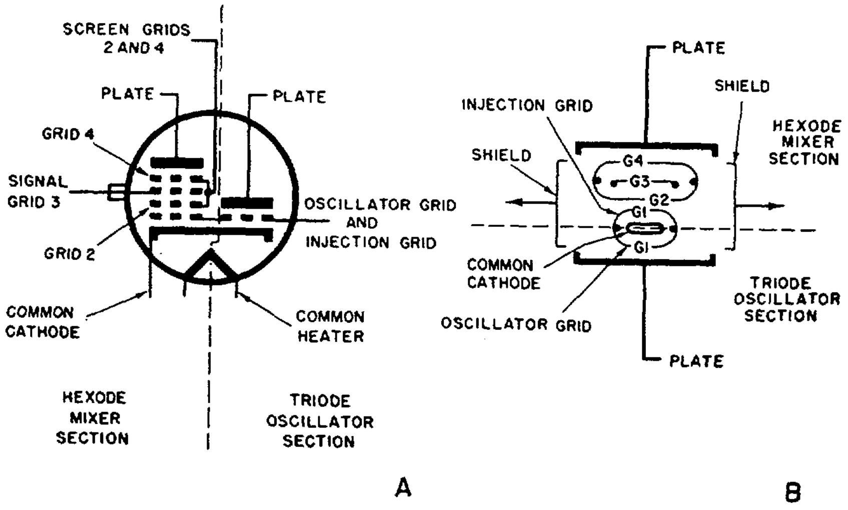

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Figure 179. Triode-hexode converter.

the mixer section serves as the oscillator injection grid, modulating the electron stream at the oscillator frequency. Two metal shields at the sides, connected to the shell of the tube, prevent stray electrons from producing undesirable coupling between the mixer and oscillator sections. They also act as a suppressor for the hexode unit, and a suppressor grid therefore can be omitted. The action of the tube in converting an r-f signal to an intermediate frequency depends on the generation of the local oscillator frequency by the triode unit, the application of this frequency to the hexode injection grid, and the mixing of this frequency in the hexode unit with that of the r-f signal applied to the hexode signal grid.

c. A typical frequency-converter circuit using a triode-hexode tube is shown in figure 180. A tickler feedback circuit is used for the oscillator section. Its output is impressed on the mixer injection grid, and then it is mixed with the r-f signal applied to grid 3. The i-f transformer in the plate circuit of the mixer section is tuned to the beat frequency.

d. The triode-hexode mixer provides good isolation between the oscillator and mixer sections, and little pulling occurs. The conversion gain is about the same as for the previously discussed circuits, and it holds up well at high frequencies. These characteristics make the tube suitable for use in high-frequency and multiband superheterodyne receivers.

132. Pentagrid Converters

a. A pentagrid converter combines the functions of the oscillator and frequency mixer in a single structure, coupling between the two units being obtained by the common electron stream. The electrode structure of an early type of pentagrid converter is shown in A of figure 181, and its connection to the external circuits is illustrated in B. Five grids are utilized. The cathode, grid 1, and grid 2 are connected to an external circuit to function as an ordinary triode oscillator. Grid 1 is the grid of the oscillator, and grid 2, consisting simply of two vertical rods placed in the electron stream between grids 1 and 3, is its plate.

b. The oscillator grid varies the intensity of the electron stream from the cathode and causes it to pulsate at the oscillator frequency. Most of the electrons from the cathode bypass the two positive oscillator plate rods (grid 2) and go on to screen grid 3, which accelerates the electron stream and serves as an electrostatic shield. Some of the electrons strike the screen and cause secondary emission, but most pass through its openings toward the r-f signal grid 4, which is biased negatively at all times. Thus a space charge of retarded electrons is formed betweeen grids 3 and 4. This space charge constitutes a *virtual cathode* for supplying the mixer section of the tube. This virtual cathode in front of grid 4 forms with each pulse of space current and then dis-

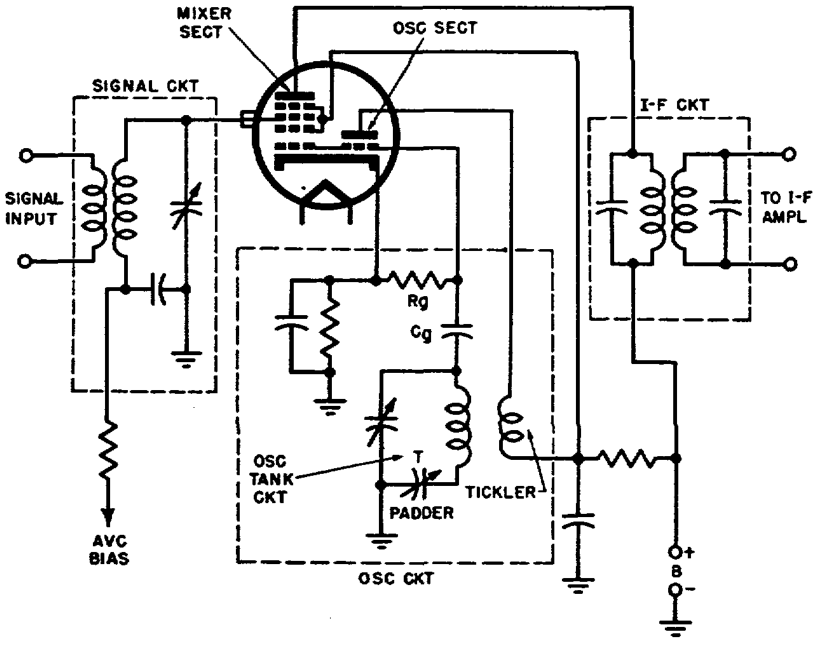

Figure 180. Triode-hexode frequency-converter circuit.

appears between the oscillator pulses; therefore, it supplies the rest of the tube with an electron stream that varies at the oscillator frequency.

c. The number of electrons that the plate is able to draw away from this pulsating virtual cathode depends on the r-f signal voltage applied to grid 4. As a result, the electron current actually arriving at the plate is modulated by both the oscillator and the signal voltages, and the two voltages are effectively mixed in the output of the tube. Because of the nonlinear characteristic of the mixer, sum and difference frequencies appear in

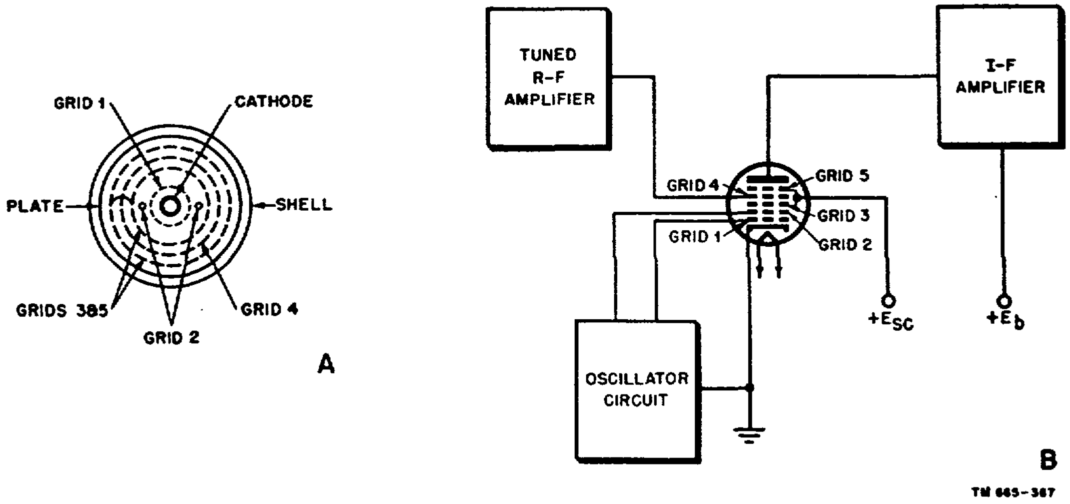

Figure 181. Pentagrid converter.

the plate current of the tube. The difference frequency is selected by the tuned i-f transformer.

d. Between the r-f signal grid and the plate of the tube is placed another screen, grid 5, which is connected internally to screen grid 3. Grids 3 and 5 together accelerate the electron stream and electrically shield signal grid 4 from the other electrodes. Grid 5 also severs to make the plate current substantially independent of the plate voltage, and so gives the pentagrid converter a high plate resistance of the same order as that obtained in ordinary pentodes. Signal grid 4 of the pentagrid converter usually has a remote cut-off characteristic. This makes it possible to control the conversion transconductance, and consequently the gain, by varying the bias on this grid.

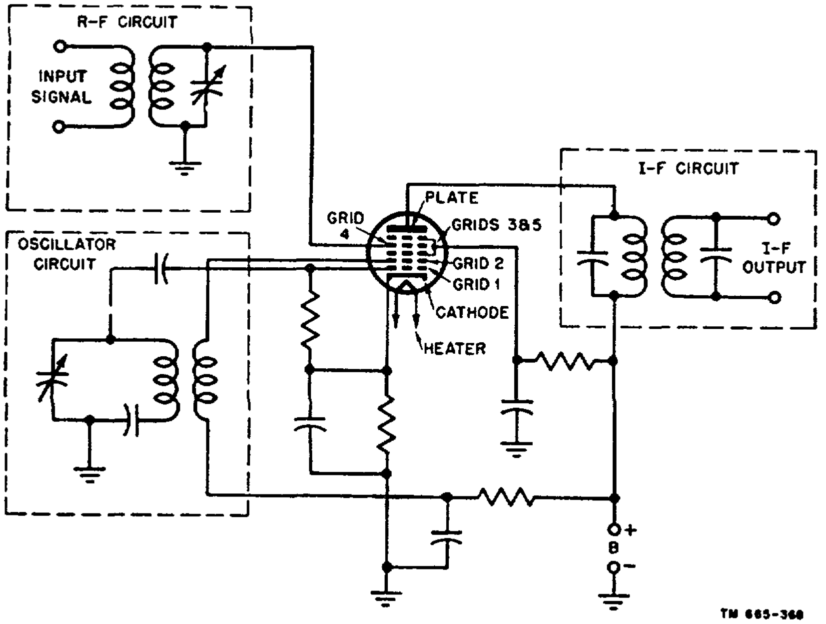

Figure 182. Pentagrid converter circuit.

e. The incoming r-f signal shown in the general circuit arrangement of the pentagrid converter (fig. 182) is selected by the tuned input circuit and is applied to signal grid 4, so that it modulates the electron stream. The local oscillator consists of a simple tickler feedback circuit. The oscillator frequency is controlled by the variable capacitor in the oscillator tank circuit. This capacitor is ganged with the signal input tuning capacitor in such a manner that it maintains a constant frequency difference equal to the desired i-f. The cathode resistor provides grid bias for the tetrode mixer portion of the converter; grid-leak resistance provides separate bias for the oscillator portion. This permits optimium biasing for the oscillator and mixer sections. The i-f transformer in the output selects the correct difference-frequency component of the plate current of the converter. This component is coupled to the succeeding i-f amplifier.

f. Pentagrid converters of the type discussed operate satisfactorily at medium frequencies, but their performance becomes increasingly poor at higher frequencies. This is caused chiefly by falling off in oscillator output as the frequency is raised and increasing interaction between the mixer and oscillator portions. Undesirable coupling between the mixer and oscillator sections appears, in spite of the two screen grids, because of a residual capacitance between grid 4 and the space charge of the virtual cathode (called *space-charge coupling*). Since the space charge pulsates at the oscillator frequency, the residual coupling causes currents at the oscillator frequency to flow from grid 4 through the tuned r-f input circuit.

g. Recent types of pentagrid converter tubes are designed to minimize the interaction between the signal grid and the oscillator plate by means of special construction of the oscillator section. The shaping, spacing, and number of turns on the grids are modified, and additional collector plates are introduced. As a result, the space charge around the cathode is unaffected by the signal grid. In addition, the arrangement of the electrodes has been changed so that no electrode functions solely as the oscillator plate (fig. 183). Grid 1 functions as the oscillator grid. Grid 1 is connected to screen grids 2 and 4, both acting as the oscillator plate. The r-f signal grid 3 is shielded electrostatically by grids 2 and 4. Grid 5 functions as the suppressor. Pentagrid converters of this type operate well to frequencies as high as the f-m band (88 to 108 mc), but have high noise levels as compared with mixer-oscillator circuits.

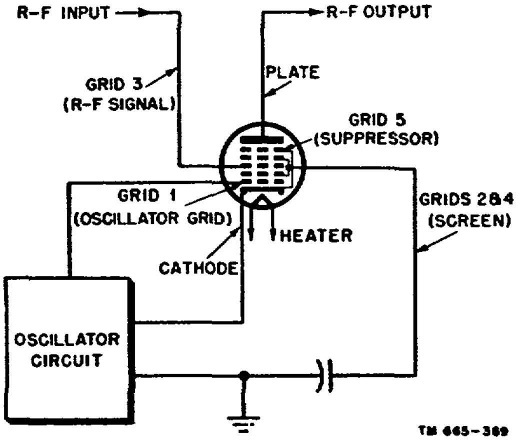

Figure 183. Pentagrid converter circuit with r-f input to grid 3.

133. Frequency Tracking

a. The mixer and oscillator circuits of a superheterodyne are said to *track* when they maintain a constant frequency difference (the i-f) between them throughout the tuning range. Since the oscillator circuit is generally set to a frequency higher than that of the mixer and r-f circuits, the capacitance and inductance of its tuned circuit must be smaller. Also, for the higher oscillator frequency, the *percentage* of frequency shift for the oscillator tuning capacitor must be smaller for the same tuning range than that of the mixer and r-f capacitors. This is achieved in some receivers by using a smaller coil and a smaller tuning capacitor with specially shaped plates in the oscillator circuit. The special shape of the plates insures tracking throughout *one* frequency band. This method cannot be used, however, in multiband receivers, since each band requires a differently shaped oscillator tuning capacitor.

b. More commonly, the same size tuning capacitors are used for both oscillator and mixer circuits. The required frequency difference then is made up with a smaller oscillator coil, and tracking is attained with *trimmer* and *paddler* capacitors. The trimmer is connected in parallel with the oscillator tuning capacitor, and the padder is connected in series with it (fig. 184). At the *high-frequency* end of the tuning range, the oscillator tuning capacitor is set for minimum capacitance. The parallel trimmer has about the same order of magnitude as this minimum value and its adjustment determines the proper resonant frequency at this end of the frequency range.

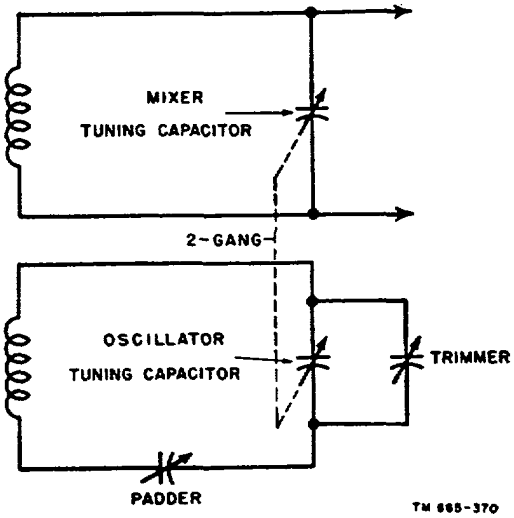

Figure 184. Padder and trimmer connections.

c. At the *low-frequency* end of the tuning range, the capacitance of the oscillator tuning capacitor is near maximum, and therefore the small parallel trimmer is negligible in comparison with it. Now, however, the series padder is comparable in magnitude to the main tuning capacitor and affects the resonant frequency. The value of the padder is usually about two to four times the magnitude of the maximum oscillator tuning capacitance. Since the total capacitance of two series capacitors is influenced chiefly by the *smaller* of the two capacitors, the effect of the series padder on the total tuning capacitance at the low-frequency end is not very great, but suffices to set the resonant frequency within the limits required for proper tracking. By proper adjustment of the padder and trimmer capacitors reasonable tracking accuracy can be attained throughout the frequency range. If several bands are utilized, a separate trimmer and padder capacitors usually are provided for each band.

134. Oscillator Stability

a. The circuits used as local oscillators in superheterodyne receivers must have a high degree of frequency stability. Obtaining the required frequency stability is a major problem in the design of the receiver, particularly where the receiver is to operate under conditions of wide temperature variation, high humidity, or severe mechanical vibration. Oscillator stability for higher-frequency receivers is a particularly difficult problem and sometime crystal oscillators are used. If the frequency of the oscillator is incorrect, the resultant intermediate frequency is no longer in the center of the pass band of the i-f amplifier. As a result, when an amplitude-modulated wave is being received, considerable distortion will occur. When very selective i-f amplifiers are used, the signal may be lost altogether.

b. Frequency variations of the local oscillator can be divided into long-time and short-time effects. Long-time changes or slow oscillator drift produces the greatest variation in frequency. This drift usually is produced as the result of heat and humidity affecting the constants of the tuned circuits and the oscillator tube. Short-time variations are caused by power-supply voltage variations, interference from power lines, and coupling from other stages, especially the mixer.

135. Intermediate-frequency Amplifier

a. The intermediate-frequency amplifier is of special importance in superheterodyne receivers because it controls, to a major extent, the selectivity and gain of the complete receiver. The amplifier contains from one to three tuned stages and utilizes high-gain pentode tubes in each stage. Operating only at the i-f frequency, the tuned circuits of the amplifier can be adjusted permanently for optimum amplification and selectivity. No variable tuning or tracking problems are met in the i-f amplifier.

b. In addition to providing high gain and sufficient selectivity between adjacent channels, the i-f amplifier must have the required fidelity to preserve intact the intelligence superimposed on the carrier at the transmitter. It will be remembered that amplitude modulation of a carrier generates side-band frequencies numerically equal to the carrier frequency plus and minus the highest modulation frequency present. For example, if modulation containing audio frequencies up to 5,000 cps is to be reproduced faithfully, the receiver must be capable of amplifying equally all frequencies in a band from 5,000 cps below the carrier frequency (lower side band) to 5,000 cps above the carrier (upper side band). This means that the i-f amplifier must pass uniformly a band of frequencies 10 kc wide.

c. The design of the tuned circuits in the i-f amplifier determines the band-pass characteristics. The tuning or selectivity of the i-f transformers must not be so sharp as to cut a portion of the lower and upper side bands containing the modulation. A 10-kc band generally is considered sufficient for reasonably faithful reproduction of speech and music. Much narrower bandwidths often are used for military communications, where a compromise between intelligibility and rejection to adjacent interference signals and noise is desired.

136. I-F Tuning

a. Coupled Resonant Circuits.

(1) Coupling in i-f amplifiers generally is obtained by using two coupled resonant circuits. A of figure 185 shows such a circuit, including the primary and secondary circuit resistances, R_p and R_s, respectively, which are chiefly associated with the coils. The resonant response of such a coupled circuit depends primarily on the degree of coupling—that is, the amount of mutual inductance, M, between the primary and secondary of the transformer. Typical resonance curves of two coupled resonant circuits for various degrees of coupling are illustrated in B. These curves have been obtained by plotting the current in the secondary of the

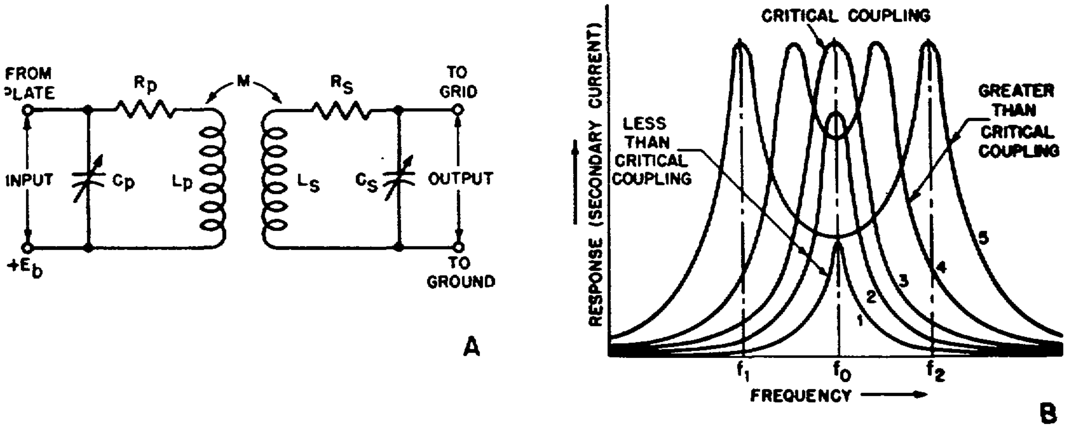

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Figure 185. Characteristics of coupled resonant circuits.

transformer against frequency for constant input voltage to the primary, and with both circuits tuned to the same resonant frequency, f_o. When the coupling between the primary and secondary is quite loose, the secondary current, and consequently the secondary voltage, are small, but the resonance curve is sharply peaked (curve 1) and the selectivity is good. As the coupling is increased somewhat, the secondary current peak becomes larger, and the resonance curve becomes broader (curve 2). This tendency continues with increased coupling until the secondary current reaches its maximum possible value for a critical degree of coupling (curve 3).

(2) *Critical coupling* occurs when the resistance reflected back into the primary by the secondary current is equal to the primary resistance. (For explanation of reflected resistances, see paragraph 21*e*.) For this condition, the coefficient of critical coupling, k, is found to be

$$\text{critical } k=\frac{1}{\sqrt{Q_pQ_s}}$$

where

$$Q_p=\text{primary circuit } Q=\frac{2\pi fL_p}{R_p}$$

$$Q_s=\text{secondary circuit } Q=\frac{2\pi fL_s}{R_s}$$

If the primary and secondary circuit Q's are equal, as is often the case, then $Q_p=Q_s=Q$, and the coefficient of critical coupling

$$\text{critical } k=\frac{1}{Q}$$

The coefficient of critical coupling is usually very small, because Q is generally high. For Q's of 100, for example, the coefficient of critical coupling is 1/100, or .01.

(3) When the coupling is increased beyond the critical value, the secondary current curve begins to display *two* humps; this is known as *double-peaking* (curve 4). The magnitude of these two peaks is the same as that obtained for critical coupling. As the coupling is increased still further, the two peaks begin to spread apart in frequency, and the valley or dip between the peaks becomes more pronounced (curve 5). For extremely tight coupling, the response between peaks may go almost to zero.

(4) The reason for the appearance of the two humps can be understood by considering the impedance reflected back from the secondary to the primary of the transformer. The impedance coupled into the primary increases as the square of the mutual inductance, M. Above critical coupling, it becomes the major factor determining the total primary impedance. At the resonant frequency, the coupled impedance is purely resistive, and there-

fore lowers the Q of the primary circuit. At frequencies below resonance, the coupled impedance is largely inductive; therefore, it cancels out part of the primary series impedance, which is capacitive below resonance. At some frequency f_1 below resonance, therefore, the coupled reactance completely neutralizes the primary reactance, and the total primary impedance becomes very low. For this condition the primary current is very large. This large primary current, in conjunction with the high degree of coupling, induces a large voltage in the secondary, and so results in a correspondingly large secondary current. This accounts for the secondary current peak below resonance.

(5) At frequencies above resonance, the coupled impedance is largely capacitive, and it therefore neutralizes part of the primary series impedance, which is inductive above resonance. At some frequency f_2 above resonance, the primary impedance again reaches a minimum, and the primary current becomes very large. This induces a high secondary voltage, which in turn results in a large secondary current. This is the reason for the secondary current peak above resonance. If the coupling is below the critical value, the coupled-in impedance is not sufficiently great to cause the separate current peaks, but it does help to broaden the resonance curve.

(6) The double-peaked characteristic is taken advantage of in i-f transformers to obtain the required band-pass characteristic. By slightly overcoupling the coils of an i-f transformer (larger than critical k), the secondary current will be approximately constant near resonance over a range of frequencies between the two peaks (from f_1 to f_2, in B, fig. 185). Beyond these two frequencies, f_1 and f_2, the response falls off very rapidly, and the selectivity for adjacent channels outside the passband is excellent. If the required bandwidth is large, the coupling must be very tight to spread the two peaks sufficiently far apart. For this condition, however, the dip between the peaks becomes very pronounced, as indicated by curve 5 in B.

(7) Two methods are in use to smooth out this dip. One method (A of fig. 186) consists of *loading* the circuit by connecting a resistance in parallel with the resonant circuit. This damps out the resonant voltage rise and pushes the peaks down near the valley level. The result is a smoother response at the sacrifice of voltage gain in the transformer. The second method, in B, consists of filling in the dip with a single-peaked resonance curve of the proper characteristics. For example, the first i-f stage may have an overcoupled i-f transformer, which produces two peaks spaced the desired bandwidth apart. The i-f transformer of the second stage then can be designed so that its response fills in exactly the dip produced by the first stage. This is attained by less than

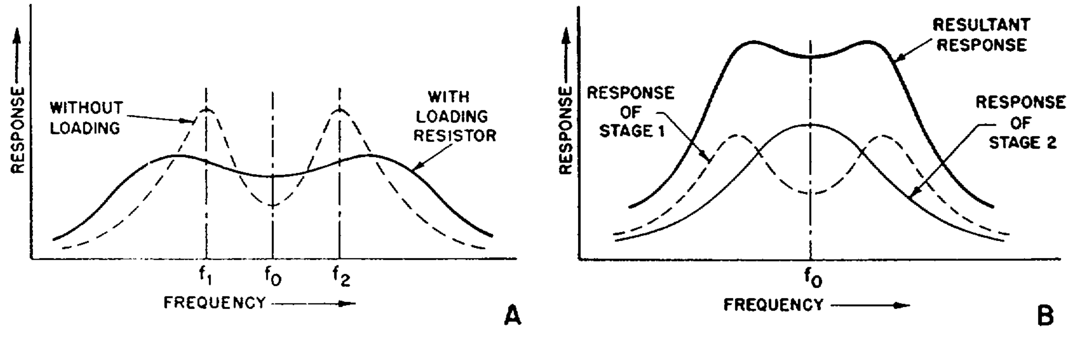

Figure 186. Two methods of smoothing out dip. A. Effect of loading. B. Combined response of two i-f stages.

critical coupling in the second i-f transformer and with a Q of about one-half that of the first i-f transformer. The resultant response of the two stages is the product of the response of each stage and can approach the ideal *flat-topped* characteristic.

(8) Frequencies f_1 and f_2 of the two current peaks for values of coupling greater than critical are given by the following relations

$$f_1=\frac{f_0}{\sqrt{1+k}}$$

and

$$f_2=\frac{f_0}{\sqrt{1-k}}$$

where

f_0=the resonant frequency of the tuned circuits

k=coefficient of coupling (greater than critical).

The bandwidth over which the response is relatively uniform is then the difference f_2 minus f_1. It can be computed from the preceeding relations, or directly by the approximation

$$\text{bandwidth}=f_2-f_1=f_0.$$

The relative bandwidth usually is expressed as the fractional deviation from the resonant frequency; that is,

$$\text{relative bandwidth}=\frac{f_2-f_1}{f_0}=k.$$

(9) For example, assume that both primary and secondary of the i-f transformer (A of fig. 185) are tuned to 455 kc, and that $R_p=10$ ohms, $L_p=350$ microhenries, $R_s=14$ ohms, and $L_s=490$ microhenries. What is the coefficient of critical coupling? If the *actual* coefficient of coupling is .02, what is the bandwith and the highest modulating frequency that is passed satisfactorily by the transformer? The primary circuit

$$Q=Q_p=\frac{2\pi fL_p}{R_p}=\frac{2\times 3.14\times 455{,}000\times 350\times 10^{-6}}{10}=100$$

The secondary circuit

$$Q=Q_s=\frac{2\pi fL_s}{R_s}=\frac{2\times 3.14\times 455{,}000\times 490\times 10^{-6}}{14}=100$$

Since $Q_p=Q_s=100$, the *critical* $k=1/Q=1/100=.01$. The actual $k=.02$; that is the circuit is overcoupled. For this condition the bandwith is approximately

$$f_0k=455\times .02=9.1 \text{ kc.}$$

Since there are two side bands containing the modulation, the highest modulating frequency is one-half the total bandwith, or 9.1/2=4.55 kc or 4,550 cps. This fidelity is satisfactory for general communications.

(10) Instead of overcoupling the primary and secondary of an i-f transformer, a double-peaked resonance curve also can be obtained by tuning the primary and secondary to slightly different frequencies with the coupling less than critical. The primary and secondary each will respond best to the frequency to which it is tuned. This type of tuning is known as ***stagger tuning***, and it is used often to attain the required bandwidth instead of overcoupling the circuits.

b. Construction of I-F Transformer. The i-f transformer circuits are contained in a metal-shield container in which the coils and tuning capacitors are mounted. The capacitors can be made of mica, or they can be air trimmer capacitors. The coils may have an air core, or a powdered-iron core, the latter providing somewhat greater Q. Powdered-iron cores can be tuned by moving the core in or out of the coil, thus varying the inductance. This is called *permeability*, or *slug*, tuning. With permeability tuning, a fixed mica capacitor can be used. The frequency stability of permeability tuning is comparable to that of variable-tuned air capacitors. Stability is important to prevent frequency drift, which reduces the gain and selectivity of the i-f stage. Small protruding adjusting shafts permit tuning the transformer outside of the case.

137. I-F Circuit

a. In the typical circuit arrangement of an i-f amplifier in figure 187, only one stage is shown, since a second stage would simply duplicate the circuit of the first. I-f amplifiers contain from one to three stages, each with a pentode amplifier tube, but two stages generally provide all the gain that can be utilized. Pentodes usually are used for

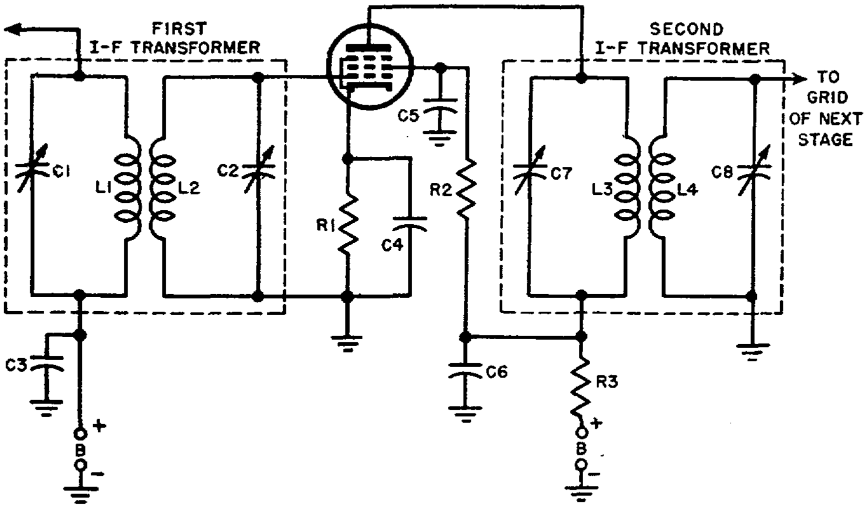

Figure 187. Typical i-f amplifier circuit (one-stage).

high gain. They are generally of the remote-cut-off type, to permit control of the gain.

b. The first i-f transformer consists of a primary circuit connected to the mixer output, and a secondary circuit connected to the control grid of the pentode. Both primary and secondary are tuned to the intermediate-frequency output provided by the mixer. Single-tuned i-f transformers with an untuned primary sometimes are used, with a consequent loss of selectivity. Resistor *R*1 and capacitor *C*4 in the cathode of the tube provide the required bias on the tube. *C*5 is the screen bypass capacitor for r-f. Resistor *R*3 and capacitor *C*6 form a decoupling filter for isolating the amplifier from the common power supply, and so prevent feedback from the later stage to the earlier stage.

c. The plate of the pentode is connected to the primary of the second i-f transformer, which consists of *C*7 and *L*3. The primary is coupled to the secondary, *L*4 and *C*8, which forms the input circuit of the next stage. This can be another identical i-f amplifier, or the detector stage. If two or three i-f stages are used, careful shielding, bypassing, and circuit layout are necessary to prevent stray coupling, which can cause instability and oscillation. Occasionally, multiple-tuned circuits and additional i-f stages are used principally for the contribution which the additional tuned circuits make to skirt selectivity of the over-all response characteristic of the receiver; gain then becomes of secondary importance.

138. Selectivity of I-F Amplifier

The selectivity of each stage depends on the Q and the coupling of the i-f transformer, which already has been discussed. The *over-all* selectivity of the i-f amplifier is proportional to the number of tuned circuits (i-f transformers) utilized. The total selectivity increases as the product of the number of stages, in a manner similar to that for the tuned r-f amplifier. Over-all selectivity also increases if the intermediate frequency used is lowered. The exact i-f amplifier selectivity of military receivers varies widely, depending on the specific use to which the receiver is placed. Most communication receivers have variable i-f selectivity. A switching arrangement permits several amounts of fixed selectivities to be obtained. In one receiver, for example, a three-position switch is used to produce a total i-f band pass of 10 kc, 6 kc, and 3 kc. Crystal filters often are incorporated in receivers used for extremely selective c-w signal reception.

139. Gain of I-F Stage

a. The gain attained in each i-f stage depends on the required *relative bandwidth* for a given i-f carrier frequency, the value of the intermediate frequency, and the transconductance, g_m, of the tube. The gain of the stage is *inversely proportional* to the relative bandwidth. In other words, the greater the ratio of the required bandwidth to the resonant frequency (i-f carrier), the smaller is the possible gain. I-f transformers of a given Q and coupling coefficient k have the same relative bandwith regardless of the frequency of operation (i-f).

b. The gain decreases as the frequency of the i-f carrier increases because of losses in the circuit and tube. High-frequency losses are caused chiefly to *loading* of the input circuit, which results from a lowering of the input impedance of the tube. The input impedance decreases at higher frequencies, because the tube interelectrode capacitances offer less reactance at these frequencies. The effect is to offer a resistive and capacitive shunt to the incoming signal. At very high frequencies, loading also is caused by the *transit time* of the electrons from the cathode to the plate (par. 49*d*(2)).

c. Finally, the gain of an i-f stage is directly proportional to the transconductance of the tube used. Modern pentodes have high values of transconductance. The *over-all gain* of the i-f amplifier is the *product* of the individual gains of each stage. If two identical i-f stages are used, the total gain is simply the *square* of the gain of one stage; for three identical stages, it is the cube, and so on.

140. Selection of Intermediate Frequency

a. The selection of the intermediate frequency is a compromise between various conflicting factors. The higher the intermediate frequency, the lower is the selectivity and the gain of the stage. On the other hand, it is impractical for the intermediate frequency to be greatly lower than the signal frequency. This is because trouble results from *image interference* if the *difference* between the signal frequency and the i-f is made very great (par. 149). A low i-f also increases the undesirable interaction between the signal and oscillator frequencies; pulling of the oscillator frequency by the mixer has been discussed previously. Although the selectivity and gain for low intermediate frequencies are excellent, image interference and pulling must be taken into account.

b. The selection of the i-f is a careful compromise between the desired selectivity and gain, and the permissible image interference and amount of pulling. For a-m reception up to approximately 10 mc, intermediate frequencies from 455 to 465 kc have been found satisfactory. An i-f of 455 to 456 kc generally is used for a-m communication receivers.

141. Improving Receiver Selectivity

It usually is desired to increase the selectivity of a superheterodyne receiver in order to reduce interference resulting from signals adjacent to the desired signal frequency, to cut down noise, and to eliminate *audio images* (explained below). The selectivity of superheterodyne receivers can be increased substantially by narrowing the bandwidth of the tuned i-f circuits. The limit of selectivity that can be used for voice reception is a bandwidth of approximately 2,000 cps. For c-w reception, the bandwidth can be as narrow as 50 to 100 cps. Such extreme selectivity, however, requires exceptional frequency stability at both the transmitter and the receiver, and makes it difficult to tune in a desired signal. The slightest frequency instability causes the signal to drift out of the restricted bandpass of the receiver.

a. Regeneration. Highly selective reception is extremely difficult to obtain with an ordinary i-f amplifier unless the chosen i-f is very low, which is rarely possible, or unless an impractically large number of tuned circuits is used. Fortunately, other methods exist for attaining the necessary degree of selectivity. One commonly used method is to introduce regeneration into one of the i-f amplifier tubes by providing a small amount of capacitive coupling between the grid and the plate. Sufficient regeneration usually is obtained by placing a short length of wire, one end of which is connected to the grid of the i-f tube, in the vicinity of the plate lead. The amount of feedback can be controlled by the ordinary cathode-resistor gain control, if provided. When the resonance curve of the plate tank circuit is peaked, regeneration has a pronounced effect. The selectivity of the i-f stage at critical regeneration (just below oscillation) is extremely sharp. The increased selectivity of regeneration also reduces the response to noise permitted to pass the preceding stages of the receiver, improving the signal-to-noise ratio. The disadvantage of regeneration, however, is the fact that it is never quite stable. The selectivity of the receiver is apt to vary considerably at times, and the gain is reduced for strong input signals.

b. Crystal Filters.

(1) As previously explained, a *piezoelectric quartz crystal* acts like a tuned circuit with an extremely high Q, and, correspondingly, high selectivity. A quartz crystal, therefore, can be used to advantage as a selective filter between two conventional i-f tuned circuits. The thickness of the crystal for this purpose is of the required value for resonance at the desired intermediate frequency.

(2) Two crystal filter circuits are shown in figure 188. In each, the crystal is made part of a balance bridge circuit, consisting of symmetrically fed input and output i-f circuits, the crystal, and a crystal *phasing capacitor*, *C*2. In A, the secondary of the input i-f transformer, *L*2, is balanced to ground through a pair of capacitors, *C*3 and *C*4; in B the same purpose is achieved through the center-tapped secondary winding, *L*2, of the mixer output transformer. The crystal filter impedance must be matched correctly to the input circuit of the following stage, which is the first i-f amplifier. This is accomplished in A by feeding the output of the filter circuit through an adjustable coupling capacitor, *C*5, to a tap on the input coil, *L*3, of the next stage. In B, the same result is obtained by replacing the tap with the primary *L*3 of an impedance-matching transformer. By closing switch *S* across the crystal, the filter is shorted out, and an ordinary i-f stage remains.

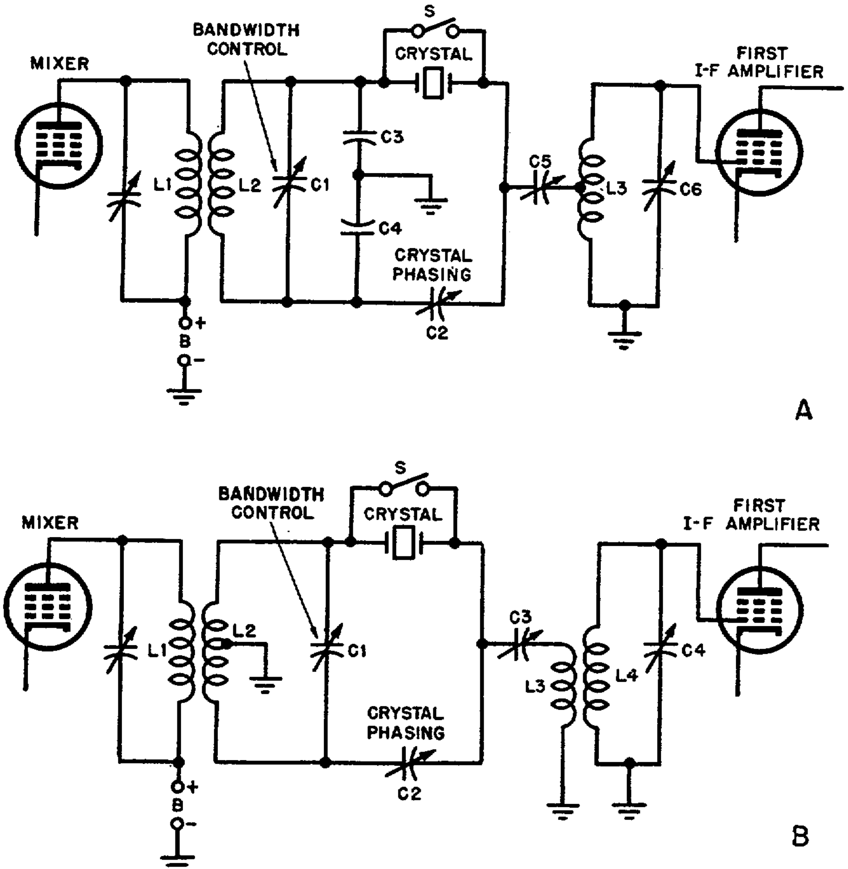

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Figure 188. Crystal filter circuits.

(3) To understand the need for the phasing capacitor, $C2$, the equivalent circuit of the quartz crystal (fig. 56) is considered. The crystal itself is represented by a series *R-L-C* circuit, which is shunted by the parallel capacitance of the crystal holder, with the crystal as the dielectric. At a certain frequency, the *R-L-C* circuit representing the crystal goes into series resonance; at a slightly higher frequency, the combination of crystal and holder becomes parallel resonant. The bridge circuit (fig. 188) with capacitor $C2$ permits neutralizing the electrostatic capacitance of the crystal and holder so that only the high-Q series-resonant circuit exists. In this way, the crystal filter passes the desired signal at the series-resonant frequency of the crystal but greatly attenuates all other frequencies. If the electrostatic holder capacitance is not balanced out by $C2$, it can bypass some undesired signals around the crystal.

(4) The phasing capacitor, $C2$, has another important use in addition to minimizing the crystal holder capacitance. If the holder capacitance is not completely neutralized, a desirable parallel resonance occurs, the frequency of which can be adjusted by $C2$. At the frequency of parallel resonance, the filter has maximum signal rejection in contrast to the maximum signal response at the series-resonant frequency. Consequently, interfering signals that are close to the desired signal (within 1,000 to 2,000 cps) are rejected effectively by adjusting $C2$, so that the parallel resonant frequency coincides with the interfering frequency.

(5) The bandwidth of the crystal filter is largely controlled by the effective resistance of the input circuit that excites the crystal. This resistance is in series with the crystal, and so lowers its Q. As the effective Q of the crystal decreases, the selectivity is decreased, or, equivalently, the bandwidth is increased. Consequently, when the input-tuned circuit, $L2C1$ (fig. 188), is adjusted to parallel resonance at the crystal frequency, the effective resistance which the crystal sees is high, and consequently the bandwidth is maximum. When the input circuit is detuned, however, by varying the tuning capacitor, $C1$, the resistance in series with the crystal is low and the bandwidth becomes small. The bandwidth of the crystal filter can be controlled in this manner by adjusting capacitor $C1$. In practice, this is generally done by a multiple switch, which permits selecting different fixed capacitors with predetermined bandwidth characteristics. Other circuits have switching arrangements for changing the resistance in the circuit.

c. Audio Filters. In addition to the highly effective crystal filters, sharply tuned filters sometimes are inserted into the *audio* stages of the receiver. These may consist of simple resonant circuits inserted into the plate-coupling circuit of an a-f amplifier tube, or they can be more elaborate band-pass filters. In either case, their purpose is to pass a very narrow audio band containing the desired signal, but eliminating all undesired frequencies outside of this passband.

142. Detector Stage

a. Diode Detector.

(1) Most superheterodyne receivers utilize a diode detector for rectification of the modulated signal. Because of the linear characteristic between the modulated r-f input voltage and the rectified output current, a diode is capable of handling high-level signals with little distortion. It is, therefore, well adapted for use after the high-gain i-f stages of a superheterodyne receiver, where the more sensitive grid-leak detector and the plate detectors would be overloaded. Therefore, diode detectors are preferred over other detectors in superheterodyne receivers.

(2) The diode detector has no gain, however, so that there is a loss of signal strength. To make up for this loss, the diode detector rarely is used alone, but is combined with an audio amplifier in the same stage. As will be seen later on, the use of dual-function tubes (diode-triodes and diode-pentodes) makes this a comparatively simple matter. The gain of the combined detector-amplifier stage is then comparable to that provided by other types of detectors.

(3) More serious is the comparatively large current the diode detector draws from its tuned input circuit. This current damps out the resonant peak of the tuned circuit, substantially reducing the selectivity of the stage. This loss in selectivity must be compensated for by having a sufficient number of tuned stages in the receiver to make the over-all selectivity satisfactory. In receivers with a separate tuned r-f amplifier and two i-f stages the selectivity is sufficient.

b. Circuit and Operation.

(1) In practice, two types of diodes are in use—*crystal* diodes and vacuum-tube diodes. Crystal diodes can be *galena*, *silicon*, or *germanium* types. At very high frequencies, crystal diodes, especially of the germanium type, often are preferred to vacuum-tube diodes. A crystal may be compared to an imperfect form of diode, since it permits current to flow freely in one direction, but does not completely suppress it in the opposite direction. In a crystal diode, a small current *can* flow in the reverse direction. In contrast, vacuum-tube diodes permit current flow in only one direction, suppressing it completely in the opposite direction (when the plate is negative). Apart from this, the principle of detection in a crystal diode is similar to that in a vacuum-tube diode. The following analysis is based on the operation of the common vacuum-tube diode detector.

(2) The basic circuit of a vacuum-tube diode detector is shown in A of figure 189. It consists of a signal input circuit, which is the secondary of the last i-f transformer, a diode rectifier tube, and an *R-C* filter. The action of the circuit can be considered as that of a half-wave rectifier. The i-f signal is coupled to the plate of the diode through the i-f input transformer. The tube conducts only when the plate is positive in respect to the cathode. Consequently, whenever the signal voltage at the plate is positive, a current pulse flows through the tube and the load resistance, *R*. During the negative half-cycles of signal voltage, no current flows. The output of the tube, therefore, consists of a series of rectified i-f current pulses.

(3) The magnitude of the current pulses depends on the signal voltage at the plate. The plate-current plate-voltage characteristic of a typical diode is shown in B. For plate voltages sufficiently large to operate the tube beyond the curved lower bend, the characteristic is almost perfectly linear. The magnitude of the rectified plate-current pulses thus will be nearly proportional to the signal voltage on the plate, and so will reproduce the modulation of the signal voltage. The remaining i-f carrier variations are smoothed out by filter capacitor *C*. The value of this capacitor must be sufficiently large that it has a very low reactance to i-f variations, but a relatively high reactance to audio frequencies. In other words, it should provide minimum opposition to high frequencies and maximum opposition to audio frequencies. For this condition, the capacitor bypasses the i-f variations around *R*, and the a-f currents develop a voltage across *R*.

(4) The action of capacitor *C* requires more detailed consideration. Each positive i-f current pulse through the diode develops a voltage across capacitor *C*, and consequently across load resistor *R*, connected in parallel with it. The capacitor charges up to the *peak value* of each voltage pulse. Between successive peaks, the applied signal voltage drops to zero and becomes negative, thus cutting off the plate current during these intervals. Since the capacitor tends to hold its charge, the voltage across *R* and *C* does not fall to zero. As the capacitor slowly leaks off its charge through the resistance during the intervals of plate-current cut-off, the voltage across the *R-C* combination also drops slowly. With the next plate-current pulse, the charge on the capacitor again is replenished, and the voltage across the *R-C* load rises to the new peak value of this plate-current pulse. Thus, the voltage across the capacitor always rises to the peak value of the plate-current pulse and drops off slowly between current pulses. In this way, the load voltage

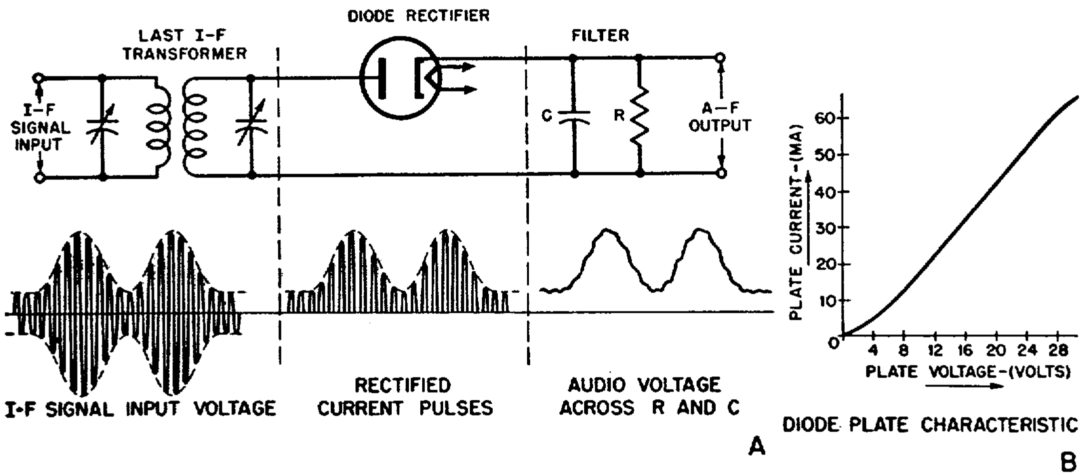


Figure 189. Action of basic diode detector.

across *C* follows the peak values of the applied signal voltage, and so reproduces the a-f modulation shown by the waveform at the right in A of figure 189. The curve is somewhat jagged, since the voltage across the capacitor does not follow the modulation peaks perfectly, but drops off slightly between successive peaks. The jaggedness represents a small i-f ripple in the load voltage, which is generally negligible for a properly chosen resistance-capacitance combination.

(5) In figure 190, which represents a diode detector and triode amplifier combined in the same stage, the signal input is coupled through the *i-f* transformer to the diode plate. The rectified signal appears across load resistance *R* in the cathode circuit of the tube and is smoothed out by capacitor *C*. The reactance of *C* must be small compared to the resistance of *R* at the *i-f* frequency being rectified, but it should be relatively large at audio frequencies. The triode grid is connected directly to a tap on the diode load resistor. The average rectified cathode current supplies a d-c voltage at the tap, which provides bias for the triode grid. With a modulated signal present, the *a-f* variations are superimposed on the d-c and are transferred from the load resistance to the triode grid,

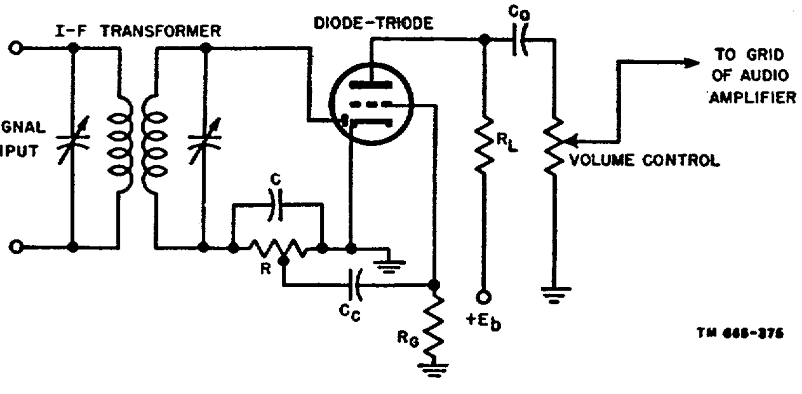


Figure 190. Diode detector circuit.

where they are amplified. The amplified audio voltage appears across the plate-load resistance R_L, and is coupled through C_o and the volume control to the grid of the next stage. The volume control permits tapping the audio output voltage at the desired level. Instead of resistance-coupling, transformer coupling can be used, and a diode-pentode can be substituted for the diode-triode tube. If a pentode is used, resistance coupling generally is preferable.

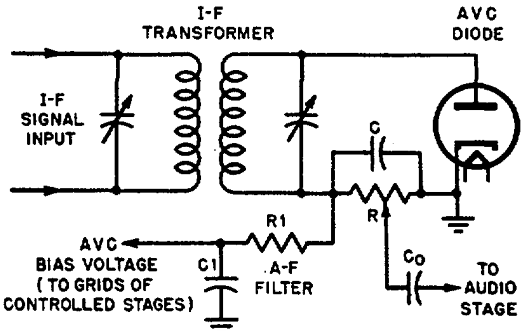
143. Automatic Volume Control

a. Need for AVC. Although manual volume controls permit regulating the gain of a receiver to a convenient output level, for several reasons it is desirable to have additional automatic control of the receiver gain. One reason is that it prevents extreme variations in loudspeaker volume. When a receiver is tuned from a weak station (for which the volume has been turned up), to a strong station, the loudspeaker will blast unpleasantly. The variations in signal strength of a signal carrier because of fading and other conditions also result in wide fluctuations of the loudspeaker volume. Furthermore, variations in signal strength at the antenna, if not compensated for, can cause serious trouble by overloading the *r-f*, *i-f*, or detector stage of the receiver, which in turn results in distortion of the signal. An automatic-volume-control circuit overcomes these troubles by automatically regulating the gain of the *r-f* and *i-f* stages. By making the gain of these stages less for a strong signal than for a weak signal, approximately constant signal input can be maintained at the detector regardless of signal strength at the antenna. The output volume from the speaker then will depend only on the degree of modulation at the transmitter.

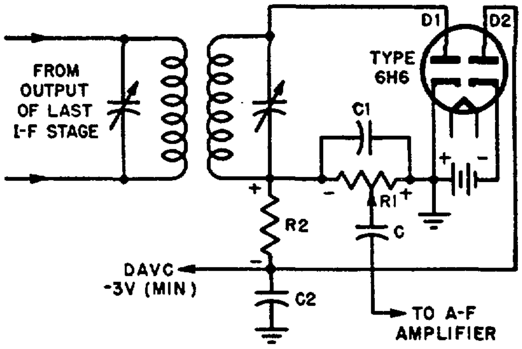
b. Circuit and Operation.

(1) The *r-f*, *i-f*, and mixer stages of a receiver utilize remote cut-off tubes whose gain can be controlled by varying the grid bias. By making the grid bias of these tubes more negative, the stage gain is reduced. If the gain of several stages is controlled by a negative bias voltage, the value of which depends on signal strength (*avc* voltage), ample reduction in receiver sensitivity can be attained for strong signals. The gain of the receiver, however, never can be *increased* beyond its maximum value in the absence of avc. The *avc* circuit simply provides this negative bias voltage, whose magnitude is proportional to signal strength, for *reducing* receiver gain.

(2) Figure 191 shows the addition of an avc circuit to the ordinary diode detector just discussed. The operation of the diode-detector portion is identical to that described in paragraph 142*b* and illustrated in A of figure 189. When the diode current flows through the load resistance, *R*, it generates a voltage drop which makes the left end of *R* negative in respect to ground. This negative voltage drop is applied through filter circuit *R*1*C*1 to bias the grids of the preceding stages which are to be controlled. When the signal strength increases, the bias



BASIC AVC CIRCUIT A



DELAYED AVC CIRCUIT B

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Figure 191. Automatic volume control circuits.

voltage developed across *R* also increases because of the greater average rectified diode current; therefore, the gain of the controlled stages is reduced. As a result, the output of the last *i-f* stage to the detector is increased only slightly for a large increase in signal level. For a decrease in signal level from the previously steady value, the action is reversed. The *avc* bias decreases, and the gain of the amplifier stages and the detector increases. The *avc* circuit always tends to counteract changes in signal level at the antenna of the receiver.

(3) The filter circuit, *R*1*C*1, prevents the *avc* bias from varying at an audio-frequency rate. Load resistance *R* and capacitor *C* of the detector are designed to filter out *i-f and r-f* variations, so that the voltage across them varies only at the audio-frequency rate of the modulation. If the *avc* were taken directly from *R* without filter *R*1*C*1, the individual *a-f* variations of the avc voltage would vary the receiver gain, thus tending to counteract the modulation of the carrier, and so produce distortion. Filter *R*1*C*1 is designed to prevent this from happening by smoothing out the *a-f* variations in the *avc* voltage, so that it does not follow the modulation and is substantially constant. The *avc* voltage, therefore, cannot vary as fast as the audio-range frequencies, but acts nevertheless sufficiently rapid to compensate for the slower amplitude variations caused by signal fading and changes in tuning from one station to another.

c. Delayed Automatic Volume Control.

(1) In the circuit shown in A of figure 191, a certain amount of *avc* bias is developed even for weak signal inputs. In many applications, however, it is desirable to have maximum r-f and i-f gain available for weak signals. Some communication receivers permit switching off the *avc* with a manual cut-out switch, when it is desired to have maximum sensitivity available. This can be achieved automatically by means of a so-called *davc* (*delayed avc*) circuit, which prevents the application of *avc* bias until the signal strength exceeds a certain predetermined value.

(2) In B, the diode section, *D*1, of the twin diode acts as a detector and *avc* diode. *R*1 and *C*1 are the diode load resistance and filter capacitor, respectively, while *R*2 and *C*2 act as an *avc* filter to smooth out the audio variations so that the avc bias will be relatively constant for these frequencies. The audio output from the detector is taken from a tap on load resistance *R*1 and is coupled through *C* to the grid of the first audio amplifier stage. The cathode of diode section *D*2 is returned through a fixed supply voltage of −3 volts to the cathode of *D*1, and ground. This fixed voltage can be supplied by a small bias cell, or by connecting the cathode of *D*2 to a tap on a power supply voltage divider. Because of the presence of the fixed voltage, a direct current flows through *R*1 and *R*2 in series with diode *D*2. The voltage drop caused by this current places the *avc* tap at the lower end of *R*2 at approximately −3 volts, since the voltage drop across *D*2 is negligibly small. The 3-volt fixed bias is approximately the proper minimum value for maximum sensitivity of the remote cut-off tubes.

(3) For signals that are not strong enough to develop a rectified voltage across *R*1 in excess of 3 volts, the *avc* bias to the controlled tubes remains constant at −3 volts. For strong signals, however, the average value of the rectified signal voltage across *R*1 exceeds 3 volts, and thus cancels out the fixed 3-volt bias. Consequently, for signals exceeding 3 volts, the plate voltage at *D*2 becomes negative in respect to the cathode, and current stops flowing through *D*2. The *avc* voltage then is controlled solely by the rectified signal voltage developed across *R*1. Any further increase of the rectified signal voltage beyond 3 volts then progressively increases the *avc* bias to the controlled stages, and so reduces their gain. Other *davc* circuits than the one described are frequently used, but the above illustrates the basic principles. Duplex-diode triodes and duplex-diode pentodes can be

utilized to advantage to combine the functions of detection, *davc*, and audio amplification in one stage.

d. Quiet AVC.

(1) One disadvantage of *avc* is that it adjusts the receiver for maximum sensitivity when no signal is received. Hence, while tuning the receiver, the background noise between stations is often excessive. Automatic circuits have been developed for avoiding this condition by *muting* the receiver during tuning between stations. The most frequently used muting systems, known as *squelch* or *qavc* (*quiet avc*) circuits, utilize the *avc* bias to block the audio or detector stage, making the receiver silent during tuning.

(2) One arrangement utilizes the principles discussed above for securing a delayed *avc* voltage. The detector diode of a twin-diode tube, however, is negatively biased with a constant delay voltage. The detector section, therefore, normally is cut off by the negative plate voltage until a signal of preset intensity overcomes the diode bias voltage and allows the detector to function normally.

(3) Another popular circuit normally blocks the first audio amplifier tube and permits it to function only when a signal is received that is stronger than the noise. An ordinary diode detector and *avc* circuit are utilized in conjunction with a special control or *squelch* tube. The output of the detector is coupled to the grid of the first audio amplifier tube, which utilizes a cathode resistor to provide its *normal* bias. The control tube is an ordinary triode or pentode whose grid bias is controlled solely by the *avc* voltage. The plate current of this control tube is made to flow through a portion of the grid resistance of the first audio amplifier and develops a large negative bias voltage there. In the absence of a signal, no *avc* bias is applied to the control tube, and the plate current of the control tube will develop sufficient grid bias in the grid resistor of the audio amplifier tube to drive the tube to plate-current cut-off. Without an incoming signal, therefore, the audio amplifier is blocked. When a signal of sufficient strength is received, however, the *avc* bias applied to the grid of the control tube will drive it to cut-off, and plate current stops flowing. Without control-tube plate current, no additional grid bias (blocking voltage) will be developed in the grid resistance of the grid audio amplifier. The tube, therefore, will unblock and function normally. This system discriminates against all signals not sufficiently strong to cut off the control tube and so permit the first audio amplifier to operate normally.

144. Noise Discrimination

a. Types of Noise. Highly sensitive modern superheterodyne receivers always have some inherent background noise which appears in the output as hiss and crackles. Some noise arises in the tubes and circuits of the receiver itself because of shot effect, thermal agitation, and other random sounds. Most of this receiver noise comes from the input circuit of the first stage, and is amplified by each succeeding stage. This amplified noise masks noise generated in other stages. Lightning and man-made interference such as electrical appliances and automobile and aircraft ignition systems cause noise in receivers which usually appears as hiss. This can result from commutator sparking of electric motors. Spark and arc discharges, such as ignition sparks, switches, and power leaks, usually result in shot noises, consisting of pulses of very short duration but having amplitudes considerably higher than those of the desired signals themselves. It is this characteristic of impulse noises that makes it possible to devise circuits that can discriminate more against the noise pulses than against the desired signal.

b. Noise-Suppression Circuits.

(1) Two general methods have been successful in reducing impulse noise. One is to render the receiver inoperative during the brief duration of any pulse which appreciably exceeds the signal amplitude. Circuits for accomplishing this are known as *silencers*, or *squelch circuits.* They are similar in design and function to *qavc* (quiet automatic volume control) circuits. The other method of reducing impulse noise is to limit the operation of

the receiver to the maximum amplitude of any desired signal. Although the receiver output is not cut off, pulse amplitudes which are greater than the desired signal amplitude cannot be reproduced in the output. Circuits that accomplish this operation are called *limiters.* Since limiters reproduce the portion of the noise pulse that is less than the maximum desired signal amplitude, their effectiveness increases directly with the amplitude of the noise impulses. For noise pulses of very high amplitude, the improvement in signal-to-noise ratio is considerable.

(2) *Noise-silencing*, circuits usually are designed to bias the final i-f amplifier tube to plate-current cut-off for the duration of a noise pulse, thus silencing the receiver. In these circuits, noise voltages in excess of the maximum desired i-f signal voltage are taken off the control grid of the i-f amplifier tube. The noise voltage then is amplified by a pentode stage and is fed to a full-wave rectifier. The resulting d-c pulse output voltage is applied as an instantaneous negative bias to the same i-f amplifier tube. It reduces the gain or completely cuts off the tube, depending on the amplitude of the pulse. A variable resistance delay circuit, called *threshold control*, is incorporated in the rectifier so that rectification does not start until the noise voltage exceeds the maximum desired signal amplitude. The delay is obtained in the same way as in a delayed *avc* circuit.

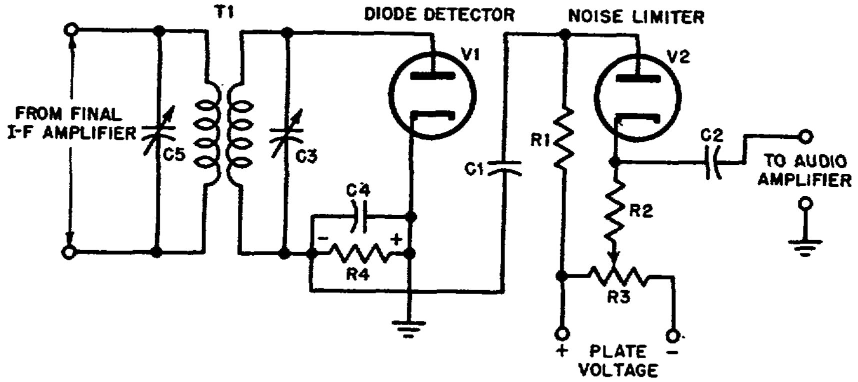


Figure 192. Typical audio noise limiter.

(3) Noise reduction also can be accomplished effectively by limiting the amplitude of the audio voltage that is applied to the a-f amplifier of the receiver. Such limiters are of simple design and keep the desired signal output nearly constant. However, this type of limiter cannot prevent large noise voltages from overloading the stages of the receiver ahead of the limiter. A typical noise limiter connected to a diode detector of a superheterodyne receiver is shown in figure 192. Diode *V*1 and its associated circuit act as an ordinary detector following the final i-f amplifier. Diode *V*2 operates as a valve through which the audio output of the detector must pass to the grid of the a-f amplifier tube.

(4) The steady diode current of *V*2 resulting from the positive plate voltage is modulated by the audio signal coming from the detector. As long as the plate of *V*2 is positive in respect to its cathode, conduction continues. Conduction ceases as soon as an audio noise voltage of sufficiently large magnitude swings the plate negative in respect to the cathode. The diode-current cut-off point is selected by the adjustment of *R*3. It is set so that the maximum desired audio signal just passes through *V*2. Noise pulses higher in amplitude than this maximum signal then are cut off. Fairly high audio signal voltages are required for good limiting action. The limiter can be used for both c-w and a-m signals.

145. Audio Amplification

a. Function of Stage. After the modulation has been extracted from an incoming signal, a relatively weak audio voltage is made available at the output of the detector. In practically all cases, this audio signal first must be strengthened by one or two stages of audio amplification before it is capable of energizing a pair of headphones or a loudspeaker. It is the function of the audio amplifier to raise the audio voltage from the detector to a comfortable listening level with a minimum of distortion. The amount of audio amplification needed depends on the power requirements of the reproducer. One stage of audio amplification generally is sufficient to operate a headset or a small loudspeaker. A large loudspeaker, however, requires a powerful audio amplifier consisting of several stages.

b. Voltage and Power Amplifiers.

(1) The audio amplifier must develop sufficient *power* to operate the reproducer properly. If the power requirements are large, several stages must be used. The last or *final stage* of the audio amplifier is designed to provide this needed power, and is therefore called the *power output stage.* By choosing triode, pentode, or beam power tubes with a high transconductance (g_m) for this stage, large plate currents can be made available with sufficient *grid excitation* (input voltage) to the tube.

(2) The power output stage must have sufficient grid excitation voltage that the full rated plate current is produced when the audio signal voltage at the input swings to its positive peak. In other words, the plate current of the power tube must reach its rated value for the maximum audio signal normally to be expected at the grid of the tube. To provide this value of grid excitation, one or more stages of *voltage amplification* are required. In a voltage amplifier the voltage gain of the stage is the primary objective, and the plate current or power output of the tube is of no interest. For this reason, high-u tubes, capable of providing large output voltages, are chosen as voltage amplifiers. Pentodes, which provide very high voltage gain, generally are preferred to triodes.

(3) If the reproducer requires little power, the detector stage often is combined with the first audio amplifier, which in turn is coupled to the power output stage.

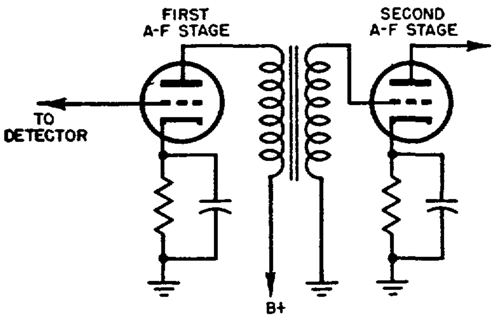
146. Coupling

Three methods generally are used to couple the amplifier audio signal from the plate of one amplifier stage to the grid of the succeeding stage (fig. 193). These are transformer coupling, illustrated in A, resistance coupling, in B, and impedance coupling, C. The grid of the first a-f stage is connected to the detector output. Depending on power and gain requirements, the second a-f stage can be either another voltage amplifier similar to the first, or it may be the power output stage that energizes the reproducer.

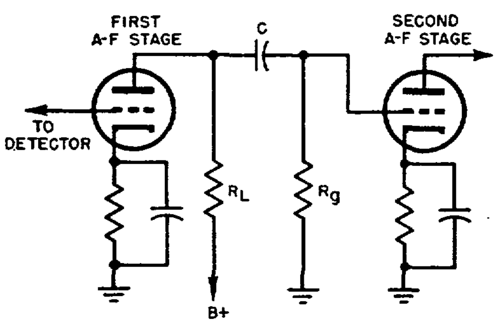
a. Transformer Coupling.

(1) The audio signal from the detector, shown in A, is impressed on the grid of the first amplifier tube, where it is amplified. The a-c component of the plate current develops a voltage across the primary of the interstage transformer, which in turn induces a voltage in the secondary. This voltage is applied to the grid of the second audio amplifier stage, where it is further amplified. Bias for each amplifier tube is supplied by a cathode resistor, which is bypassed for audio frequencies by a shunt capacitor.

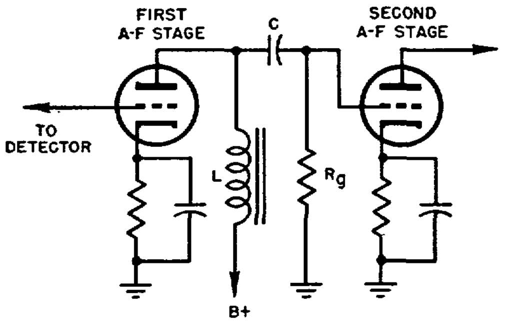
(2) The chief advantage of transformer coupling is that additional voltage amplification can be obtained by using a transformer with a step-up ratio between the primary and the secondary. Thus, if the voltage gain of the first a-f amplifier is 20, and the transformer has 1 to 3 step-up ratio, the total voltage gain from the grid of the first a-f stage to the grid of the second a-f stage is 3 times 20, or 60. The additional voltage step-up provided by the transformer was of some importance in the early days of radio, when only low-mu triodes were available. With the development of high-mu triodes and pentodes, this advantage became less of a factor.



TRANSFORMER COUPLING A



RESISTANCE COUPLING B



IMPEDANCE COUPLING C

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Figure 193. Audio interstage coupling methods.

(3) Disadvantages of transformer coupling are the bulkiness and high cost of properly designed interstage transformers. It is a fairly difficult matter to design a transformer that will pass all the frequencies of the audio range uniformly and meet low distortion requirements. Most transformers tend to accentuate a frequency band between about 3,000 and 4,000 cps. This is caused by resonance resulting from the transformer self-inductance and the distributed capacitance of the windings. Self-resonance also produces considerable harmonic distortion. Unless specially compensated, the frequency response of the transformer falls off rapidly at low frequencies, and also falls off at frequencies above the resonant peak.

b. Resistance Coupling.

(1) A coupling network consisting of a plate-load resistor R_L, a coupling capacitor C, and a grid resistor R_g, shown in B, is used to transfer the signal from the plate of the first a-f stage to the grid of the second a-f stage. As before, cathode bias is utilized. Because the coupling network adds no gain to the amplifier, high-gain pentodes generally are preferred to triodes (shown here to simplify the discussion) when resistance coupling is used.

(2) The amplification of the resistance-coupled amplifier can easily be made uniform over the entire audio-frequency range. However, extreme uniformity in frequency response must generally be paid for by some reduction in the gain available from the stage. The voltage amplification of the first a-f stage increases directly with the value of the plate-load resistance, R_L, up to an upper limit given by the numerical value of the *amplification factor of the tube.* If R_L is made too high, however, the available plate voltage at the tube becomes low, and the output voltage is reduced. The response at high frequencies also drops off somewhat as R_L is increased. Since grid resistor R_g is effectively in parallel with R_L, its value must be high to avoid excessive shunting, thus reducing the output voltage. R_g must not be too high, however, since otherwise the gas currents of the tube will set up a considerable *positive* bias, which can harm the tube. In practice, R_g usually is made from one

to two times the value of R_L. Coupling capacitor C blocks direct current at the plate of the first a-f tube from reaching grid of the second stage. Its reactance must be negligible at the lowest frequency that is to be amplified. Under this condition, the response at higher audio frequencies will not be affected. Recommended values for the coupling network, cathode bias resistor, and capacitor are given in tube manuals for various operating conditions and tube types.

(3) Resistance coupling is used almost universally for audio voltage amplifiers, since its performance is excellent, and it is inexpensive, compared with transformer coupling. Where negligible amounts of power are involved (that is, voltage amplification), resistance coupling has no disadvantages.

c. Impedance Coupling. The impedance-coupled audio amplifier shown in C can be considered a resistance-coupled amplifier in which inductance L has been substituted for plate-load resistance R_L. The inductor lowers the d-c voltage drop occurring in R_L, but maintains a high impedance at audio frequencies. In this way, a higher plate voltage is supplied to the first amplifier tube for the same available d-c supply voltage. Consequently, the voltage output of the first a-f tube is higher than for resistance coupling. Impedance coupling is used rarely, since it does not provide the voltage step-up of transformer coupling, and has the same disadvantages.

d. Output Coupling. Figure 194 shows a typical pentode power output stage. High-gm pentodes or beam-power tubes are preferred to triodes in this application, since they provide relatively high output power with a small grid excitation voltage. The input of the power stage can be resistance-coupled as shown, for transformer-coupled to the output of the preceding voltage amplifier stages. To attain optimum power transfer from the high-impedance output tube to the low-impedance voice coil of the speaker, the output of the power stage is always transformer-coupled to the speaker. (Impedance matching of the output stage is discussed in detail in paragraph 151.) A screen-dropping resistor, R_s, and bypass capacitor C_s are used. If screen grid and plate both can be operated at the same voltage, R_s and C_s are omitted. Cathode bias is shown in the diagram, although fixed bias occasionally is utilized in power output stages.

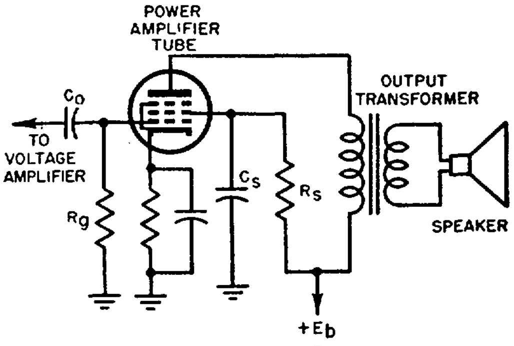

Figure 194. Output stage coupling.

147. Distortion

a. Frequency Distortion. If the audio amplifier does not pass uniformly all of the frequencies contained in the audio range (about 16 to 16,000 cps), it is said to have frequency distortion. For communication purposes, however, the primary objective is *intelligibility* rather than maximum fidelity. Good intelligibility is realized if the audio circuit amplifies frequencies from about 150 to 3,500 cps equally well. Frequency discrimination should be a minimum within at least this narrow band.

b. Harmonic Distortion. More serious is *harmonic distortion* produced by nonlinear circuit conditions. It will be remembered that vacuum tubes have characteristics that are not linear, especially at low plate currents and voltages. If the tube is operated in this curved portion of its i_p–e_g characteristic, the output current will not be proportional to the input voltage, and nonlinear distortion results. The output waveform then is no longer the same as the input waveform and contains frequency components that were not present in the input. These new frequencies in the output waveform are related harmonically to the frequencies present in the input circuit; that is, the added output frequencies are integral multiples of the input frequencies. Usually the second harmonic predominates, but odd harmonics also can be present. Harmonics cause unpleasant sound reproduction at the loudspeaker and therefore must be kept to a minimum. The primary source of *intermodulation distortion* is the presence in the desired signal of two or more strong frequency components which may or may not be harmonically related. The intermodulation distortion products are the sum and difference frequencies between any two or more strong signal components and are produced by the nonlinear characteristics of amplifier tubes.

148. Negative Feedback

a. When a portion of the output voltage of an amplifier tube is fed back to the input of the same or a preceding tube in opposite phase to the applied signal, *degeneration* takes place. A circuit for providing degeneration is called an inverse or *negative feedback* circuit. When degeneration is introduced in the circuit, the voltage fed back is opposing the applied input voltage and therefore reduces its amplitude. Since the feedback voltage subtracts from the applied input signal, the gain of the stage is reduced. Two important advantages compensate for this reduction in amplification. Frequency and nonlinear distortion both are reduced considerably for stages included in the feedback circuit. Also, the stability of the amplifier is increased materially.

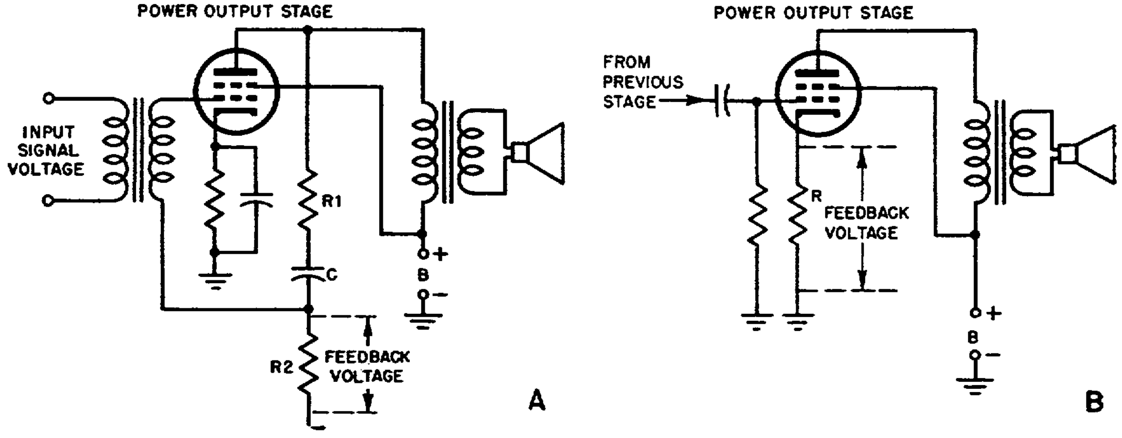

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Figure 195. Negative feedback circuits.

b. Two commonly used circuits (fig. 195) illustrate the application of negative feedback in audio amplifiers. In A, a voltage divider consisting of *R*1 and *R*2 is connected across the plate circuit of an audio output tube. Capacitor C between the two resistors prevents the d-c plate voltage from reaching the grid of the tube. The voltage divider applies a portion of the output voltage of the tube back to the grid. This voltage is equal approximately to the fraction *R*2/*R*1 plus *R*2 of the output voltage. The feedback voltage is in series with the input transformer secondary and in opposite phase to the voltage induced in that winding by the preceding amplifier stage. This feedback is known as *constant-voltage* feedback, since its magnitude depends on the output voltage. It frequently is used to reduce distortion in output pentodes or beam-power tubes.

c. In B, negative feedback is obtained by omitting the bypass capacitor across the cathode bias resistor. As a result, the portion of the output signal voltage developed across cathode resistance *R* opposes the signal input voltage between the grid and ground. Consequently, degeneration takes place, and the gain of the stage is reduced. It can be shown that the plate resistance of the output tube is increased at the same time. This method of feedback is called *constant-current* feedback, since the feedback voltage is proportional to the cathode current.

d. These two simple circuits of figure 195 illustrate the basic types of negative feedback. Much more elaborate circuits frequently are used. For example, a portion of the output voltage from the secondary of the output transformer may be fed back over several stages to the grid of some preceding amplifier tube. In this way the over-all frequency response can be improved and the distortion reduced at the expense of voltage amplification. To compensate for this reduction in gain, an additional amplifier stage may be required.

149. Radio-Frequency Amplifiers

The basic superheterodyne receiver will operate without an r-f amplifier. However, one or two tuned r-f stages ahead of the frequency converter are used almost always in modern superheterodyne receivers, since several important advantages can be attained with an r-f amplifier. The most important of these are suppression of image interference, improvement in selectivity, improvement in signal-to-noise ratio, and isolation between the antenna and frequency converter (radiation suppression). The addition of the r-f amplifier, of course, also improves the gain of the receiver, but this is not its primary function since gain is more efficiently obtained in the i-f amplifier. The circuit and operation of an r-f stage in a superheterodyne receiver is the same as that of the r-f stage in a trf receiver (ch. 7).

a. Image Response.

(1) It has been explained that the mixer stage generates an intermediate frequency which is the frequency difference between two signals beating together. The two frequencies involved are the frequency of the incoming signal and the local-oscillator frequency. However, *any two signals* whose frequency differs by an amount equal to the i-f can produce an intermediate frequency in the mixer stage. Since the mixer output and the succeeding *i-f* stages all are tuned to the intermediate frequency, they cannot discriminate between different signals—desired or undesired—that produce this frequency.

(2) As an example, consider a superheterodyne receiver tuned to a desired incoming signal of 600 kc, with an intermediate frequency of 455 kc. Assume that the oscillator is tuned *above* the frequency of the desired received signal, which is usually the case. The oscillator therefore is set at a frequency of 600 plus 455 = 1,055 kc, so that the frequency difference is equal to the *i-f* (fig. 196). Assume also that an *undesired* signal is received with a frequency of 1,510 kc, and that this signal is present at the input of the mixer. The 1,510-kc signal, known as the *image frequency*, also beats with the oscillator frequency of 1,055 kc to produce an i-f of 455 kc. Since both the desired 600-kc signal and the undesired 1,510-kc image frequency produce the same *i-f*, *image interference* is caused in the *i-f* amplifier that cannot be suppressed by the *i-f* stage itself. Image suppression can be provided only by the tuned circuits of the mixer and the *r-f* amplifier stages preceding it by preventing the interfering signal from reaching the grid of the mixer.

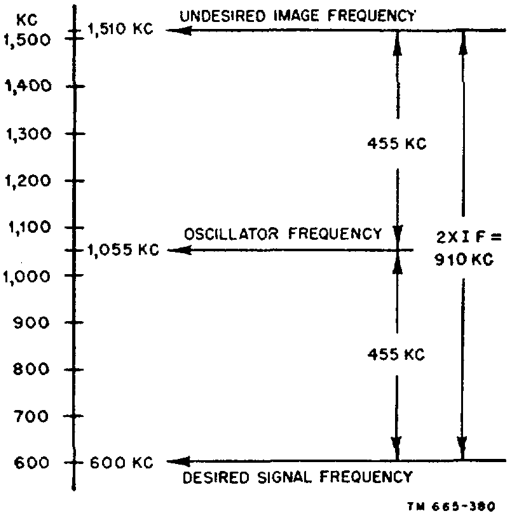

Figure 196. Image interference.

(3) The image frequency always differs from the desired signal frequency by an amount equal to *twice* the intermediate frequency. If the oscillator is tuned above the desired signal, the image frequency is the desired signal frequency plus twice the intermediate frequency. If the oscillator is tuned below the desired signal, the image frequency is the signal frequency minus twice the intermediate frequency. Consequently, the higher the image frequency compared to the signal frequency, the greater is the spacing between the desired signal and the image, and therefore the easier it is for the tuned circuits preceding the converter to suppress the response at the image frequency.

(4) For an *i-f* of 455 kc, the images of all but the lowest frequencies in the broadcast band (550 to 1,600 kc) fall outside the band. For those frequencies for which the image falls within the band (that is, signal frequencies below 1,600 minus 910=690 kc), the relative frequency separation between desired and image signal is so great that the image response of the tuned circuits is negligible. The same *i-f* of 455 kc in the short-wave band (6 to 30 mc), however, can cause bad image interference. For a signal of 20 mc, for example, the image frequency would be 20.91 mc (20 plus .910=20.91 mc), which is still a difference of 910 kc from the desired signal. The *relative* frequency spacing between desired and image signal is now only .91/20=.045, or 4.5 percent. It is clear that the tuned circuits of the r-f amplifier must be extremely selective to discriminate between signals separated by this small relative frequency difference. For application in the range from approximately 6 to 30 megacycles and also for very high frequencies, double conversion sometimes is used. For example, the incoming signal first may be converted to an intermediate frequency between 5 and 10 mc, and, after amplification, this frequency is *again* converted to a lower *i-f* of 445 kc. In this way, sufficient relative separation can be maintained between the signal and image frequencies. A receiver of this type is called a *double superheterodyne* receiver. Figure 197 shows a double conversion communication receiver.

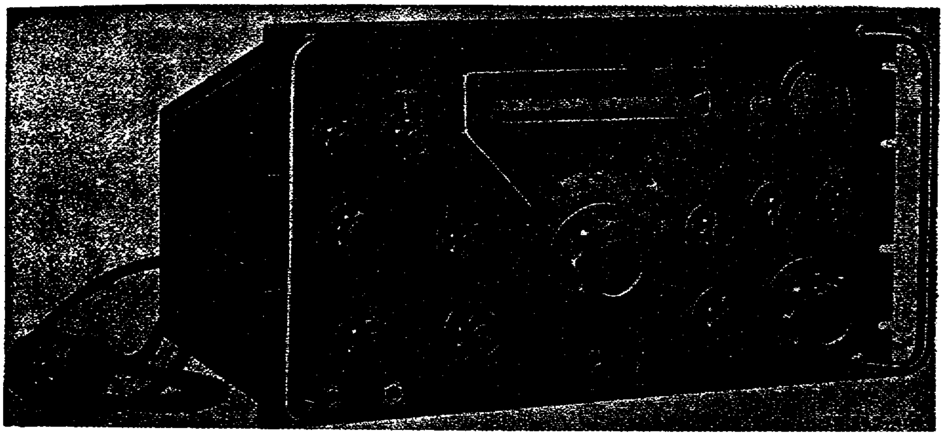

Figure 197. Communications receiver.

(5) If signal and image frequencies of equal strength are applied to the input of a receiver, the ratio of the signal voltage to the image voltage at the output of the receiver is called the *image rejection ratio*. As explained, the image rejection ratio increases with the intermediate frequency selected. For a *given* i-f, the image rejection ratio depends directly on the number and bandwidth of the tuned r-f circuits preceding the mixer tube. To obtain a sufficiently great image rejection ratio, some communication receivers operating at high frequencies utilize as many as three tuned r-f amplifier stages ahead of the mixer. In general, however, one of two tuned r-f stages are used.

(6) Besides images, other spurious signals can produce an intermediate frequency, and so cause interference. Harmonics of the local-oscillator frequency can beat with signals far removed from the desired frequency to produce an i-f output that can be heard. Heterodyning can occur also in the r-f amplifier itself, if sharp cut-off pentodes with nonlinear characteristics are used. Finally, harmonics generated by a nonlinear detector can be reintroduced in the r-f and mixer stages by stray coupling and cause interference by beating with the desired signals. Interference caused by beating the

desired signal and spurious frequencies is called *cross modulation*. To prevent this type of interference, high selectivity in the r-f stages, good isolation, and adequate shielding, especially of the local oscillator, are necessary.

(7) In addition to the spurious signals which can produce intermediate frequencies, there is cross-product interference—that is, sum and differences. For instance, if one listens to the frequency which is the sum or difference of two nearby stations, the two signals may be heard.

b. Signal-To-Noise Ratio. In addition to increasing the selectivity and image ratio of the receiver, a tuned r-f amplifier also improves the signal-to-noise ratio. The converter of a superheterodyne receiver has little gain and a fairly high amount of noise. If it is used directly after the antenna without an intermediate r-f amplifier, the converter contributes its noise to the signal, and amplifies it a little. Consequently, the signal-to-noise ratio is poor. The situation is reversed if an r-f amplifier is interposed between the antenna and the converter. The gain of the r-f amplifier is high, whereas its inherent noise is fairly low. Consequently, the initially weak signal is greatly amplified with little addition of noise, and the signal-to-noise ratio at the output of the r-f amplifier is high. Having reached this high level of amplification, the signal is little affected by the additional noise introduced by the converter stage.

c. Isolation. An r-f amplifier provides good isolation between the antenna and the converter stage. Changes in the load presented by the antenna for different frequencies cannot affect the mixer circuit, with an r-f amplifier interposed. Thus, less interaction takes place between the mixer and oscillator portions of the frequency converter. The isolation provided by the r-f amplifier also helps to keep the output of the local oscillator from reaching the antenna and being radiated. Finally, an r-f stage aids in preventing strong undesired signals at the antenna from reaching the mixer and detector stages, which can cause cross modulation, as described above.

d. Wave Traps.

(1) If strong signals in the intermediate-frequency range are present at the antenna of a receiver and reach the mixer, they will be amplified by the i-f amplifier and cause interference. *Wave traps* are simple parallel-resonant or series-resonant circuits (A and B of fig. 198) which eliminate signals in the i-f range, or other specific unwanted frequencies.

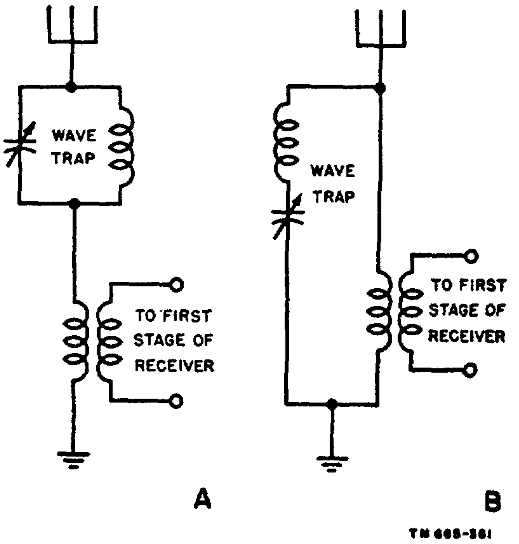

Figure 198. Wave-trap circuits.

(2) The parallel-resonant circuit in A is connected in series with the antenna and input transformer. It is tuned to the frequency of the i-f or other undesired signal. It will thus present to currents of this frequency a very high impedance, but permit currents of all other frequencies to enter the receiver.

(3) The series-resonant circuit in B is connected in parallel with the antenna input circuit. It is tuned to the frequency of the unwanted signal. It offers to currents of this frequency a very *low* impedance, and thus effectively bypasses these unwanted currents to ground. For currents of all other frequencies, however, the impedance of the wave trap is high compared to the antenna input circuit, and consequently little shunting results at these frequencies.

e. R-F Gain Control.

(1) The amplifier in the typical r-f stage, shown with both manual and automatic sensitivity control in figure 199, is of the

design used for trf receivers. The signal from the antenna or a preceding r-f stage is coupled by means of an r-f transformer to the tuned grid circuit of the amplifier tube. A remote cut-off pentode is used to provide the proper characteristic for smooth variation of gain with applied grid bias. The amplified output signal from the plate circuit is coupled through an r-f transformer to the tuned grid circuit of the following stage, which can be the mixer stage, or another r-f amplifier of similar design. The screen grid is supplied from the d-c voltage supply through the screen-dropping resistor, *R*2, which is bypassed for r-f by capacitor *C*2. Cathode bias is utilized.

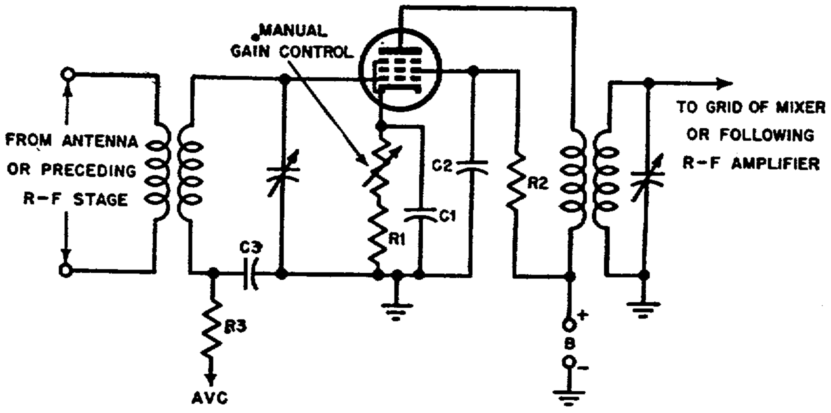

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Figure 199. Typical r-f amplifier stage with manual and automatic gain control.

(2) Both manual and automatic gain control are attained by varying the bias voltage present at the grid of the remote cut-off pentode. *Manual gain control* is secured in the cathode circuit by a variable resistor in series with a fixed resistor, *R*1. Both are bypassed for r-f by capacitor *C*1. *R*1 provides the necessary minimum bias to the grid of the tube when the manual gain control is set at zero resistance. By increasing the resistance of the gain control, more bias voltage is developed across the cathode resistance, which in turn reduces the amplification and gain of the stage. If a second r-f amplifier tube is used, its cathode may be tied to the cathode of the first r-f amplifier, to secure variable bias for both tubes from the same control. In this way, more effective gain control is realized.

(3) *Agc* (*automatic gain control*) is provided through introduction of an *avc* voltage into the grid circuit of the tube. The *avc* voltage is applied through the filter, *R*3 and *C*3, which prevents any residual i-f pulsations in the detector output from reaching the grid of the r-f tube. Capacitor *C*3 is inserted between the lower end of the input transformer secondary and ground to avoid shorting out the *avc* voltage. In elaborate communication receivers, an r-f gain control is provided in addition to the usual manual volume control in the detector or first audio stage. This permits satisfactory adjustment of receiver sensitivity and loudspeaker volume.

f. Tuning. The principles of tuning and tracking the mixer and oscillator circuits of a superheterodyne receiver have been discussed previously in this chapter. It was pointed out (par. 133) that a constant frequency difference equal to the i-f must be maintained between the mixer and oscillator tuned circuit throughout the frequency range of each band. If this condition is attained, the circuits are said to *track*. For convenience, the tuning capacitors are ganged together, and tracking is achieved by small fixed series and parallel capacitors. Tracking at the high-frequency end of each band is obtained by trimmer (parallel) capacitors, whereas tracking at the low-frequency end is assured by padder (series) capacitors. Padders usually are provided only for the local-oscillator circuit. When an r-f amplifier is used, the only change required in the tuning is the addition of an extra section in the ganged tuning capacitor for each r-f stage. Thus, for one stage of r-f amplification a three-gang tuning capacitor must be used, one section for the r-f tuned circuit, one for the mixer circuit, and one for the local-oscillator circuit. If a two-stage r-f amplifier is utilized, a four-gang tuning capacitor is required, for a three-stage r-f amplifier, a five-gang capacitor, and so on. For proper tracking, the r-f sections of the ganged capacitors are provided with trimmers.

g. Push-button tuning.

(1) Push-button tuning facilitates quick selection of one of a number of preset (fixed-tuned) frequency channels. This is frequently of importance in military communications when no time can be wasted on tuning adjustments, when interference is present on one of the assigned frequencies, or when a quick change must be made to some stand-by frequency. Push-button tuning systems can be either *electrical* or *mechanical*. In electrical systems, the resonant frequency of each tuned circuit is adjusted by switching the proper capacitor or coil into the circuit. In the mechanical system, the main gang capacitor is rotated either manually or by motor to the position corresponding to the desired frequency.

(2) When the push button is depressed in an electrical system, the resonant frequencies of the oscillator, mixer, and r-f amplifier tuned circuits must all be adjusted to the proper values for the reception of the desired transmitter signal. This can be done by substitution of the proper tuning capacitor or inductor, by adding extra capacitors or inductors to the circuit, or by adjustment of iron-dust cores in coils (slug tuning). If capacitors are inserted, they are in the form of trimmers, which can be *pretuned* to the proper frequency when alining the push-button system. In coil substitution, slug tuning is utilized to pretune each coil. An iron-dust core can be moved in and out of the coil by turning a threaded shaft to which the core is fastened. By adjusting these slugs manually, the inductance of the coil, and therefore of the frequency, can be preset. Depressing the push button then will switch the properly tuned coils into the various tuned circuits. Finally, the push button can be arranged for direct slug tuning, when it will move the iron-dust cores of the r-f amplifier, mixer, and oscillator coils into prearranged positions for each station selected. This is accomplished by a ratchet-and-cam mechanical system, connected to the shafts on which the iron-dust cores are mounted. In electrical systems, the proper coils or capacitors usually are connected into the tuned circuits by multiple switches fastened to the buttons themselves. Some switching arrangements, however, make use of relays and electrically operated contactors. Figure 200 shows a typical slug-tuned oscillator assembly in a modern military receiver.

(3) In simple mechanical systems, the pressure on the push button is utilized directly for turning the shaft of the main tuning capacitor to the desired position. In one popular arrangement the push button is in the form of a spring-loaded plunger to which are attached rods, the length of which can be adjusted to the correct value for each desired station. The capacitor shaft terminates in a flat piece of metal. When the button is depressed, the rods make contact with the metal plate and rotate it. The extent of the rotation depends on the length of the rods and their relative inclination. In more elaborate systems, a motor is geared to the shaft of the tuning capacitor for driving it. A special control device determines the direction and amount of rotation of the motor and so of the capacitor shaft for each station selected. Motor-driven *rotary switches* also are oc-

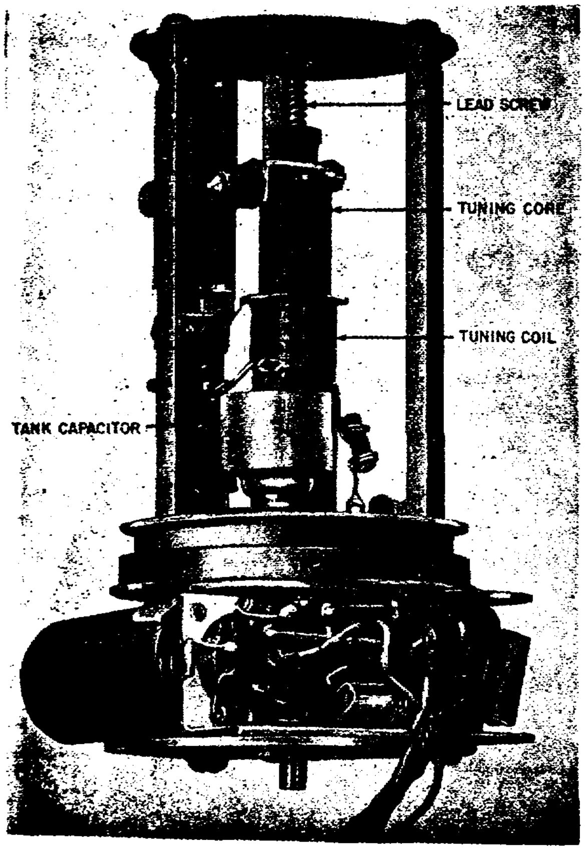

Figure 200. Slug-tuned oscillator coil.

casionally used. Motor-driven systems are especially suited for remote-control tuning of receivers.

150. Power Supply

a. General.

(1) Operation of vacuum tubes and other components of a receiver requires a source of energy which is the function of the power supply. The filaments of vacuum tubes can be heated by low-voltage a-c or d-c. The plates and screen grids, however, require essentially pure d-c of relatively high voltage for proper functioning. The power supply must be capable of furnishing these various voltages efficiently.

(2) A variety of power supplies can be utilized, depending on requirements (see TM 11-663). For small, low-power receivers and receiver-transmitters, batteries frequently are used. In larger portable and mobile equipments, the high-voltage d-c plate power is furnished by dynamotors or vibrators which are energized by storage batteries or hand generators. The filaments are supplied directly from storage batteries. Large semiportable installations generally are equipped with gasoline-driven generators, which provide a 110-volt, 60-cps, a-c power source. Fixed installations ordinarily use the available commercial a-c line supply. In this section, only a brief review is given of d-c and a-c power supplies used for low-power receiver applications.

b. Batteries. A *battery power pack* consisting of dry batteries may be used to furnish energy to small portable receivers of the handy-talkie and walkie-talkie type. The battery pack contains all necessary filament (A supply), plate (B supply), and grid (C supply) batteries for operation of the receiver. Separate filament, grid, and plate batteries are used in some receivers. Battery receivers generally utilize vacuum tubes that have low plate currents and require low filament voltages. In this way the current drain from the batteries is kept low, and continuous operation for several hours is possible, before the batteries must be replaced. Because batteries supply d-c, no rectifier and filter circuits are required in battery sets. In more elaborate receivers where relatively large voltages and currents are required, batteries have the disadvantage of being heavy and expensive to replace.

c. Dynamotor. A dynamotor is a combination small motor and generator, mounted on a common frame, which can obtain a high-voltage d-c output from a low-voltage d-c supply. The armature of a dynamotor carries two windings, each connected to a commutator at opposite ends of the shaft. A common single field winding is used to provide the magnetic field for the motor and generator portions of the unit. One armature winding, when energized by a low-d-c voltage (6- or 12-volt storage battery), produces the driving force to rotate the shaft. The other armature winding generates a high a-c voltage when rotated within a magnetic field. This high a-c voltage is changed to d-c by a commutator connected to the generator winding. Dynamotors are well shielded and equipped with interference suppressor filters in the high-voltage leads to smooth out the current and prevent radio interference caused by sparking between brushes and commutator segments. Efficiencies of approximately 50 to 60 percent normally are obtained when daynamotors are used.

d. A-C Power Supply. In fixed and large semiportable field installations, a-c power supplies generally are used. When available commercial 110-volt, 60-cps power lines are used. Otherwise, gasoline engine or diesel engine generators directly furnish the a-c voltage. For field installations, these generators are used almost universally. These generators provide 115/230-volt 60-cps a-c and are used to provide power similar to that supplied by commercial power lines. The output of these a-c supplies first must be transformed to the required voltage before it can be applied to the receiver. In addition to transforming the supply voltage to a lower value for the operation of filaments, and also to a much higher value for the operation of rectifier power supplies, an a-c perated power supply contains both rectifier and lter circuits to supply high-voltage d-c to those portions of the receiver circuitry which require it.

e. Rectifier Circuits.

(1) The ordinary diode vacuum tube is the most frequently used means for rectifying a-c. The *half-wave rectifier* A of figure 201, consists of a single diode connected between the power transformer secondary winding and the load. The load is represented by a simple resistance. Actually, it consists of the filter, voltage divider, and the receiver circuit. In operation, an a-c voltage is applied to the transformer primary which induces a similar voltage across the secondary. This secondary voltage appears at the diode plate. During the positive half-cycles, when the plate is positive in respect to the cathode, the diode conducts, and a current flows from the cathode to the plate through the transformer secondary and the load. During the negative half-cycles of a-c voltage, the plate is negative in respect to the cathode, and consequently no current can flow. It is seen, therefore, that current can flow in only one direction through the load resistance. The shape of the rectifier output wave is shown at the right, in the form of a pulsating d-c voltage.

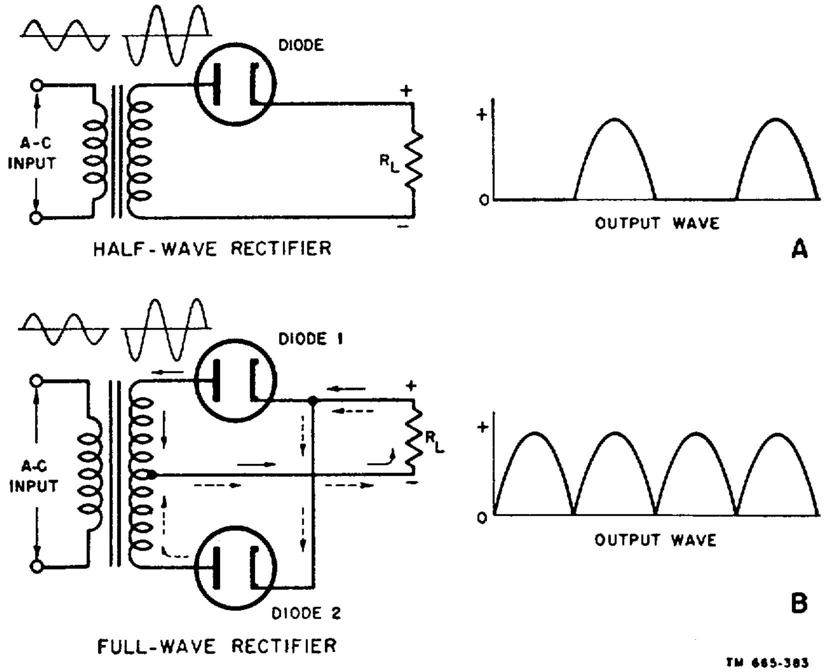

Figure 201. Vacuum-tube rectifier circuits.

(2) The *full-wave rectifier* circuit, in B, which utilizes both half-cycles of the applied a-c voltage is the most frequently used rectifier circuit for receivers. It combines the outputs of two half-wave rectifiers operating on opposite alternations of the full a-c cycle. A power transformer with a center-tapped secondary winding is required. During the first half-cycle of the applied voltage, the plate of tube 2 is positive in respect to the center tap of the transformer. Consequently, a current flows through diode 2, the lower half of the transformer secondary, and through the load, in a direction indicated by the dashed arrows. Current cannot flow through tube 1, since at this moment its plate is negative in respect to its cathode.

(3) During the next half-cycle of the a-c voltage, the polarity of the voltage across the transformer secondary reverses, making the plate of diode 1 positive in respect to the center tap. The plate of diode 2 now is negative, and no current flows through it. Current does flow through diode 1, then through the lower half of the transformer secondary, and through the load, as indicated by the solid arrows. It is seen from the arrows and the output waveshape that current always flows through the load resistance in the same direction. Since there are two d-c pulsations for each complete a-c cycle, the frequency of the pulsations at the output of the rectifier is twice that of the input frequency. This makes possible less output filtering than is required for the half-wave rectifier. Also, with both half-cycles utilized, the average d-c output voltage from the rectifier is higher than for the half-wave rectifier. For the comparatively low voltages required in receivers, the two diodes generally are combined in the same envelope to form a dual-diode.

(4) Compact *selenium* and *copper-oxide* rectifiers of sufficiently high voltage and current ratings often are used to replace vacuum tubes in the rectifier circuits of small receivers. Having no heaters, these metal rectifiers require no heating power. The selenium rectifier is especially popular. For comparable power, the voltage drop across its terminals is much less than for a diode-tube rectifier. Selenium rectifiers generally are built up as an assembly of circular or square disks that are mounted by means of a central hole. The current flows through the disks more easily in one direction than in the opposite direction, and consequently rectification takes place. By combining the proper number and size of disks, practically any voltage and d-c current rating can be obtained. For example, a 100-ma type consists usually of four disks, and measures only 1¼ inches in diameter and ¾ inch in height. Selenium or copper-oxide rectifiers can be used in the same circuits as vacuum tubes. Both half-wave and full-wave circuits are popular, as well as bridge-type circuits.

f. Filter Circuits.

(1) The d-c pulsations from the output of the rectifier must be smoothed out before they can be applied to the plate and grid circuits of vacuum tubes. This smoothing action is obtained by filter networks consisting of choke coils and capacitors (fig. 202). A is a typical *choke-input* filter and B is a *capacitor-input* filter. Only one filter section is shown in each diagram, but several identical sections often are used to improve the smoothing action.

(2) In A, the choke-input inductor readily passes d-c from the rectifier, but opposes any a-c pulsations. Fluctuations in the current that remain after passing through the choke are largely bypassed around the load by the shunt capacitor in the output of the filter. A small *a-c ripple* is still present in the filter output, but is considered negligible if it is less than 1 percent of the steady d-c voltage. A 1-percent ripple can be obtained in a typical receiver, for example, with a 10-henry choke and a 8-μf capacitor. The d-c output voltage of the choke-input filter changes little with changes in load and therefore is said to have good *voltage-regulation.*

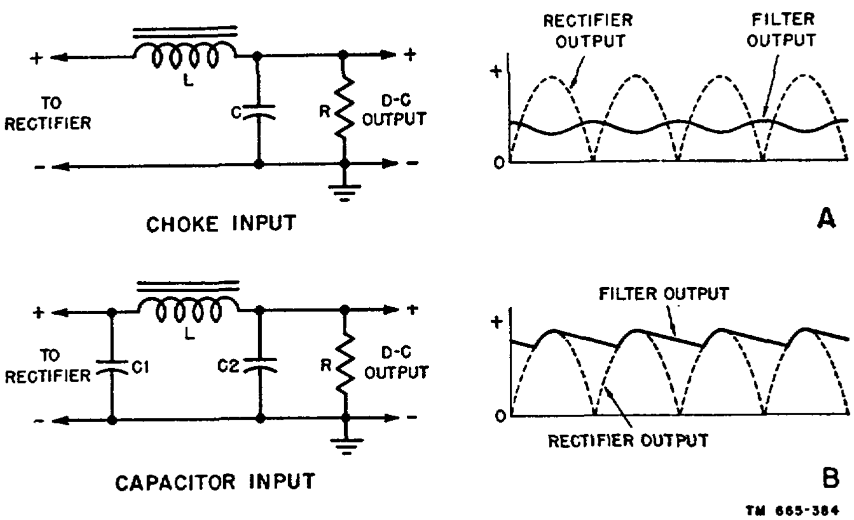

Figure 202. Filter circuits.

(3) The action of the capacitor-input filter, in B, is slightly different. The rectifier output voltage first charges the capacitor to the *peak value* of the pulsations. The capacitor tends to hold this charge between successive pulses, discharging slowly through the choke and load. Consequently, the voltage across the capacitor remains approximately constant near the peak value. Thus, the output voltage of the capacitor-input filter is higher than that of a choke input filter for the same input voltage. The remaining fluctuations of the current are opposed by the series choke, and bypassed to ground by the output capacitor. As before, an a-c ripple remains in the output. The voltage regulation of the capacitor-input filter is considerably poorer than that of the choke-input filter, because the output voltage falls off rapidly with increasing load.

(4) The resistance, *R*, connected across the output of each filter circuit is known as a *bleeder resistor*. Its purpose is to place a minimum load across the rectifier during the time when the receiver tubes are heating up and do not draw any current. In this way, an initial high-voltage surge is prevented when the receiver is turned on. The bleeder also serves to maintain a constant output voltage during changes in load. Finally, the bleeder resistor discharges the capacitors after the set has been shut off, and so helps to prevent dangerous shocks. The resistor may be provided with taps to act as a *voltage divider* for supplying the proper voltages to the different tube electrodes (ch. 2).

151. Reproducers

a. General. In the preceding chapters, the progress of a message spoken into a microphone at the transmitters has been followed through transmitter circuits to the transmitting antenna, from there to the receiving antenna, and finally through the various stages of the receiver to the output of the audio amplifier. The a-f output contains *in electrical form* the original modulation superimposed on the carrier at the transmitter. It is the function of the *reproducer* to convert the a-f current variations in the output stage of a receiver into audible energy corresponding to the sounds originally spoken into the transmitter microphone. Reproducers are *electromechanical* devices which translate the current variations at their input into corresponding mechanical vibrations at the output. These mechanical vibrations, in turn, generate the air-pressure variations which produce the sensation of *sound.*

b. Sound.

(1) Sound is the sensation of hearing caused by waves of vibratory energy striking

the mechanism of the ear and transmitted usually by air. These vibrations can be generated by a great many vibrating bodies, such as vocal cords (speech), the strings of a violin (music), the diaphragm of a telephone receiver, or the paper cone of a loud-speaker. When the diaphragm of a telephone receiver moves to and fro in accordance with the audio-frequency variations of the electrical current that energizes its coils, each outward movement of the diaphragm compresses the air in front of it, and each backward movement rarefies the air in front of the diaphragm. These alternate *compressions* and *rarefactions* travel outward from the telephone receiver as a disturbance, called *sound waves*. When the compressions and rarefactions that comprise sound waves enter the ear, they produce the *sensation* of sound.

(2) The ear of the average person is capable of hearing sound waves vibrating at frequencies from approximately 16 to 16,000 cps. For the purpose of intelligible speech communication, it has been found adequate to transmit and reproduce audio frequencies from about 150 to 3,500 cps. Actual sounds are usually *complex waves* containing many frequencies that are in harmonic relation to each other. The fundamental frequency of these harmonics (or *overtones*) is called the *pitch* of the sound, whereas the harmonics determine the *quality* of the sound. If the high frequencies containing most of the harmonics are not reproduced, the naturalness of the sound is diminished. Finally, the intensity of the sound waves determines the *loudness* which they are perceived by the ear. Depending on the frequency and type of sound, intensity variations of over 100,000,000 to 1 can be heard. This tremendous range of intensity cannot be reproduced by the average loudspeaker. Fortunately, realistic reproduction is attained with a much smaller range of about 100,000 to 1.

c. Loudspeakers.

(1) The loudspeaker must transform electric currents in the audio-frequency range into the corresponding sound waves. Sound waves are radiated best if the loudspeaker makes contact with a large surface of air surrounding it. For this purpose, the electromechanical *driving mechanism* of a loudspeaker is coupled mechanically or acoustically to fairly large cones or horns, capable of pushing large amounts of air in front of them. However, even with efficient designs, these radiators generally cannot transform more than 5 to 10 percent of the electrical input to the loudspeaker into corresponding sound energy. Furthermore, most loudspeakers produce considerable frequency and harmonic distortion of the a-f waveform. Harmonic distortion of the waveform occurs because the complicated loudspeaker driving mechanism cannot be made to act in a strictly *linear* manner. As in detectors, nonlinear operation introduces new (harmonically related) frequencies into the output, which were not present in the input.

(2) Frequency distortion occurs because the loudspeaker assembly and inclosing cabinet break into *mechanical resonance* at several frequencies within the response range. The moving parts of the loudspeaker assembly have a natural frequency of vibration, which depends on their mass, the stiffness of supports, the size of the paper cone or horn, and other factors. A very small audio input produces a very large vibration at this natural frequency, which is usually in the range between 50 to 200 cps. In addition, the speaker cabinet, like any other object, has a frequency of mechanical resonance which decreases the greater the mass of the cabinet. Mechanical resonances tend to accentuate unpleasantly the frequency band near resonance. Other effects tend to reduce the response at certain frequencies. Thus, if an open cabinet or sound board, called a *baffle*, is used to mount the speaker, the sound waves from the front of the cabinet or baffle tend to cancel the sound waves from the back at certain frequencies (*destructive interference*) and so reduce the response. If the baffle or cabinet is made large, this effect usually

occurs at frequencies at the lower end of the response range or below audibility.

(3) In general, the low-frequency response of a speaker improves in accordance with the increase in mass and size of the radiating element and its cabinet. However, these are exactly the conditions for *poor high-frequency response*. This is because at frequencies whose wavelengths are small compared to the diameter of the radiator (high frequencies=small wavelengths), the loudspeaker cone can no longer push the air in front of it efficiently. The mass of the moving mechanism becomes too great to follow the rapid variations at high frequencies.

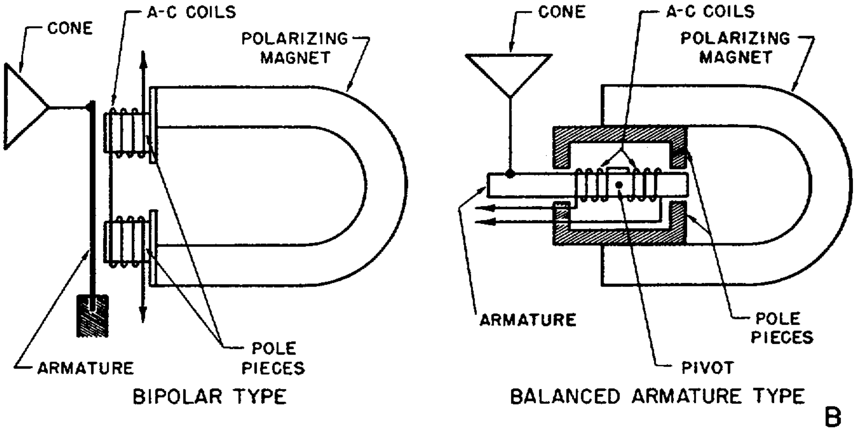

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Figure 203. Two types of magnetic speakers.

Various refinements have been made in the design of speakers to permit good reproduction at both low and high audio frequencies. In general, however, some compromise must be made between speaker size and desired frequency response, or two differently sized speakers must be used to cover the audio range.

(4) In Signal Corps receivers, the size of the speaker is determined chiefly by the considerations of size and weight, and little attention is paid to frequency distortion, although *harmonic* (nonlinear) distortion must be kept to a minimum for good intelligibility of speech. Although these considerations apply to all speakers, the driving mechanisms which translate the electrical variations into sound waves differ considerably and must be studied separately. Two main types of driving mechanisms are in use: electromagnetic systems, and dynamic (moving-coil) systems. The dynamic types can be classified, according to how they are energized, into electrodynamic and p-m (permanent-magnetic) types.

d. Electromagnetic Speakers. The earliest speakers were of the *electromagnetic* type (A of fig. 203). These are essentially large versions of telephone receivers or headphones and use the same type of driving movement.

(1) A permanent magnet is utilized with a coil of fine wire wound around each *pole piece*. The audio-frequency current flows through these coils in series. An *armature*, consisting of an iron diaphragm and a radiating cone, is mounted in the magnetic field of the permanent magnet near the pole pieces. The magnet exerts a *constant* pull on the armature, so that the diaphragm is under tension. Depending on the strength and polarity of the a-f currents, the magnetic field produced by the coils adds to or subtracts from this constant pull on the diaphragm. Its physical position near the pole pieces, therefore, fluctuates in accordance with the audio currents. These fluctuations of the diaphragm are translated into air-

pressure variations by the cone, or horn radiator, mounted on the armature.

(2) An improved type of magnetic speaker is shown in B. Here the armature is balanced in the center of the magnet between the pole pieces. Depending on the polarity of the a-f current flowing through the coils, the armature is pulled either to the right or to the left from the center position. The armature drives either a diaphragm or the cone-type radiator shown. In older types, a diaphragm was utilized over which a horn extension was mounted. More modern types use cone radiators.

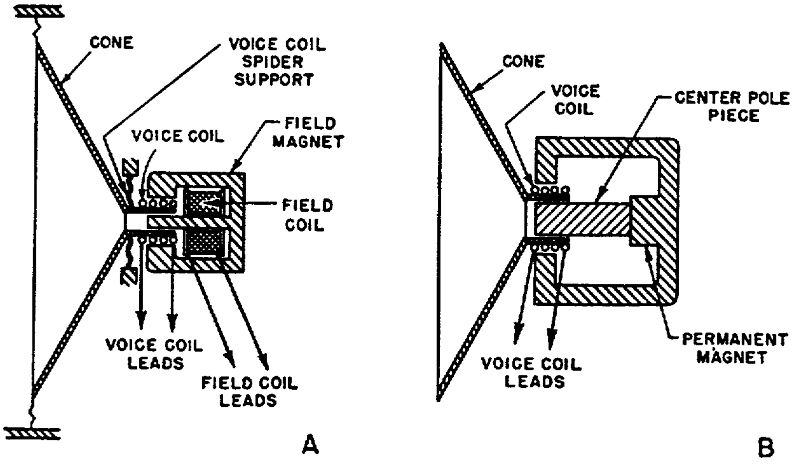

Figure 204. Dynamic speakers.

(3) Magnetic speakers sometimes are used in small portable receivers because they are highly sensitive, and compact. Since the a-c coils are wound with many turns of fine wire, they have a high impedence which approximately matches the plate impedance of audio output tubes. Consequently, no output transformer is required as for other types of speakers, and the speaker windings are connected directly in series with the plate circuit of the power amplifier. The bulk and cost of the output transformer can be an important factor in small portable radio receivers. The chief disadvantage of magnetic speakers, which has made them practically obsolete for general applications, is their *low acoustic output*. Although they are highly sensitive, they are overloaded easily. For large audio inputs, the mechanism becomes highly nonlinear, and the output becomes very distorted. The undistorted output of such a speaker is very small, particularly at the lower frequencies.

e. Dynamic Speakers. Most modern loudspeakers are of the *dynamic* type, in which a *voice coil* carrying the voice currents moves in and out of a strong surrounding magnetic field. The two basic types of dynamic speakers, the electrodynamic and the permanent-magnetic, or p-m, are shown in A and B, respectively, of figure 204. Except for the manner in which the magnetic field is produced, the action of these two types is identical. Dynamic speakers can provide high acoustic output with little harmonic distortion. Their frequency response can be made substantially uniform over the entire audio range. They are the most rugged speakers available. The discussion is based on the electrodynamic speaker, shown in A.

(1) As is apparent from the figure, a large electromagnet is used which has a central pole piece around which a coil of many turns is wound. This coil, which energizes the magnet, is called the *field coil*, and the entire magnet assembly is known as the *field magnet*. In the narrow pole gap of the magnet a small coil is suspended, consisting of a few turns of wire

wound around a paper or plastic form. This so-called *voice coil* carriers the audio currents from the output of the a-f amplifier. At one end of the voice coil is mounted a fairly large cone radiator made of stiff paper, treated cloth, or plastic material. The cone is held around its edges by a flexible suspension ring fastened to the metal framework of the speaker. At the other end of the moving assembly, another suspension keeps the voice coil in a central position in respect to the pole piece. This suspension, mounted at the juncture of the cone and voice coil, is known as the *spider*. It is constructed of flexible material, and permits forward or backward (longitudinal) motion of the voice coil, but no lateral (sideways) motion. The entire cone and voice-coil assembly is, therefore, free to move as a unit in a *longitudinal* direction. The clearance between the voice coil and the central pole piece is made small to concentrate the magnetic flux in the gap.

(2) When the field coil is energized by d-c of several watts power, a strong magnetic field is produced between the pole pieces of the electromagnet. The magnetic field produced by the a-f currents in the voice coil is at right angles to the field of the electromagnet. The two fields attract or repel each other, depending on the strength and polarity of the audio currents. Since the position of the electromagnet is fixed, the attraction or repulsion of the fields produces an inward or outward movement of voice coil and cone assembly. The movements of the voice coil can be made proportional to the strength of the a-f currents through it. The voice-coil vibrations, in turn, move the radiating cone, thus producing corresponding sound waves.

(3) The field coil which energizes the electromagnet generally is connected either in series or in parallel with the filter circuit of the rectifier power supply, and so is provided with fairly well filtered d-c. In the series connection, the field coil is used as an additional filter choke, and has a low-resistance winding to cut down the voltage drop across its terminals. In the parallel connection, the field coil acts as a bleeder, and must have a high-resistance winding to avoid excessive shunting. To neutralize the a-c ripple of the current flowing through the field coil, which causes hum, most speakers have an additional hum-bucking coil connected in series-opposing with the voice coil. Both the voice coil and the hum-bucking coil pick up a hum component from the field coil. However, since the hum-bucking coil is connected in series-opposition to the voice coil, its field cancels the hum component of the voice-coil field without affecting the a-f voice-coil currents.

f. Permanent-Magnet Speakers. In the *p-m* dynamic speaker shown in B, a permanent magnet is utilized to generate a strong magnetic field instead of an electromagnet. Highly efficient magnetic materials have been developed which provide high magnetic flux with relatively small-sized magnets. One very popular magnetic material is an alloy of *al*uminum, *ni*ckel, and *co*balt called *alnico*. As shown in the figure, the magnet is mounted to the inside back portion of the frame, so that it is in series with the magnetic circuit. The pole pieces concentrate the flux around the voice coil. The action of the p-m speaker is the same as that of the electrodynamic speaker discussed above.

g. Output Circuits.

(1) Loudspeaker output circuits are designed to transfer efficiently the a-f power from the audio output tubes to the voice coil of the loudspeaker. As previously explained (ch. 2), a power source delivers maximum energy to its load when the internal impedance of the source is equal to the load impedance. Consequently, for maximum power transfer from the output tube to the speaker, the voice-coil impedance should be made equal to (or *match*) the plate resistance of the output tube. This is not possible, however, for several reasons. To insure sufficient lightness and rugged construction in the small space available, the voice coil is wound with a few turns of low-resistance wire. The impedance of the average voice coil at low frequencies, therefore, is generally from 2 to 8 ohms. This in-

cludes the resistance of the winding as well as the inductive reactance, which varies widely with frequency and the acoustic loading of the speaker. In contrast, the plate impedance of the output tube varies between 2,000 and 10,000 ohms, depending on the type of tube and output circuit. Obviously, very poor power transfer would result if the voice coil were directly connected into the plate circuit of the output tube. In addition, the output from the tube would be badly distorted.

(2) To achieve the proper *impedance match* between the voice-coil impedance and the plate impedance of the tube, an *output transformer* with a step-down ratio is utilized in the output-tube plate circuit. By use of a transformer with the proper turns ratio, the low voice-coil impedance across the secondary winding will be *reflected* as a high impedance across the terminals of the primary winding to match the plate impedance for optimum operation. Figure 205 shows two typical output circuits with an output transformer. The circuit in A is called *single-ended*, since only one output tube is utilized. The output transformer is connected in series with the plate and the d-c plate-supply voltage. It is a step-down transformer with many turns in the primary circuit, and fewer turns in the secondary circuit. In practice, the voice-coil impedance is *not* matched to the value of the plate resistance of the tube, since this would operate the tube in a part of its characteristic where considerable distortion is present. To avoid this distortion, a part of the available power is sacrificed. It is found that a good compromise between power output and distortion is reached when the plate-load impedance (of triodes) is made from two to three times the value of the plate resistance of the tube. The value of the *optimum load impedance* for a particular tube and type of operation is given in tube manuals. The voice-coil impedance is matched to the value of this optimum load impedance.

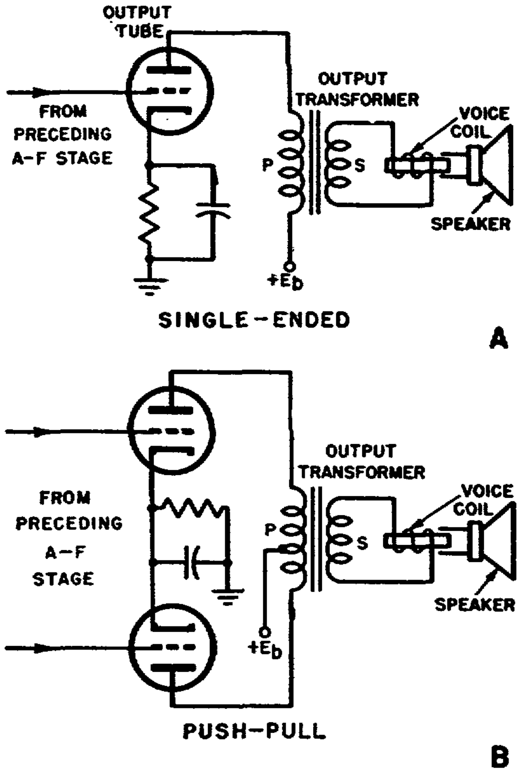

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Figure 205. Loudspeaker output circuits.

(3) In B, showing a triode *push-pull* output circuit, the plate circuits of the two tubes are connected in series through the output transformer. The transformer is provided with a center tap on the primary to permit feeding equal d-c plate voltages to the tubes from the common power supply. The primary winding must have a sufficient number of turns—considerably more than in a single-ended transformer—that each *half* of the winding matches the recommended plate-load impedance of one tube. Equivalently, the *full* winding must match the recommended *plate-to-plate load impedance* of *both* tubes. The *plate-to-plate load impedance* for two tubes is generally from approximately one and a half to three times the value for a single tube. The optimum value for low distortion is given in tube manuals for a variety of

operating conditions. The output transformer must match the voice-coil impedance to this optimum plate-to-plate load impedance.

(4) As previously explained, the *impedance ratio* of a transformer is approximately equal to the *square of the turns ratio.* Expressed differently, for a desired impedance ratio between primary and secondary, the *turns ratio* between primary and secondary must be equal to the *square root of this impedance ratio.* The mathematical formula is

$$\frac{Z_p}{Z_s}=\left(\frac{N_p}{N_s}\right)^2 \text{ or } \frac{N_p}{N_s}=\sqrt{\frac{Z_p}{Z_s}}$$

where

Z_p= the primary impedence=recommended plate-load impedance,

Z_s= the secondary impedance=loudspeaker voice-coil impedance,

N_p= the number of turns on the primary winding,

N_s= the number of turns on the secondary winding,

N_p/N_s= the primary-to-secondary turns *ratio.*

(5) For example, assume that it is desired to find the turns ratio required to match a 10-ohm voice-coil impedance to a 10,000-ohm recommended plate-load impedance of a single-ended output stage. The output transformer requires a primary-to-secondary turns ratio equal to

$$\frac{N_p}{N_s}=\sqrt{\frac{Z_p}{Z_s}}=\sqrt{\frac{10{,}000}{10}}=\sqrt{1{,}000}=31.6$$

This means that the primary winding must have 31.6 times as many turns as the secondary winding.

(6) As another example, the recommended plate-to-plate load impedance of a push-pull output stage is 9,000 ohms, and the output transformer has a primary-to-secondary turns ratio of 39. What should be the voice-coil impedance of the loudspeaker connected across the secondary to match the recommended primary load impedance?

$$\frac{Z_p}{Z_s}=\left(\frac{N_p}{N_s}\right)^2 \quad (39)^2=1{,}520$$

and therefore,

$$Z_s=\frac{Z_p}{1{,}520}=\frac{9{,}000}{1{,}520}=5.9 \text{ ohms}$$

A voice-coil impedance of 6 ohms, the nearest commercially available value, will match closely the plate-to-plate impedance of the push-pull output tubes.

152. Typical Superheterodyne Receiver

The superheterodyne receiver (fig. 206) is an eight-tube superheterodyne, consisting of one stage of tuned r-f amplification, a pentagrid mixer and local h-f Hartley oscillator, one stage of i-f amplification, a combined detector, *avc*, a first a-f amplifier stage and a push-pull power-amplifier stage. The receiver is operated from the 110-volt a-c line through a full-wave rectifier power supply and filter circuit. The power supply provides both the high-voltage d-c for the plates and screen-grids, and the low-voltage a-c for the heaters of the vacuum tubes. A detailed circuit analysis follows:

a. Antenna Input and R-F Amplifier. A signal intercepted by the receiver antenna is coupled to the grid of the r-f amplifier tube *V*1, through the r-f input transformer, *T*1. The grid-input circuit of the tube is tuned to the desired signal with a tank circuit consisting of the secondary of *T*1 and variable capacitor *C*1. *C*1 is ganged to the mixer and oscillator tuning capacitors. The selected signal then is amplified by *V*1 and fed to the mixer stage through the r-f coupling transformer, *T*2. An *avc* voltage is applied to the grid of *V*1 through *R*1.

b. Local H-F Oscillator. The local oscillator, consisting of *V*7 and associated circuits, generates oscillations higher than the r-f carrier frequency by an amount equal to the i-f (say 456 kc). For this purpose a conventional Hartley oscillator is used, and its output from the grid of triode oscillator tube *V*7 is coupled through *C*22 to injection grid 3 of the pentagrid mixer tube, *V*2. The oscillator is tuned with the ganged tuning capacitor, *C*3. A parallel trimmer capacitor, *C*24, assures tracking at high frequencies. A series padder capacitor, *C*25, is used for low-frequency tracking; it is made adjustable by means of a small parallel trimmer, *C*26.

c. Mixer. The r-f and local-oscillator frequencies are mixed in the pentagrid mixer tube, *V*2.

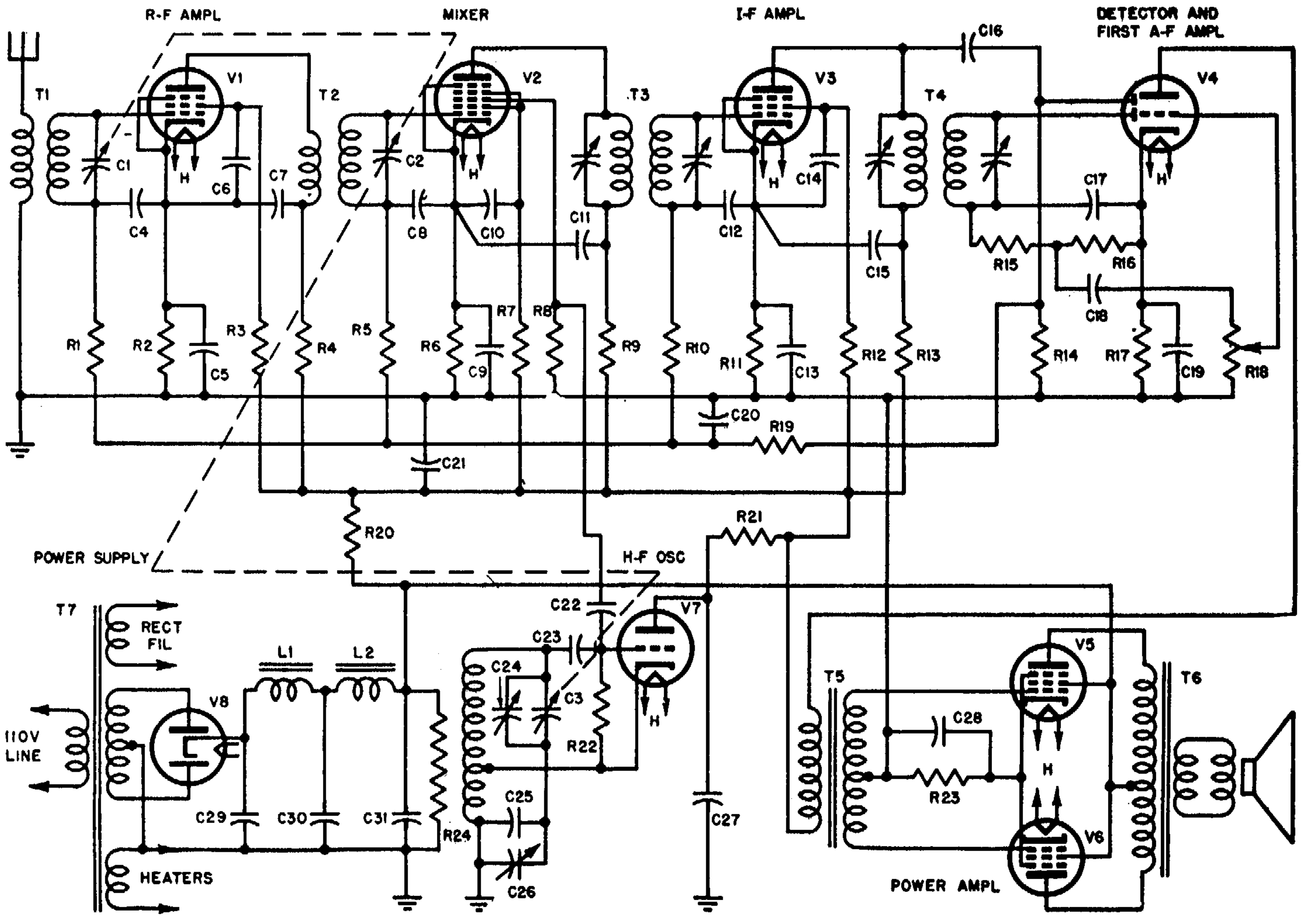

Figure 206. Typical superheterodyne circuit.

The r-f signal is fed to grid 1 of the mixer tube from the tuned input circuit of $T2$ and $C2$. Tuning capacitor $C2$ is ganged with the r-f and oscillator tuning capacitors for single-control tuning. As mentioned, the local-oscillator signal is applied to grid 3 of the mixer tube. The r-f and local-oscillator frequencies are mixed in the electron stream of the mixer tube, producing a number of sum and difference frequencies in the plate output circuit. The i-f transformer, $T3$, in the plate circuit of the mixer tube is tuned to the *difference frequency* (i-f) present in the output of the tube.

d. I-F Amplifier. A conventional i-f stage is used consisting of i-f amplifier tube $V3$, input i-f transformer $T3$, and output i-f transformer $T4$. Both transformers are tuned to the intermediate frequency (456 kc). The i-f signal is coupled through $T3$ to the control grid of the pentode i-f amplifier tube, $V3$. The amplified output from the plate of the tube is coupled through i-f output transformer $T4$ to the diode detector stage.

e. Detector Avc, and First A-F Amplifier. A duplex-diode-triode, $V4$, is used in this stage to combine the functions of a diode detector, *avc*, and first a-f amplifier. The i-f signal is coupled through i-f transformer $T4$ to the lower diode section of $V4$, which acts as the detector. Series resistors $R15$ and $R16$ form the detector load resistance, and $C17$ is the load capacitor. The audio output from the detector is tapped off at the junction of $R15$ and $R16$ and is coupled through blocking capacitor $C18$ and volume control $R18$ to the grid of the triode amplifier portion of $V4$. The volume control is a tapped variable resistor to permit feeding any portion of the a-f output voltage to the grid of $V4$. The a-f signal is amplified by the tube and is coupled to the power amplifier through interstage coupling transformer $T5$. I-f voltage from the plate of the preceding i-f amplifier also is fed through blocking capacitor $C16$ to the upper diode section of $V4$, which rectifies the signal voltage for *avc* purposes. $R14$ is a *separate avc* diode load resistor. The d-c *avc* voltage developed across this resistor is applied to the grids of r-f amplifier $V1$, mixer $V2$, and i-f amplifier $V3$ through the *avc* filter, $R19$ and $R20$, which eliminates the audio component from the rectified *avc* voltage.

f. A-F Power Amplifier. The audio output from the plate of $V4$ is fed to the grids of the power amplifier pentodes, $V5$ and $V6$, through the interstage coupling transformer, $T5$. This transformer is center-tapped to apply the audio signal in opposite phase relation to the grids of the two tubes, a necessary condition for push-pull operation. The output from the power amplifier is coupled to the voice coil of the loudspeaker through the center-tapped output transformer, $T6$. The transformer assures a correct match between the voice-coil impedance and the recommended plate-to-plate load impedance of the amplifier.

g. Power Supply. The 110-volt, 60-cps a-c line input is coupled to the plates of full-wave rectifier tube $V8$ through power transformer $T7$. The transformer carries additional windings to supply the rectifier filament and the heaters of the receiving tubes. The pulsating d-c output from the rectifier tube is applied to a two-stage capacitor-input filter consisting of filter capacitor $C29$, $C30$, and $C31$, and filter chokes $L1$ and $L2$. A bleeder resistor, $R24$, is connected across the filter output to provide a minimum load and improve the voltage regulation.

153. Tuning Indicators

Highly selective modern superheterodyne receivers generally require some form of tuning aid to indicate when the receiver circuits are accurately tuned to the center (carrier) frequency of the incoming signal. Mistuning causes sideband cutting and consequent distortion. Because the *avc* circuit tends to maintain the loudness level of the receiver output, even for considerable mistuning, it is difficult to judge by the ear alone when the receiver is tuned properly. Two types of *tuning indicators* are in general commercial use—meter indicators and electron-ray, or *magic-eye*, indicators. However, the Signal Corps uses only the tuning meter type of indicator.

a. Meter Indicators. The simplest type of tuning indicator is an ordinary direct-current meter connected in series with the plates of the *avc*-controlled *i-f* or *r-f* tubes, or both. The range of the meter may be from a few hundred microamperes to a few milliamperes, depending on receiver sensitivity. When the receiver tuning is off frequency, the grid bias on the *r-f* and *i-f* tubes is low, and consequently the plate current is high. As the receiver is tuned more closely, the *avc* circuit applies increasing negative bias to the tubes, and the plate current *decreases*. The correct tuning point is indicated by minimum plate current registered by the meter. Since the pointer deflection decreases as the correct tuning point is approached, meter-type tuning indicators often are mounted in an upside-down position. Scale calibration points may be provided to indicate the relative signal strength. In some receivers, the tuning meter reads the unbalanced current of a bridge circuit connected across the *avc* line. A *forward* meter indication is obtained in this case, and the meter can be mounted in the conventional position.

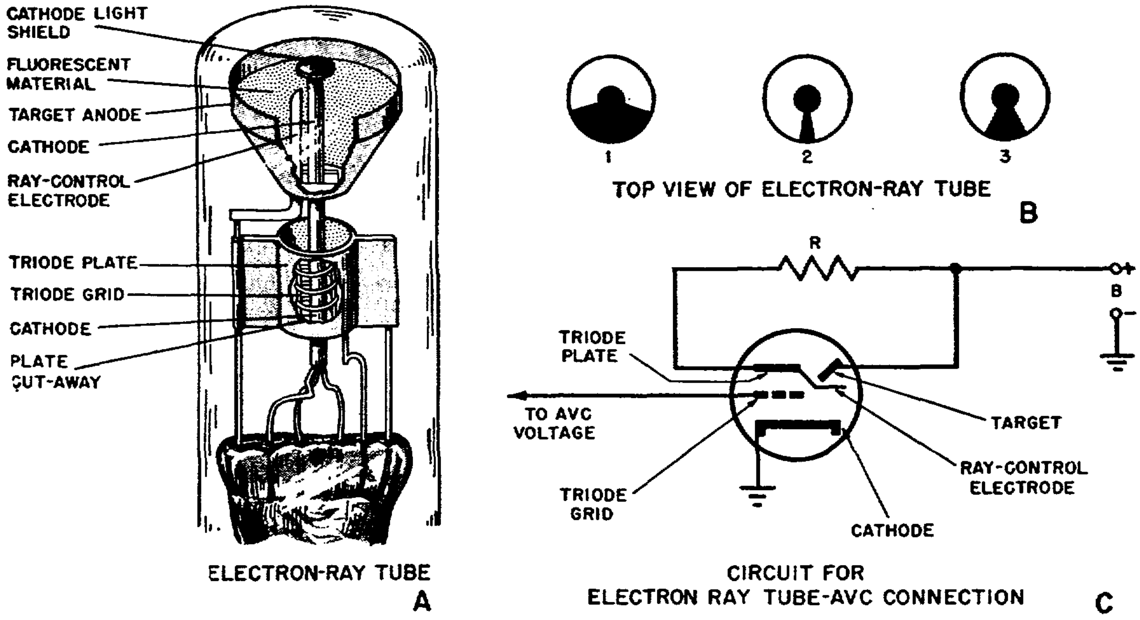

Figure 207. Electron-ray tube tuning indicator.

b. Electron-Ray (Magic-Eye) Indicators.

(1) Electron-ray indicators are used frequently as visual tuning aids in modern receivers. The tube consists of a double-electrode system combining a miniature cathode-ray tube and an ordinary triode in the same envelope (A of fig. 207). In addition to the triode, two special electrodes are utilized, namely the *target* and the *deflector*, or *ray-control electrode.* The target is connected to the plate voltage supply of the receiver. Operating at a high positive voltage, it attracts electrons from the cathode of the tube. When electrons strike the target they produce a greenish glow on its fluorescent coating. Under these operating conditions, the target appears as a ring of green light.

(2) The deflector or ray-control electrode is mounted between the cathode and the target. It has the form of a thin vertical vane which shades part of the target. When the ray-control electrode is less positive than the target, electrons flowing to the target are repelled by the field of the ray-control electrode and do not reach the portion of the target behind the electrode. Since these shielded portions of the target do not glow, the ray-control electrode casts a shadow on the target. The width of the shadow depends on the relative voltages on the target and the ray-control electrode. When the control electrode is much more negative than the target, the shadow angle is approximately 100°, as shown in 1, B of figure 207. The shadow angle approaches 0° when the control electrode is at about the same potential as the target shown in 2, B. For intermediate relative voltages on the target and control electrode, the shadow has some value between these two extremes, which is 3, B. A dark spot in the center

of the ring of light is caused by the *cathode light shield* which is purposely added to make the deflection more noticeable.

(3) The basic circuit connections of the electron-ray tube are shown in C. The grid of the triode section is connected to the *avc* voltage. When no signal is received, the *avc* voltage is zero; therefore, the bias on the triode control grid is also zero. Consequently, a high plate current flows through the tube and produces a large voltage drop across the plate load resistance, *R*. This voltage drop subtracts from the voltage on the plate, and consequently from that on the ray-control electrode, which is internally connected to the plate. The voltage on the ray-control electrode, therefore, will be much less than that on the target, which is connected to the high-voltage plate supply. For this condition, the shadow angle is a maximum.

(4) When the receiver has been properly tuned to the carrier of a radio station, the *avc* voltage is a maximum, and therefore the triode control-grid bias is highly negative. Consequently, the plate current is low, and the voltage drop across *R* is small. The ray-control electrode has nearly the same voltage as the target, and therefore the shadow angle is a minimum. The greater the strength of the signal, the larger will be the *avc* bias, and the smaller the minimum shadow. The electron-ray tuning indicator, therefore, indicates both correct tuning and signal strength.

154. Summary

a. The superheterodyne receiver differs essentially from the trf receiver in that it changes the frequency of the received signal to a lower, fixed value, at which the tuned amplifying circuits can be designed to operate with maximum stability, selectivity, and sensitivity. It has fewer tunable circuits and is easily adapted to multiband reception.

b. The conversion of the received signal into a lower i-f frequency is based on the *heterodyne* principle.

c. When a modulated radio signal is heterodyned with a locally generated signal, the envelope of the resulting beat frequency (i-f), contains the modulation of the original radio signal.

d. Two r-f signals of different frequency will interact only if they are combined in a *mixer* with a *nonlinear* characteristic. Besides the difference frequency between the two signals, a mixer generates numerous harmonic, sum, and difference frequencies between harmonics. Of these, only the difference frequency (i-f) of the original signals is selected by a tuned circuit in the output of the mixer stage.

e. The principle of frequency conversion inherently provides higher selectivity than a trf circuit. It increases the relative frequency separation between closely spaced adjacent carriers.

f. The basic components of a superheterodyne receiver are the antenna, the r-f amplifier, the frequency converter consisting of mixer and local oscillator, the i-f amplifier, the detector, the a-f amplifier, and the reproducer.

g. Frequency conversion is accomplished by vacuum-tube oscillator and mixer circuits. The plate current of the mixer tube is varied at the combination frequency of the signal and local-oscillator frequencies to produce the desired intermediate frequency, which is the difference between the two.

h. Separate mixer and oscillator tubes may be used—triodes, pentodes, or pentagrid mixers. The mixer and oscillator tubes also can be combined in one envelope, as in a triode-heptode, triode-hexode, or pentagrid converter.

i. The local-oscillator and signal voltages can be inductively or capacitively coupled and impressed on the same grid of the mixer (single-electrode input), or they can be applied to two different grids of the mixer (double-electrode input) In the latter, coupling is provided by the common electron stream of the tube.

j. The *conversion transconductance* is the ratio of the i-f current at the output of the mixer tube to the r-f signal voltage applied to the grid of the mixer.

k. The *conversion efficiency*, or *conversion gain*, is the ratio of the i-f output *voltage* from the mixer to the r-f input voltage to the mixer.

l. Triode and pentode mixers operate like plate detectors and are characterized by high conversion gain, low noise level, and low cost. They have the disadvantage of causing undesirable coupling (pulling) between the mixer and the oscillator. *Frequency pulling* is the term applied to the change in the oscillator frequency when the tuning of the mixer input is adjusted.

m. Pentagrid mixers avoid pulling by providing complete isolation between the oscillator and r-f signal circuits. They also have excellent stability at high frequencies.

n. A constant frequency difference (called *frequency tracking*) is maintained between the mixer and oscillator circuits by means of trimmer capacitors at high frequencies, and by *padder* capacitors at low frequencies. These are connected in parallel or in series, respectively, with the main oscillator tuning capacitor.

o. The selectivity, fidelity, and gain of the superheterodyne receiver is controlled to a major extent in the intermediate-frequency amplifier stages.

p. I-f amplifiers can be one-, two-, or three-stage vacuum-tube amplifiers, each stage being provided with an input and output *i-f transformer*.

q. The i-f transformer usually consists of two coupled resonant circuits, whose band-pass characteristics depend on the degree of coupling. If the coupling is greater than the *critical value*, a double-peaked resonance curve results, which provides substantially uniform response between peaks. The band-pass characteristic is controlled by the separation of the peaks.

r. The selectivity of each i-f amplifier stage depends on the Q and the coupling of the i-f transformer. The *over-all* selectivity is proportional to the number of tuned i-f circuits utilized.

s. The gain attained in each i-f stage depends on the required relative bandwidth, the intermediate frequency, and the transconductance, g_m, of the amplifier tube.

t. The selection of the intermediate frequency is a compromise between the desired selectivity and gain on the one hand, and the permissible amount of pulling and *image interference* on the other hand. The higher the i-f, the lower is the selectivity and gain; the lower the i-f, the greater is the possible image interference and pulling.

u. Most superheterodyne receivers use a diode detector, because its linear characteristics give it high signal-handling ability with low distortion. A diode detector, however, has poor selectivity and low sensitivity.

v. Automatic volume control maintains approximately constant signal input to the detector—regardless of signal strength—by making the gain of the r-f and i-f stages less for a strong signal than for a weak signal. *Avc* thus prevents overloading of the r-f, i-f, and detector stages and eliminates extreme variations in loudspeaker volume caused by tuning or fading.

w. An *avc* circuit derives a negative bias voltage proportional to the carrier amplitude by rectifying the carrier with a diode detector.

x. In a delayed *avc* circuit, the application of the *avc* voltage to the grids of the preceding r-f and i-f amplifiers is delayed until the signal strength exceeds a given value.

y. Quiet *avc* eliminates the high background noise present during tuning by muting the receiver between stations.

z. The function of the audio amplifier is to strengthen the a-f output from the detector to a comfortable listening level. One stage of audio amplification usually is sufficient to operate a headset or a small loudspeaker. Several stages may be required to provide sufficient power to operate a large speaker.

aa. The power to operate the speaker is developed in the final audio stage, called the *power amplifier*. The grid excitation voltage needed to operate the power amplifier is provided by one or more stages of *voltage amplification*.

ab. Coupling between a-f stages can be made by means of transformers, impedances (chokes), or resistors and capacitors. Transformer coupling provides additional voltage step-up, but is bulky and expensive. Resistance-capacitance coupling has excellent frequency response. Impedance coupling is used in special applications only.

ac. Frequency distortion takes place in an audio amplifier, if the frequencies of the audio band (16 to 16,000 cps) are not uniformly amplified. Some frequency distortion does not reduce the *intelligibility*.

ad. Harmonic distortion occurs in a-f amplifiers if nonlinear circuit elements introduce harmonic frequencies into the output which were not present in the input of the amplifier. Beat frequencies between those harmonics cause *intermodulation distortion*.

ae. Negative feedback is degeneration of the input signal produced by feeding back a portion of the output voltage from the plate of the output tube to the input of the same or a preceding tube out of phase with the applied voltage.

af. The r-f amplifier in a superheterodyne receiver provides the following advantages: suppression of image interference, improved selectivity, improved signal-to-noise ratio, and isolation between the antenna and frequency-converter stage (reradiation suppression).

ag. Manual sensitivity control often is incorporated into the r-f stage in the form of a variable cathode resistor providing variable bias to the grids of remote cut-off amplifier tubes.

ah. *Push-button tuning* facilitates quick selection of any one of a number of fixed-tuned frequency channels; it can be of either the electrical or the mechanical type.

ai. The power supply of a receiver must furnish the low a-c or d-c voltages for the heaters of the vacuum tubes, and relatively high d-c voltages for the screen grids and plates.

aj. Small portable receivers are frequently powered by a *battery power pack*, which contains all necessary filament (A-supply), plate (B-supply), and grid (C-supply) batteries.

ak. *Dynamotors* provide high-voltage d-c plate supply from a low-voltage d-c source (6- or 12-volt batteries). They consist basically of a small motor and generator, both mounted on a common frame. Dynamotors use a common field winding and low- and high-voltage armature windings.

al. A-c power supplies operate from a commercial 110-volt, 60-cps, a-c line, or from gasoline-engine and diesel-engine generators.

am. The output of an a-c supply must be transformed to the required voltage, rectified, and filtered, before it can be used in a receiver.

an. Half-wave rectifiers are simple diodes which rectify alternate half-cycles of the sine-wave input. Vacuum-tube or crystal diodes can be used in the same circuits. *Full-wave* rectifiers utilize both half-cycles of the a-c input by rectifying each with a separate diode.

ao. Filter circuits smooth out the pulsations at the output of the rectifier. Basic filter circuits are *choke-input* and *capacitor-input* filters. Choke-input filters consist of series inductor (choke) at the input, followed by a shunt capacitor; their output voltage is equal to the *average* value of the input pulsations. They have good filtering action and excellent voltage regulation. Capacitor-input filters consist of a shunt capacitor at the input, followed by a series choke, and a shunt capacitor at the output. Their output approaches the peak value of the input pulsations; however, their voltage regulation is poor.

ap. The reproducer converts the electrical audio frequencies in the power output stage into the corresponding audible sound waves.

aq. Loudspeakers can be of the *electromagnetic* or the dynamic (moving-coil) type. The latter are either *electrodynamic* or *permanent magnetic*, depending on whether they use an electromagnet or a permanent magnet to produce a strong magnetic field.

ar. Electromagnetic speakers occasionally are used in small portable receivers, because they are sensitive, and compact, and require no output transformer. However, they have low acoustic output and become overloaded easily, with resulting distorted output.

as. Most modern loudspeakers are of the dynamic type, in which a coil carrying the audio-frequency currents moves in and out of a strong magnetic field. Dynamic speakers provide high acoustic output with little harmonic distortion. Their frequency response can be made substantially uniform over the audio range, and they are of rugged construction.

at. The output transformer in the power output stage of an audio amplifier is designed to match the voice-coil impedance of the speaker to the recommended plate-load impedance of the output stage. When the impedances are matched properly, optimum power transfer will take place from the output stage to the voice coil of the speaker.

au. *Tuning indicators* give visual indication, when the receiver is tuned to the carrier frequency of the incoming signal. They also give an approximate measure of relative signal strength. Indication is either by means of *meters* or by *electron-ray* indicators, either type being connected in the *avc* circuit of the receiver.

av. Receiver noise can be of the *hiss* type, consisting of a series of overlapping random pulses, or of the *shot* type, consisting of separated single impulses of brief duration and very high amplitude.

aw. Shot or impulse noise can be reduced by i-f noise *silencers*, or a-f noise limiters.

ax. Hiss noise can be reduced by increasing the selectivity of the i-f stages, either by regeneration or by use of crystal or audio filters. This also helps to eliminate *audio-frequency images*, and ~~cuts down~~ adjacent signal interference.

ay. Crystal filters consist of piezoelectric quartz crystals, cut to the intermediate frequency, and inserted into a balanced i-f coupling circuit.

az. Audio filters are simple resonant circuits or band-pass filters inserted between two a-f amplifier stages. They are adjusted to the frequency of the audio beat tone.

155. Review Questions

a. State three disadvantages of the trf receiver which are overcome by the superheterodyne receiver.

b. State briefly the steps involved in reception of an a-m signal by a superheterodyne receiver.

c. Describe the process of frequency conversion in a mixer.

d. Describe another method of frequency conversion.

e. State the relative advantages of triode, pentode, and pentagrid mixers and contrast them with those of combined mixer-oscillator tubes, such as triode-hexodes, triode-heptodes, and pentagrid converters.

f. How can the local oscillator voltage be injected into the mixer? State at least three different methods and how they work.

g. Define *conversion transconductance* and *conversion gain.* What is the conversion gain of a pentagrid mixer, which has a conversion transconductance of 400 micromhos and a plate-load impedance of 15,000 ohms?

h. Which type of converter tube has the poorest noise factor?

i. Explain *frequency pulling*, and how it is avoided.

j. What methods are used to assure frequency tracking between the oscillator and mixer signal circuits? Explain.

k. Define *critical coupling*. Explain what happens when the coupling is greater.

l. If the coupling coefficient of a 456-kc i-f transformer is .03, what are the frequencies of the lower and upper frequency peaks? What is the bandwidth? If the Q of the primary winding of the same transformer is 120, and the secondary Q is 80, what is the critical K?

m. Explain which factors influence the selectivity of each i-f stage.

n. What factors influence the choice of the intermediate frequency?

o. Explain the operation and advantages of the diode detector in a superheterodyne receiver; what are its disadvantages compared to other detectors?

p. What is the purpose of *avc*, and how is it obtained? Does the inclusion of *avc* do away with the need for manual control of volume and sensitivity?

q. What must be done to the a-f output from the detector before it can be made to operate a loudspeaker properly?

r. What determines the number of a-f stages required?

s. Name three methods of a-f amplifier interstage coupling, and state their relative advantages or disadvantages.

t. Define *frequency* and *harmonic* distortion, and explain how each is caused.

u. What is *negative feedback*, how is it obtained, and what does it do?

v. Why is an r-f amplifier used in a superheterodyne receiver? Give four reasons, and justify each in detail.

w. What are the *image frequency* and the *image interference?*

x. A superheterodyne receiver is tuned to an a-m signal of 950 kc. If the i-f is 455 kc, what is the oscillator frequency? At what frequency could image interference occur?

y. How can the sensitivity of the r-f amplifier be controlled by a manual gain control? What type of r-f amplifier tube should be used for this purpose?

z. State the basic principles of tuning a superheterodyne receiver.

aa. Why is push-button tuning used? Describe at least three different methods of *push-button tuning.*

ab. What voltages and currents must be supplied by a power supply? State the type of supply most likely found in a small portable receiver; a mobile receiver-transmitter; and a large fixed installation.

ac. Draw the circuit and explain the operation of a full-wave rectifier.

ad. What is the purpose of filter circuits and of a *bleeder* resistor?

ae. Distinguish between a choke-input and a capacitor-input filter. Describe the operation and advantages of each. Is the output from a filter pure dc?

af. What does a reproducer do? Is it mechanical or electrical? Explain.

ag. Distinguish between different types of loudspeakers, and explain the principles of operation of each type.

ah. Would you use an electromagnetic speaker in a public-address system?

ai. What are the principal causes of frequency and harmonic distortion in loudspeakers?

aj. What is the purpose of the output transformer? What turns ratio (primary-to-secondary) would you choose to match a 2-ohm voice coil to a recommended plate-load impedance of 14,000 ohms?

ak. Describe the purpose and operation of two types of tuning indicators?

al. List various types of receiver noise and their possible causes.

am. Distinguish between noise *silencers* (squelch circuits) and noise *limiters.*

an. What do crystal filters do, and what are their advantage compared with regenerative and noise-limiting circuits?

ao. What is the function of the *phasing capacitor* in the crystal filter?

ap. What is the function of *audio* filters?

CHAPTER 9

C-W DETECTION

156. Need for C-W Detection

a. The receivers discussed in the two preceding chapters were designed for the reception of amplitude-modulated r-f signals. They can receive but not detect continuous waves (c-w signals) unless some modifications are made. The function of the detector circuit in an a-m receiver is to separate the audio-frequency components from the radio-frequency carrier of the incoming signal in order to recover the sound intelligence. Since c-w code signals are not modulated, the intelligence contained in them cannot be recovered by the ordinary detection process.

b. To understand what happens when a c-w signal passes through the detector stage of an a-m receiver, refer to figure 208. A represents the received c-w signal at the input of the detector. This signal is rectified at the detector by the clipping of the negative half cycles of the c-w signal, in B. If a plate detector is used, for example, the a-c plate-current component of the rectified c-w signal appears as shown by the solid line. The average or d-c component of the plate current is indicated by the dotted line. The filter circuit in the output of the detector eliminates all a-c fluctuations for each group of sine waves, and only the d-c component of the plate current remains, as in C. If a pair of headphones is connected in the plate circuit of the detector, this direct current flows through the phone coils and actuates the diaphragm continuously, with the result that no audible tone is heard. Consequently, the detector used in a-m receivers cannot be used for c-w reception.

157. Heterodyne Detection

a. In the reception of c-w signals from a radio telegraph transmitter, some means must be provided for producing an audio-frequency voltage in the detector circuit of the receiver from an unmodulated r-f signal. This is accomplished by the *heterodyne principle*, which was discussed in the preceding chapter. The procedure is to beat the incoming c-w signal with locally generated oscillations to obtain a convenient audio frequency, such as 1,000 cps. This audio frequency is the difference frequency. The difference frequency then is rectified and smoothed out by an ordinary detector. The audio beat note is reproduced through a telephone headset or a loudspeaker.

b. As an example, consider the heterodyne reception of the code letter A (A of fig. 209) which consists of a short burst of c-w energy, followed by a longer burst of c-w energy (dot-dash). Assume that the frequency of the received c-w signal is 500 kc. The locally generated oscillations are adjusted to a frequency which is higher than the incoming r-f signal (in this case, 501 kc), as in *B*. The mixed-frequency voltage, which is the addi-

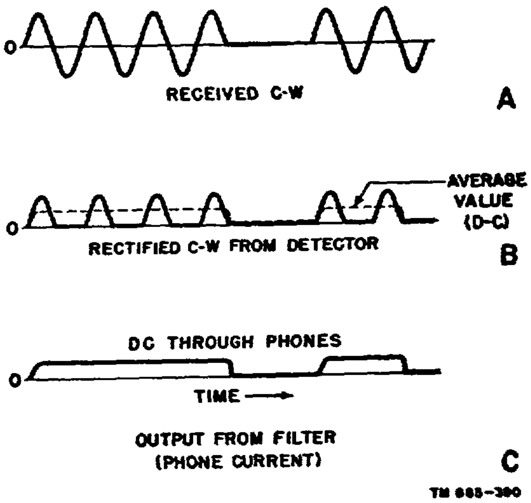

Figure 208. Action of a-m receiver on an unmodulated (c-w) signal.

tion of the c-w signal voltage and the local-oscillator voltage, is illustrated in *C*. Its amplitude (envelope) varies at the beat or difference frequency of 501,000 minus 500,000 or 1,000 cps. Rectification removes the negative half-cycles of the mixed frequency, as in *D*. The peaks of the positive half-cycles follow the 1,000-cps beat frequency. An r-f filter in the detector output removes the c-w signal pulsations so that only the envelope of the rectified pulses remains. The envelope, in *E*, is the 1,000-cps audio beat note. After passing through a reproducer, a 1,000-cps dot-dash tone is heard, which is identified by the operator as the letter A.

c. The heterodyne method of reception has the inherent advantage of very high selectivity, which minimizes interference from adjacent c-w stations. For example, assume that it is desired to receive a c-w signal from a radiotelegraph station operating at 10,000,000 cps, while an adjacent station is operating on a frequency of 10,000,300 cps at the same time. Since the two carrier frequencies differ by only .003 percent, a tuned tank circuit could not be used easily to discriminate between them. However, if heterodyne detection with a local-oscillator frequency of 10,001,000 cps is used, beat notes of 1,000 cps and 700 cps are produced by the desired and undesired signals, respectively. These audio frequencies can be distinguished easily by a selective circuit, since they differ by 30 percent. Even if two incoming c-w signals produce exactly the same beat frequency, they can be separated easily by a slight adjustment of the local-oscillator frequency, which is usually variable. For example, assume that a desired incoming c-w signal with a frequency of 700 kc is mixed with a local-oscillator frequency of 701 kc to produce a 1,000-cps beat note. A radiotelegraph station operating on 702 kc also produces this 1,000-cps beat note, and interference results. However, by adjusting the local oscillator to a frequency of 699 kc for the desired signal, a beat frequency of 1,000 is obtained and the undesired signal (702 kc), now produces a beat note of 3,000 cps. The operator can distinguish easily between these widely differing audio tones.

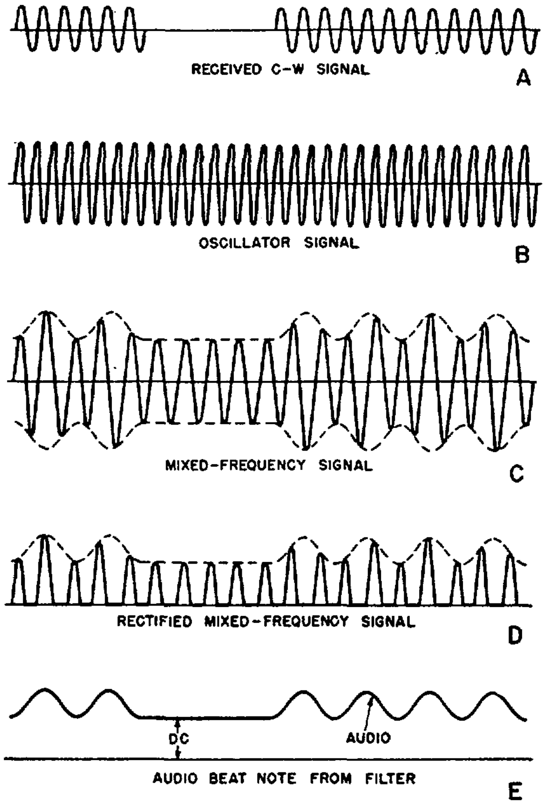

Figure 209. Heterodyne detection of c-w code signal (letter A).

d. Two types of circuits have been developed for heterodyne reception of c-w signals. In one method, the ordinary regenerative detector (par. 118) is operated with sufficient feedback so that it breaks into self-oscillation. The oscillations are mixed with the incoming c-w signal, and a beat note results. This method of beating a self-generated oscillation with an incoming signal of slightly different frequency is called *autodyne reception*. In the second method, a superheterodyne receiver is utilized in conjunction with an additional oscillator. The frequency of this oscillator (*beat-frequency oscillator*) is adjusted to differ, by a convenient audio frequency, from the i-f of the receiver. When the output of the bfo is injected into the receiver i-f system, the mixed frequency is rectified by the second detector, and an audio beat note is produced. In communication receivers, the second method is used ordinarily since the superheterodyne receiver has greater flexibility and somewhat higher sensitivity than the regenerative receiver.

158. Regenerative Detector for C-W Reception

It has been shown (par. 128) that oscillations are produced in a regenerative detector if the amount of energy fed back from its plate-output circuit is sufficient to overcome the losses in its grid-input circuit. The device then functions as an *oscillating detector*.

a. Circuits (fig. 210). The addition of an antenna and a reproducer (headphones) makes each detector a self-contained basic c-w receiver. In practice, however, the regenerative c-w receiver ordinarily contains an r-f amplifier stage ahead of the detector for isolation purposes and increased sensitivity. An additional a-f amplifier stage usually is interposed between the detector and reproducer.

b. Analysis.

(1) The oscillating detector arrangements shown in figure 210 are the same as those used for regenerative detectors, the only difference being that regeneration in the oscillating detector is carried to the point of self-oscillation. These oscillations heterodyne with any signal present in the tuned grid-input circuit (*L-C*) of the detector. For example, assume that the grid circuit of the detector shown in A is tuned to a frequency of 3,001 kc and that a 3,000-kc c-w signal is received. A slight detuning of the grid tank circuit is necessary to produce beats, but it hardly affects the strength of the incoming c-w signal. (If no detuning is present, zero beats result.) Both frequencies are present on the grid of *V*1 and are mixed. The

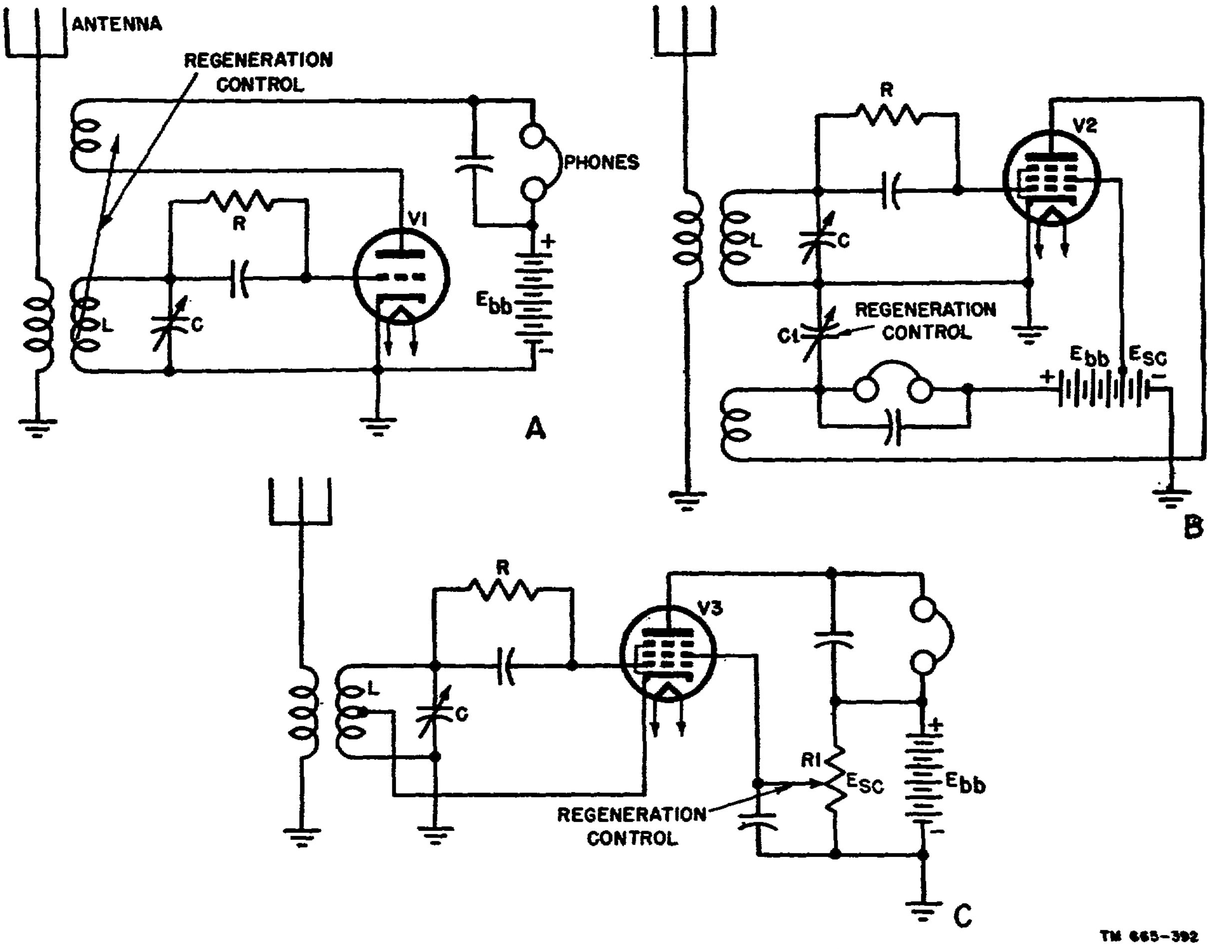

Figure 210. Oscillating detectors for c-w reception.

resulting beats are rectified by the detector to produce a 1,000-cps beat note in the detector output. The a-f currents in the plate circuit actuate the phones. The oscillating detector, therefore, produces its own oscillations, heterodynes them with an incoming signal, and, finally, rectifies them.

(2) Grid-leak rectification always is used in oscillating detectors. Grid-leak resistor *R* provides proper grid bias for the oscillations and assures high sensitivity. The circuit shown in A uses a triode in a tickler feedback circuit. Adjustable regeneration is provided by varying the physical position of the tickler coil in respect to the grid tank coil, thus charging the mutual coupling between them. When the coupling is so loose that oscillations are barely maintained, a *continuous* audio note is sometimes heard, known as *threshold* or *fringe howl*. This howl will interfere with normal c-w reception. It can be avoided by reducing the detector sensitivity through increased coupling, by using a resistive output load, or by using a pentode which is not subject to fringe howl instead of a triode.

(3) Two pentode circuits are shown, in B and C. The circuit in B is equivalent to the triode tickler feedback circuit in A, except that regeneration control is effected by changing the electrostatic coupling between the plate and grid circuit with variable capacitor *C*1. Fixed magnetic coupling between the tickler (plate) coil and the grid coil is used. The circuit in C utilizes a Hartley circuit for its oscillating portion. Regeneration control is obtained in this case by varying the screen-grid voltage with a tapped voltage divider, *R*1, across the high-voltage supply. The circuit usually is adjusted so that oscillations occur when the screen grid has a fairly low voltage and stop when the screen-grid voltage reaches a value from approximately 20 to 40 volts. If the oscillations are extinguished at higher screen-grid voltages, an annoying thump is heard whenever the circuit goes into or out of oscillation. If the critical stopping point is too low, however, the detector efficiency also is low because of the small plate current.

c. Advantages and Limitations. The regenerative detector is used for the reception of short-wave code signals because it is easy to adjust, and has high sensitivity and good selectivity. At high frequencies, the amount of signal detuning necessary to produce an audio beat note is a small percentage of the signal frequency and causes no trouble. The use of the regenerative detector for low-frequency code reception usually is avoided, however, since at low frequencies the detuning required to produce the proper audio beat frequency is a considerable percentage of the signal frequency. Regenerative detectors have the further disadvantage that they cannot be used in conjunction with superheterodyne receivers, which have become standardized in communications.

159. Superheterodyne Receivers for C-W Reception

The addition of a beat-frequency oscillator is all that is required to make an a-m superheterodyne receiver suitable for the reception of c-w signals. When the oscillator is switched on by the use of the bfo switch, its output heterodynes with any incoming c-w signal to produce an audio beat tone. The receiver can be made ready again instantly for a-m reception by simply turning off the bfo. This easy convertibility from a-m to c-w reception makes it advantageous to use the superior performance of the superheterodyne circuit in a combined a-m and c-w receiver. The arrangement of a communication superheterodyne receiver for both a-m and c-w reception is shown in the block diagram of figure 211. All the stages discussed in chapter 8 are present with the addition of the beat-frequency oscillator. The output of the bfo is shown here, feeding into the input of the detector stage. Alternately, it could be connected to the i-f amplifier. Various methods of bfo injection are possible, but in each case the purpose is to mix the bfo output with the intermediate frequency before detection can take place. The functioning of all stage illustrated (excluding the bfo) is identical with the corresponding stages discussed in the preceding chapter.

160. Beat-Frequency Oscillator

a. Any standard oscillator circuit can be used as a beat-frequency oscillator. Figure 212 illustrates a typical Hartley pentode circuit. Feedback is

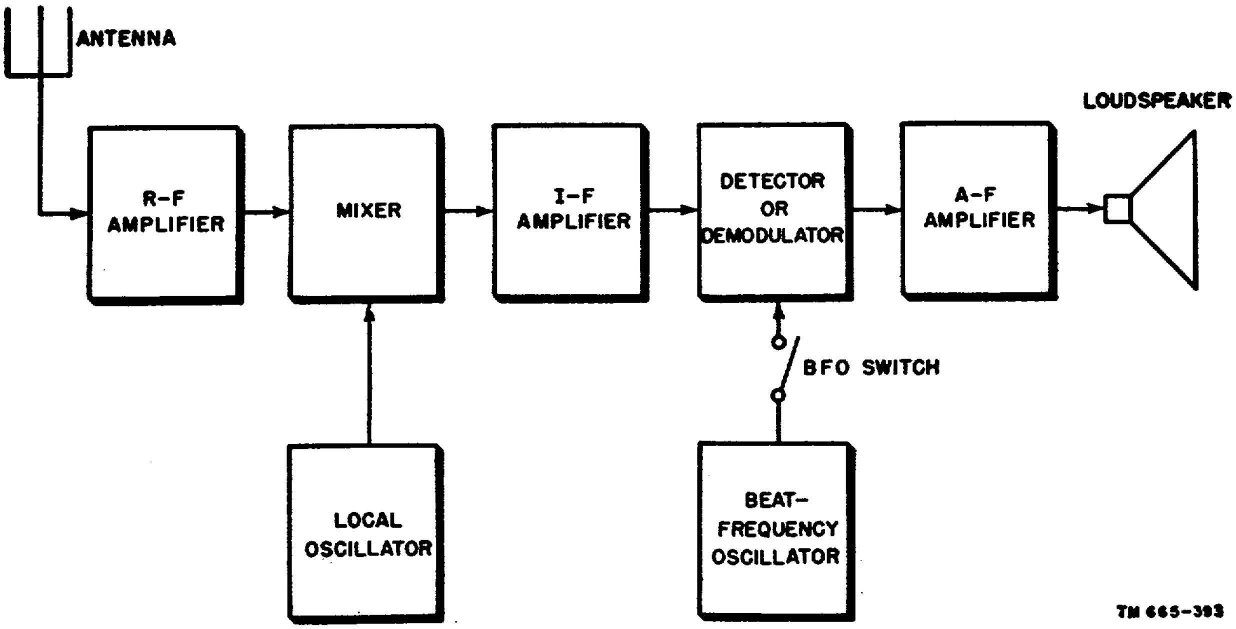

Figure 211. Block diagram of an a-m and a c-w superheterodyne receiver.

obtained from grid to plate through capacitor *C*1. The screen-grid voltage is developed across *R*1. *C*2 is the screen-grid bypass capacitor. *C*3 and *R*2 develop bias for the stage. *C*4 is the oscillator tuning capacitor and *C*5 is its trimmer. The stator of the oscillator tuning capacitor is grounded to avoid detuning of the oscillator because of body capacitance. Detuning frequently occurs when both sides of the tuning capacitors are above ground. The suppressor grid in this circuit is directly connected to ground, since the cathode is not at ground potential. In operation, the main tuning capacitor is preset to the i-f of the receiver, while the parallel trimmer permits detuning the oscillator frequency over a band ranging from a few hundred to about 1,000 cps.

b. The output of the beat-frequency oscillator can be injected at one of a number of points into the i-f amplifier. In the circuit illustrated, the oscillations from the grid coil of the bfo are loosely coupled through *C*6, which has a capacitance of approximately 2 to 5 $\mu\mu$f, to the plate of the diode detector. Here the oscillations are mixed with i-f currents from the secondary of the last i-f transformer, *T*1. The bfo oscillations also can be injected at an earlier stage in the i-f amplifier. One method sometimes used is to take the oscillations from the bfo and feed them directly to the screen grid of the first or second i-f amplifier tube where they are electron-coupled with the i-f through the common electron stream. No coupling capacitor is required in this case. In another method, the functions of the bfo and first i-f amplifier are combined in the envelope of a multi-unit tube. A triode-pentode can be used for this purpose. The pentode section of the tube functions as an ordinary i-f amplifier; the triode section operates as a beat-frequency oscillator which can be switched into the circuit for c-w reception. The oscillations from the triode must be injected into the pentode portion of the tube through some form of inductive or capacitive coupling. Numerous other ways of injecting the bfo output into the i-f amplifier are possible, but in practice it makes little difference which method is chosen.

c. Most modern communication superheterodyne receivers are provided with front panel controls, which permit switching in and out of the *avc* and bfo circuits as well as controlling the pitch of the audio note from the beat-frequency oscillator. When the bfo is switched on for reception of a code signal, the *avc* circuit always should be disconnected, and the manual volume control should be used. This is necessary because the output from the beat-frequency oscillator might reduce the receiver sensitivity through the increased bias voltage developed across the *avc* resistor. After the c-w signal has been tuned in properly, the bfo pitch control should be set at a comfortable audio tone, usually somewhere near 1,000 cps. Some less elaborate receivers do not have a variable pitch control for the bfo, but the frequency of the oscillations can be permanently set by the i-f of the receiver. The c-w signal must first be tuned in by zero-beating it against the output of the beat-frequency oscillator. The receiver must then be detuned slightly to produce a beat signal of a few hundred cycles. The bandwidth of the receiver is generally of sufficient width that the small amount of detuning does not appreciably affect its sensitivity. It has been pointed out that a slight change in pitch of the bfo for an incoming c-w signal sometimes makes it possible to discriminate against nearby interfering signals. Sometimes more serious than adjacent signal interference, however, is the problem of *noise interference* (par. 144), which often mars c-w reception.

d. Audio Images. In a c-w receiver of ordinary selectivity, most incoming code signals within approximately 5,000 cps of the desired signal cause audible beat notes. Since their pitch differs from that of the desired signal, they make it more difficult for the operator to concentrate on the desired signal alone. Also, two adjacent code signals can interfere with each other by producing the same audio-beat note. For example, assume that the bfo is set at 456 kc to give a 1,000-cps beat note when the intermediate frequency is 455 kc. If an interfering signal with an i-f of 457 kc should also be present, it will heterodyne with the bfo signal to produce the same audio tone of 1,000 cps. In other words, the desired a-f signal can be obtained in two different ways. In one, the 1,000-cps audio note is the difference between the bfo signal and the desired intermediate frequency (456 kc minus 455 kc=1,000 cps). In the other, the audio note is the difference between the undesired intermediate frequency and the bfo signal (457 kc minus 456 kc=1,000 cps). In the latter case, the frequency of the undesired i-f is above the desired i-f by an amount equal to *twice* the desired audio frequency. This frequency is known as the *audio image frequency*. The a-f image effect can be reduced by narrowing the bandwidth of the i-f amplifier (increasing its selectivity) so that the heterodyne response at 457 kc is low. Consequently, only a single beat note of the desired frequency is heard. Highly selective circuits, including crystal filters (par. 141) are used for this purpose.

161. Summary

a. A-m detectors do not detect c-w signals because c-w signals are not modulated.

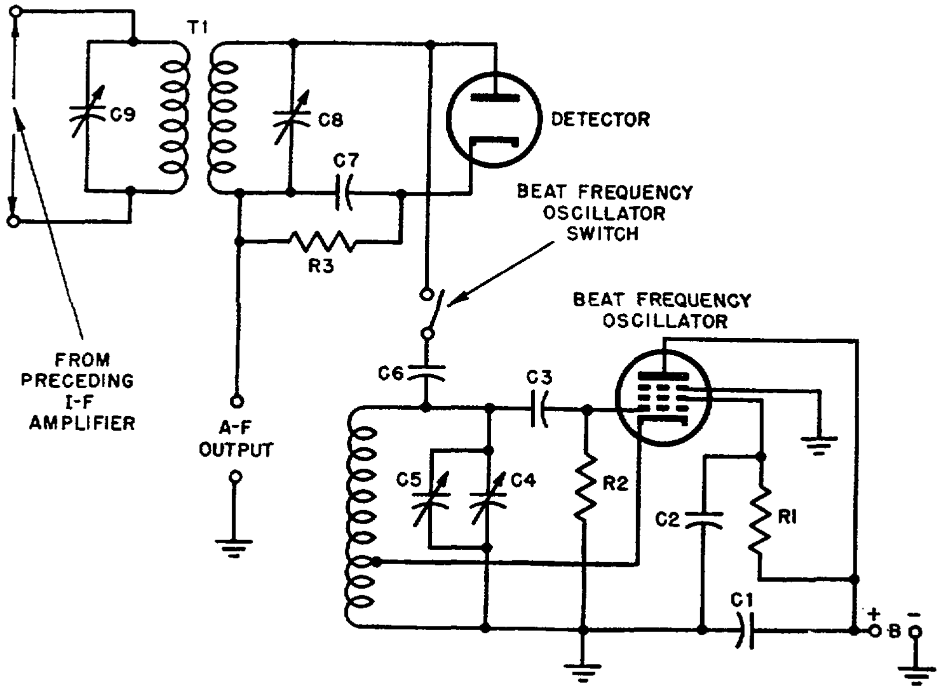

Figure 212. Typical beat-frequency oscillator circuit.