CHAPTER FOUR

Radio Receiver Theory

A radio receiver may be defined as a device for reproducing in the form of useful output the intelligence conveyed by radio waves applied to it. Usually an antenna is a necessary adjunct to the receiver. The antenna will not be discussed in this chapter, however, as the function and design of antennas is thoroughly covered in Chapter 20.

Receiver Tubes. The tube manufacturers have been lavish in their production of tubes for use in radio receivers. Many similar tubes are made in different forms, such as metal tubes, glass tubes with standard bases, glass tubes with octal bases similar to those used on metal tubes, glass tubes with tubular envelopes, glass tubes encased in metal shells and fitted with octal bases and tubes with similar characteristics but differing in their heater or filament voltage and current ratings. Some tubes are designed for dry-battery filament supply, others for automobile service and another group for operation from an a.c. source.

In general, there are certain distinct classes of tubes for particular purposes. Screen-grid tubes were primarily designed for radio-frequency amplifiers, yet they are often employed for regenerative detectors, mixers and high-gain voltage audio amplifiers. General purpose triode tubes are used as oscillators, detectors and audio amplifiers. Power triodes, tetrodes and pentodes are employed for obtaining as much power output as possible in the output audio amplifier stage of a radio receiver. Diodes are designed for use as power supply rectifiers, radio detectors, automatic volume control circuits and noise suppression circuits. In addition to these general types of tubes, there are a great many others designed for some particular service, such as oscillator-mixer operation in a superheterodyne receiver.

Vacuum tubes require a source of power for the filament and other electrodes. Certain components in a radio receiver are for the purpose of supplying direct-current energy to the electrodes of the tubes, such as the plate and screen circuits. In nearly all circuits, the control grid of the vacuum tube is biased negatively with respect to the cathode, for proper amplifier action. This bias is obtained in several ways, such as from a self-biasing resistor in series with the cathode, fixed bias from the power supply or grid leak bias for some oscillators and detectors.

By-pass and coupling condensers are found in different portions of the circuits throughout a radio receiver. By-pass condensers provide a low impedance for r.f. or audio frequencies around such components as resistors and choke coils. Coupling condensers provide a means of connection between plate and grid circuits in which the d.c. voltage components are of widely different values. The coupling condenser offers an infinite impedance to the d.c. voltages, and a relatively low impedance to the r.f. or a.f. voltages.

Screen-grid tubes have a higher plate impedance than triodes and, therefore, require a much higher value of plate load impedance in order to obtain the greatest possible amount of amplification in the audio or radio circuits. Screen-grid tubes are normally used in all r.f. and i.f. amplifiers because the control grid is electrostatically screened from the plate circuit. Lack of this screening would cause self-oscillation in the amplifier; when triodes are used in radio-frequency amplifiers, the grid-to-plate capacities must be neutralized. The r.f. amplification from a triode amplifier in a radio receiver is so much less than can be obtained from a screen-grid tube amplifier that triodes are no longer used for this purpose.

Detection. All receivers use some sort of detector to make audible the intelligence impressed on the radiated carrier wave at the transmitter. The process of impressing the intelligence on the carrier wave is known as modulation, and as the detector separates this modulation from the carrier, it is often known as a *demodulator.* One of the simplest practical receivers consists of a tuned circuit for selecting the desired radio signal and a detector for separating the modulation from the carrier. The detector may be either a mineral such as galena or carborundum, or else a vacuum tube. Figure 1 shows such a receiver using a diode vacuum tube as a detector. The *sensitivity* of this receiver, or in other words its ability to make audible weak signals, would be very low, but it is useful to illustrate the basic action of all receivers.

Resonant Circuits such as are formed by coil L_2 and condenser C, are almost always used to couple the antenna to the first tube in a radio receiver. When the current induced in the antenna is caused to pass through a coil, such as L_1 in figure 1, a voltage is induced across the coil. It will be recalled from chapter 1 that this voltage across the coil is equal to the product of the current and the impedance of the coil. The impedance of a non-resonant coil such as L_1 is made up principally of its reactance. This reactance is a function of the coil dimensions and the frequency of the impressed current.

Coils L_1 and L_2 in figure 1 are said to be *inductively coupled,* as radio-frequency energy is transferred from one to the other by virtue of the fact that the alternating inductive field around L_1 links and unlinks with the turns of L_2, thus inducing a voltage in L_2.

Disregarding the tube, V, for the moment, the current flowing through L_2 of figure 1 is limited by the reactances of the coil and condenser C. The reactance of the coil increases with frequency while the reactance of the variable condenser decreases with frequency. For any setting of C there is a frequency at which the *capacitive reactance* and the *inductive reactance are equal.* These two reactances are opposite in effect and neutralize each other at this frequency, resulting in a circuit having zero reactance, and a condition known as *resonance.*

At resonance the current flowing back and forth between L_2 and C is limited only by their resistances, and since the resistance of modern condensers is very small, the current is actually limited by the resistance of the coil. The high radio-frequency (r.f.) current flowing through the coil and condenser causes an r.f. voltage to be developed across them equal to the product of the current and the impedance of the circuit. As the impedance of the parallel tuned circuit at resonance is high, the voltage across it is also

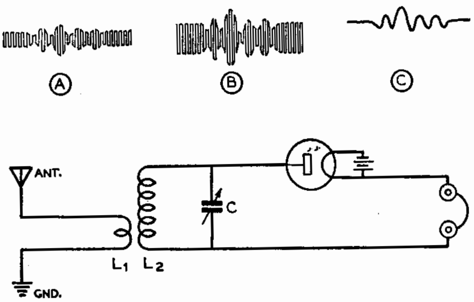


Figure 1.
DIODE DETECTOR RECEIVER.
While it would make a poor receiver, this type of circuit is useful in illustrating how the detector separates the modulation from the carrier wave.

high. Thus, it may be seen that at its resonant frequency the voltage across a tuned circuit may be very much higher than what might be expected from looking at the diagram and assuming that a simple transformer action took place between the primary and secondary.

The voltage step-up in the tuned circuit is illustrated by the drawings representing the modulated carrier wave above the different portions of the receiver circuit in figure 1. "A" represents the radio signal as it is picked up at the antenna, while "B" represents the same wave considerably increased in amplitude after it has passed through the tuned circuit.

Rectification of the radio-frequency carrier takes place in the diode vacuum tube, V, and a pulsating d.c. voltage as illustrated at "C" is passed through the earphones. The pulsations in this voltage correspond to the modulation voltage originally placed on the carrier wave at the transmitter. As the diaphragms in the earphones vibrate back and forth following this pulsating d.c. voltage they audibly reproduce the modulation on the carrier.

Regenerative Receivers

The Triode Detector. The simple receiver shown in figure 1 would be an extremely poor one, being suitable for use only in the immediate vicinity of a transmitting station. The sensitivity of the receiver may be increased considerably by replacing the diode detector by a triode in a regenerative detector circuit as shown in figure 2.

The regenerative receiver has been quite popular in high-frequency work for many years. It combines high sensitivity, simplicity, low cost, good signal-to-noise ratio and

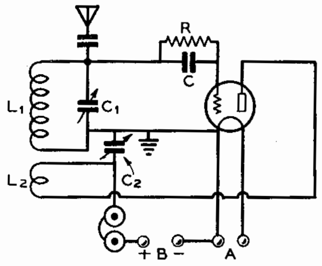


Figure 2.
TRIODE REGENERATIVE DETECTOR.
The regenerative detector makes the simplest practical high-frequency receiver.

reliability. Its principal disadvantage, however, and the one which has caused it to assume a secondary role in the high-frequency receiver picture, is its lack of selectivity when subjected to large signal inputs.

Operation. The regenerative detector, diagrammed in figure 2, operates as follows: In the absence of a signal in the input circuit and with the proper voltages applied to the filament and plate, the plate current assumes a value near the upper bend of the tube's plate characteristic. When a signal voltage is applied across the input circuit the plates on the coil side of the grid condenser, C, become positive (lose some of their electrons) each half-cycle of the signal voltage. When this side of the grid condenser goes positive, electrons from the filament flow to the grid and into the plates on the grid side of C, the resulting excess of electrons trapped on the grid causing it to assume a negative potential and reducing the plate current.

To prevent the grid from becoming more and more negative as electrons accumulate on the condenser, a high-resistance grid leak, R, is connected across the condenser. This resistor allows the negative charge on the grid to become cumulative only during the number of r.f. cycles that constitute one-half an audio cycle, thus allowing the plate current to follow the modulation on the impressed signal. This type of *grid-leak detector* gives high audio output, since rectification takes place in the grid circuit and the amplifying properties of the tube are utilized. Unfortunately, however, this type of detector is prone to give rather high distortion when signals having a large percentage of modulation are impressed on it. The grid-leak detector is not limited to triodes; either tetrodes or pentodes may be used, these generally having greater sensitivity than the triodes.

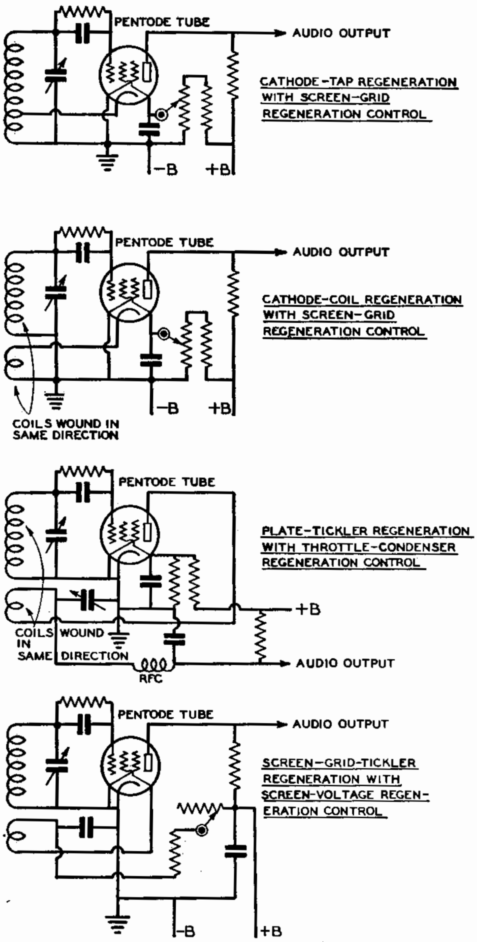


Figure 3.
REGENERATIVE DETECTOR CIRCUITS.
These circuits illustrate some of the more popular regenerative detectors. Values of one to three megohms for grid leaks are common. The grid condenser usually has a capacity of .0001 μfd., while the screen by-pass is 0.1 μfd. Pentode detectors operate best when the feedback is adjusted so that they start to oscillate with from 30 to 50 volts on the screen grid.

For the reception of c.w. (constant-wave telegraphy) signals, it is necessary to provide some means of securing a heterodyne, or "beat note" with the incoming signal. In the autodyne detector this is done by coupling some of the radio-frequency energy in the plate circuit back into the grid circuit and allowing the tube to oscillate weakly. The feedback or *tickler,* coil, L_2, is closely coupled to the grid coil and thus provides the feedback necessary to make the stage oscillate.

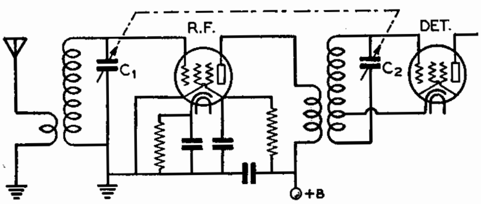


Figure 4.
R.F. AMPLIFIER CIRCUIT.
An r.f. amplifier ahead of the regenerative detector will increase the receiver's selectivity and sensitivity.

Since the detector is most sensitive on the edge of oscillation, a variable condenser, C_2, may be used as a variable plate by-pass to adjust the detector for its most sensitive condition. This condenser is called a "throttle condenser," or regeneration control.

With the detector *regenerative,* that is, with feedback taking place, but not enough to cause oscillation, it is also extremely sensitive. When the circuit is adjusted to operate in this manner, modulated signals may be received with considerably greater strength than when the detector is in a non-regenerative condition.

Other Regenerative Detectors. The circuit shown in figure 2 is by no means the only one which will give satisfactory results as a regenerative detector. There are several methods by which regeneration may be obtained, and also several alternative methods of controlling the regeneration. In tubes with an indirectly-heated cathode, regeneration may be obtained by tapping the cathode onto the grid coil a few turns up from the ground end or by returning the cathode to ground through a coil coupled to the grid winding. With tetrode or pentode tubes, feedback is sometimes provided by connecting the screen, rather than the plate, to the tickler coil.

Alternative methods of controlling regeneration consist of providing means for varying the voltage on one of the tube elements, usually the plate or screen. Examples of some of the possible variations in regeneration and control methods are shown in figure 3.

Amplifier Stages

The sensitivity and selectivity of the receiver may be increased by adding a tuned radio-frequency amplifier between the detector and the antenna. The radio-frequency (r.f.) amplifier stage increases the strength of the r.f. voltage applied to the detector, and thus the receiver with an r.f. stage is capable of giving a useful audio output on signals much weaker than those which represent the minimum useful level of signal strength for the detector alone. The addition of the tuned circuits required in the r.f. amplifier also increases the selectivity of the receiver.

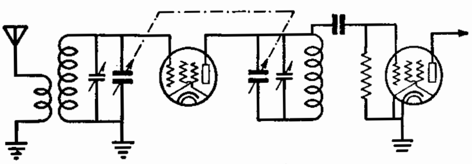


Figure 5.
CAPACITY COUPLING BETWEEN STAGES.
This type of coupling circuit is often used at ultra-high frequencies when it is desired to have a high impedance plate load for the r.f. stage.

Audio frequency amplifiers may be added after the detector to enable weak signals which have been detected to be amplied sufficiently to actuate the sound producing mechanism in the headphones or speaker.

Radio Frequency Amplifiers. A typical tuned radio-frequency amplifier connected ahead of a regenerative detector is shown in figure 4. A pentode tube is used in the r.f. stage with a tuned grid circuit and inductive coupling from the antenna and to the detector. Capacitive coupling could be used in both instances, but in the case of the coupling between stages a high-impedance radio-frequency choke would have to be connected to the plate of the r.f. stage to allow plate voltage to be applied to the tube. A capacity-coupling system which allows the r.f. choke to be dispensed with is shown in figure 5. This circuit is often used at ultra-high frequencies where a high-impedance resonant circuit in the plate of the r.f. tube is desired in order to obtain greater amplification.

The dotted line running between condensers C_1 and C_2 in figure 4 indicates that their rotor shafts are mechanically connected (or *ganged*) together so that both tuned circuits may be resonated to the desired signal with but a single dial. When the r.f. stage is separate from the receiver and its tuning control is not ganged with that of the receiver proper it is commonly known as a *preselector*. A preselector may be added to any receiver but it is most often used with the super-heterodyne type.

The amplification obtained in an r.f. stage depends upon the type of circuit which is used; if the plate load impedance can be made very high, the gain may be as much as 200 or 300 times that of the signal impressed across the grid circuit. Normal values of gain in the

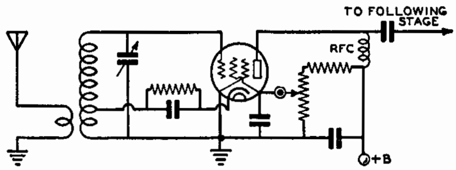


Figure 6.
REGENERATIVE R.F. AMPLIFIER CIRCUIT.
The use of regeneration in an r.f. stage allows greater amplification to be obtained at the expense of an increase in tube noise.

broadcast band are in the vicinity of 50 times. A gain of 30 per r.f. stage is considered excellent for shortwave receivers which have a range of from 30 to 100 meters. Radio-frequency amplifiers for the very short wavelengths, such as from 50 to 20 meters, seldom provide a gain of more than 10 times, because of the difficulty in obtaining high load impedances, and the shunt effect of the rather high input capacities of most screen-grid tubes.

Regenerative R.F. Stages. In low cost receivers and in those where maximum performance with a minimum number of stages is desired, controlled regeneration in an r.f. stage is often used. The regenerative r.f. amplifier increases amplification and selectivity in a manner similar to that of the regenerative detector. The regenerative r.f. amplifier is never allowed to oscillate, however; the greatest amplification is obtained with the circuit operating just below the point of oscillation. Figure 6 shows a regenerative r.f. stage of the type generally used on the higher frequencies.

One minor disadvantage of the regenerative r.f. stage is the need for an additional control for regeneration. A more important disadvantage is that, due to the high degree of selectivity obtainable with the regenerative stage, it is usually impossible to secure accurate enough tracking between its tuning circuit and the other tuning circuits in the receiver to make single-dial control feasible. Where single-dial control is desired, a small "trimmer" condenser is usually provided across the main r.f.-stage tuning condenser. By making this condenser operable from the front panel, it is possible to compensate manually for slight inaccuracies in the tracking. A further discussion of regenerative r.f. stages will be found under the section on superheterodyne receivers, in which connection they are most often used.

Audio Amplifiers. Audio amplifiers are employed in nearly all radio receivers. The audio amplifier stage or stages are usually of the class A type, although small class B stages are used in some receivers. The operation of both of these types of amplifier was described in Chapter 3. The purpose of the audio amplifier is to bring the relatively weak signal from the detector up to a strength sufficient to operate a pair of headphones or a loud speaker. Either triodes, pentodes, or beam tetrodes may be used, the pentodes and beam tetrodes usually giving greater output. In some receivers it is possible to operate the headphones directly from the detector, without audio amplification. In such receivers a single audio stage with a beam tetrode or pentode tube is ordinarily used to drive the loud speaker. Several representative audio amplifier arrangements will be found in the chapter on Receiver Construction.

Superregenerative Receivers

At ultra-high frequencies, when it is desired to keep weight and cost at a minimum, a special form of the regenerative receiver known as the *superregenerator* is often used. The superregenerator is essentially a regenerative receiver with a means provided to throw the detector rapidly in and out of oscillation. The frequency at which the detector is made to go in and out of oscillation varies in different receivers but is usually between 20,000 and 100,000 times a second. As a consequence of having the detector go in and out of oscillation at such a rapid rate, a loud hiss is present in the audio output when no signal is being received. This hiss diminishes in proportion to the strength of the signal being received, loud signals eliminating the hiss entirely.

Detector Operation. There are two systems in common use for causing the detector to break in and out of oscillation rapidly. In one a separate *interruption-frequency* oscillator is arranged so as to vary the voltage rapidly on one of the detector tube elements (usually the plate, sometimes the screen) at the high rate necessary. The interruption-frequency oscillator commonly uses a conventional tickler-feedback circuit with coils appropriate for the frequency at which it operates.

The second, and simplest, type of superregenerative detector circuit is arranged so as to produce its own interruption frequency oscillation, without the aid of a separate tube. The detector tube damps (or "quenches") itself out of signal-frequency oscillation at a high rate by virtue of the use of a high value of grid leak and proper size plate-blocking and grid condensers. In this type of "self-quenched" detector the grid leak is usually returned to the positive side of the power supply (through the coil) rather than to the cathode. A representative self-quenched superregenerative detector circuit is shown in figure 7.

Both types of superregenerative detectors act as small transmitters and radiate broad, rough signals unless they are well shielded and preceded by an r.f. stage. For this reason they are not too highly recommended for use on frequencies below 60 Mc. However, there are occasionally cases where their use is justified on the 56-to-60 Mc. band. The superregenerative receiver tunes very broadly, receiving a band at least 100 kc. wide. For this reason it is widely popular for the reception of unstable, modulated oscillators at ultra-high frequencies.

Frequency modulation reception is possible with superregenerative receivers, although with the amount of "swing" ordinarily used in frequency-modulated transmitters the audio output of the receiver is comparable to that obtained when the signal is amplitude modulated at a rather low percentage. If a relatively wide swing is used in the transmitter, however, the audio output of the receiver will compare favorably with that obtained from a fully amplitude modulated carrier of equivalent strength.

Practical superregenerative receiver circuits along with a further discussion of their operation will be found in Chapter 18.

Superheterodyne Receivers

Because of its superiority and nearly universal use in all fields of radio reception except at the extremely high "micro wave" frequencies, the theory of operation of the superheterodyne should be familiar to every radio experimenter, whether or not he contemplates building a receiver of this type. The following discussion concerns superheterodynes for amplitude-modulation reception. It is, however, applicable in part to receivers for frequency modulation. The points of difference between the two types of receivers together with circuits required for F.M. reception will be found in Chapter 9.

Principle of Operation. In the superheterodyne, a radio-frequency circuit is tuned to the frequency of the incoming signal and the signal across this circuit applied to a vacuum-tube mixer stage. In the mixer stage the signal is mixed with a steady signal generated in the receiver, with the result that a signal bearing all the modulation applied to the original *but of a frequency equal to the difference between the local oscillator and incoming signal frequencies* appears in the mixer output circuit. The output from the mixer stage is fed into a fixed-tune *intermediate-frequency amplifier,* where it is amplified and detected in the usual manner and passed on to the audio amplifier. Figure 8 shows a block diagram of the fundamental superheterodyne arrangement.

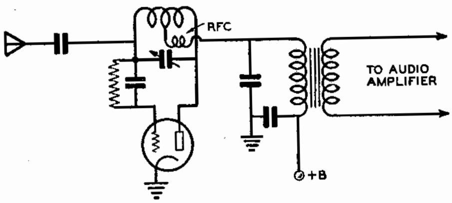


Figure 7.
SUPERREGENERATIVE DETECTOR.
This extremely sensitive self-quenched detector arrangement is often used at ultra-high frequencies. The plate blocking condenser must have low reactance at the quench frequency; a value of .006 μfd. is common.

Superheterodyne Advantages. The advantages of superheterodyne reception are directly attributable to the use of the fixed-tune intermediate-frequency (i.f.) amplifier. Since all signals are converted to the intermediate frequency, this section of the receiver may be designed for optimum selectivity and amplification without going into the extremely complicated tunable band pass arrangements or the number of stages which would be necessary if the signal-frequency tuning circuits were designed to have a comparable degree of selectivity and gain. High amplification is easily obtained in the intermediate-frequency amplifier, since it operates at a relatively low frequency, where conventional pentode-type tubes give a great deal of voltage gain. A typical i.f. amplifier stage is shown in figure 9.

From the diagram it may be seen that both the grid and plate circuits are tuned. Tuning

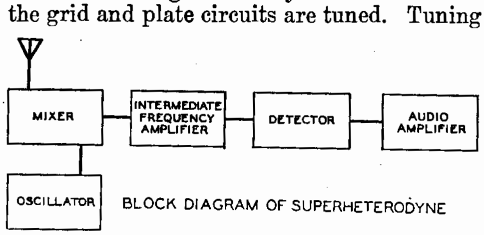


Figure 8.
THE ESSENTIAL PARTS OF A SUPER-HETERODYNE RECEIVER.
There are several possible variations of this arrangement. R.f. amplifier stages often are used ahead of the mixer. Occasionally the i.f. amplifier stages are omitted in simple superheterodynes.

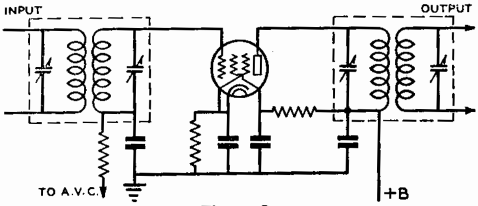


Figure 9.
INTERMEDIATE FREQUENCY AMPLIFIER STAGE.

6K7 and 6SK7 variable-μ pentodes are usually used as i.f. amplifier tubes. These types require cathode and screen resistors of approximately 300 and 100,000 ohms, respectively. The higher transconductance types such as the 1851-52-53 will require lower values of cathode and screen resistors for best operation. By-pass condensers are usually .05 or 0.1 μfd.

both circuits in this way is advantageous in two ways: it increases the selectivity, and it allows the tubes to work into a high-impedance resonant plate load, a very desirable condition where high gain is desired. The tuned circuits used for coupling between i.f. stages are known as *i.f. transformers.* These will be more fully discussed later in this chapter.

Choice of Intermediate Frequency. The choice of a frequency for the i.f. amplifier involves several considerations. One of these considerations is in the matter of selectivity; as a general rule, the lower the intermediate frequency the better the selectivity. On the other hand, a rather high intermediate frequency is desirable from the standpoint of *image* elimination and also for the reception of signals from television and F.M. transmitters and modulated self-controlled oscillator, all of which occupy a rather wide band of frequencies, making a broad selectivity characteristic desirable. Images are a peculiarity common to all superheterodyne receivers, and for this reason they are given a detailed discussion later in this chapter.

While intermediate frequencies as low as 30 kc. were common at one time, and frequencies as high as 20,000 kc. are used in some specialized forms of receivers, most present-day communications superheterodynes nearly always use intermediate frequencies around either 455 kc. or 1600 kc. Two other frequencies which are sometimes encountered in broadcast-band receivers are 175 kc. and 262 kc.

Generally speaking, it may be said that for maximum selectivity consistent with a reasonable amount of image rejection for signal frequencies up to 30 Mc., intermediate frequencies in the 450–470 kc. range are used, while for a good compromise between image rejection and selectivity the i.f. amplifier will often operate at 1600 kc. For the reception of both amplitude and frequency modulated signals above 30 Mc., intermediate frequencies near 2100, 3000 and 5000 kc. are most often used. The intermediate amplifiers in television receivers will usually be found to operate in the region between 8000 and 15,000 kc.

Arithmetical Selectivity. Aside from allowing the use of fixed-tune band pass amplifier stages, the superheterodyne has an overwhelming advantage over the t.r.f. type of receiver because of what is commonly known as *arithmetical selectivity.*

This can best be illustrated by considering two receivers, one of the t.r.f. type and one of the superheterodyne type, both attempting to receive a desired signal at 10,000 kc. and eliminate a strong interfering signal at 10,010 kc. In the t.r.f. receiver, separating these two signals in the tuning circuits is practically impossible, since they differ in frequency by only 0.1 per cent. However, in a superheterodyne with an intermediate frequency of, for example, 1000 kc., the desired signal will be converted to a frequency of 1000 kc. and the interfering signal will be converted to a frequency of 1010 kc., both signals appearing at the input of the i.f. amplifier. In this case the two signals may be separated much more readily, since they differ by 1 per cent, or ten times as much as in the first case.

Mixer Circuits. The most important single section of the superheterodyne is the *mixer.* No matter how much signal is applied to the mixer, if the signal is not converted to the intermediate frequency and passed on to the i.f. amplifier it is lost. The tube manufacturers have released a large variety of special tubes for mixer applications and these, as well as improved circuits with older type tubes, have resulted in highly efficient mixer arrangements in present-day receivers.

Figure 10 shows several representative mixer-oscillator circuits. At "A" is illustrated control-grid *injection* from an electron-coupled oscillator to the mixer. The mixer tube for this type of circuit is usually a remote-cut-off pentode of the 57—6J7 type. The coupling condenser, C, between the oscillator and mixer is quite small, usually 1 or 2 $\mu\mu$fd.

This same circuit may be used with the oscillator output being taken from the oscillator grid or cathode. The only disadvantage to this method is that interlocking, or "pulling," between the mixer and oscillator tuning controls is liable to take place. A rather high value of cathode resistor (10,000 to 50,000 ohms) is usually used with this circuit.

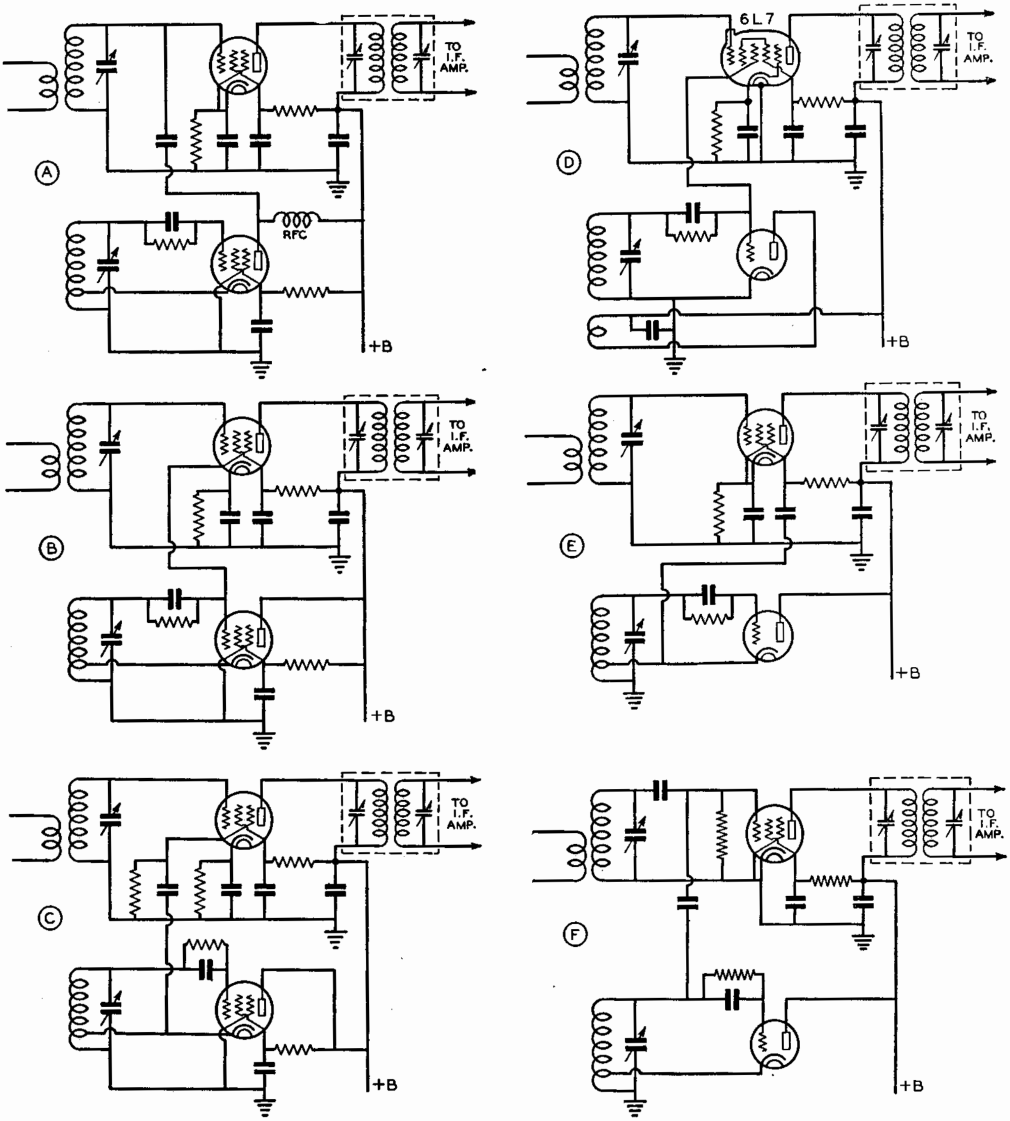


Figure 10.
MIXER-OSCILLATOR COMBINATIONS.
The various oscillators do not have to be used with the mixers with which they happen to be shown. The triode oscillator shown at E could replace the pentode circuit shown at B, for instance.

Injection of oscillator voltage into mixer elements other than the control grid is illustrated by figures 10B, C, D and E. The circuit of 10B shows injection into the suppressor grid of the mixer tube. The suppressor is biased negatively by connecting it directly to the grid of the oscillator.

An alternative method of obtaining bias for the suppressor, and one which is less prone to cause interlocking between the oscillator and mixer is shown in figure 10C. In this circuit the suppressor bias is obtained by allowing the rectified suppressor-grid current to flow through a 50,000- or 100,000-ohm resistor to ground. The coupling condenser between oscillator and mixer may be 50 or 100 $\mu\mu$fd. with this circuit, depending upon the frequency. Output from the oscillator may be taken from the cathode instead of the grid end of the coil, as shown, if sufficient oscillator output is available. Mixer cathode resistors having values between 500 and 5000 ohms are ordinarily used with the circuits of 10B and C.

The mixer circuit shown in 10D is similar in appearance to that of 10B. The difference in the two lies in the type of tube used as a mixer. The 6L7 shown in 10D is especially designed for mixer service. It has a separate shielded *injector grid,* by means of which voltage from the oscillator may be injected. This circuit permits the same variations as the suppressor-injection system in regard to the method of connection into the oscillator circuit. The 6L7 requires rather high screen voltage and draws considerable screen current, and for these reasons the screen-dropping resistor is usually made around 10,000 or 15,000 ohms, which is considerably less than the values of 50,000 to 100,000 ohms used with most other mixer tubes.

Figure 10E shows injection into the mixer screen grid. When connected in the manner shown, a rather large (.01 to 0.1 μfd.) coupling condenser may be used. This circuit is liable to cause rather bad pulling at high frequencies as there is no electrostatic shielding within the mixer tube between the screen grid and the control grid. A variation of this circuit in which the pulling effect is reduced considerably consists of using an electron-coupled oscillator circuit similar to that shown in 10A and connecting the plate of the oscillator and the screen of the mixer directly together. A voltage of about 100 volts is then applied to both the oscillator plate and the mixer screen.

E.C.O. Harmonics. One disadvantage to the use of an electron-coupled type oscillator with the output taken from the plate, which should be borne in mind by the constructor, is that due to the fact that the untuned plate circuit of the e.c. oscillator contains a large amount of harmonic output, considerable selectivity must be used ahead of the mixer to prevent the harmonics of the oscillator from beating with undesired signals at higher frequencies and bringing them in along with the desired signal. If it is desired to use an e.c. type oscillator to secure receiver stabilization in regard to voltage changes it will usually be found best to take the oscillator output from the tuned grid circuit, where the harmonic content is low. The plate of the oscillator tube may be by-passed directly to ground when this arrangement is used.

Improved Control-Grid Injection. In figure 10F an improved control-grid injection type mixer circuit is shown. This circuit allows peak mixer conversion transconductance under wide variations in oscillator output. The bias on the mixer is automatically maintained at the correct value through the use of grid-leak bias, rather than by the more common cathode bias arrangement. The mixer grid leak should have a value of from 3 to 5 megohms. As in the circuit shown at 10A, the coupling condenser should be quite small —on the order of 1 or 2 $\mu\mu$fd. It is absolutely essential that a rather high value of series screen dropping resistor be used with this circuit to limit the current drawn by the mixer tube in case the oscillator injection voltage, and consequently the mixer bias, is inadvertently removed. The value of the screen resistor will probably lie around 100,000 ohms or above, depending upon the type of mixer tube and the available plate voltage. The resistor value should be determined experimentally by using a value which limits the mixer cathode current when the oscillator is not operating to the maximum permissible current specified by the tube manufacturer.

The different oscillator circuits shown in figure 10 are not necessarily limited to use with the mixers with which they happen to be shown. Almost any oscillator arrangement may be used with a particular mixer circuit. Examples of some of the possible combinations will be found in Chapter 6.

Converter Tubes. There is a series of *pentagrid converter* tubes available in which the functions of the oscillator and mixer are combined in a single tube. Typical of these tubes are the 6A7, 6A8, and 6SA7. The term *pentagrid* has been applied to these tubes because they have 5 grids, one of the extra grids being used as grid and the other as the anode for the oscillator section of the circuit. Suitable circuits for use with these tubes are shown in figure 11A and 11B.

Dual Unit Converters. Another set of combination tubes known as *triode-heptodes* and *triode-hexodes* is also available for use as combination mixers and oscillators. These tubes are exemplified by the 6J8G and the 6K8; they get their name from the fact that they contain two separate sets of elements—a triode and a heptode in one case, and a triode and a hexode in the other. Representative circuits for both types of tube are shown at 11C and 11D.

Separate Oscillator. Certain of the combination mixer-oscillator tubes make exceptionally good high frequency mixers when their oscillator section is left unused and the oscillator section grid is connected to a separate oscillator capable of high output. The

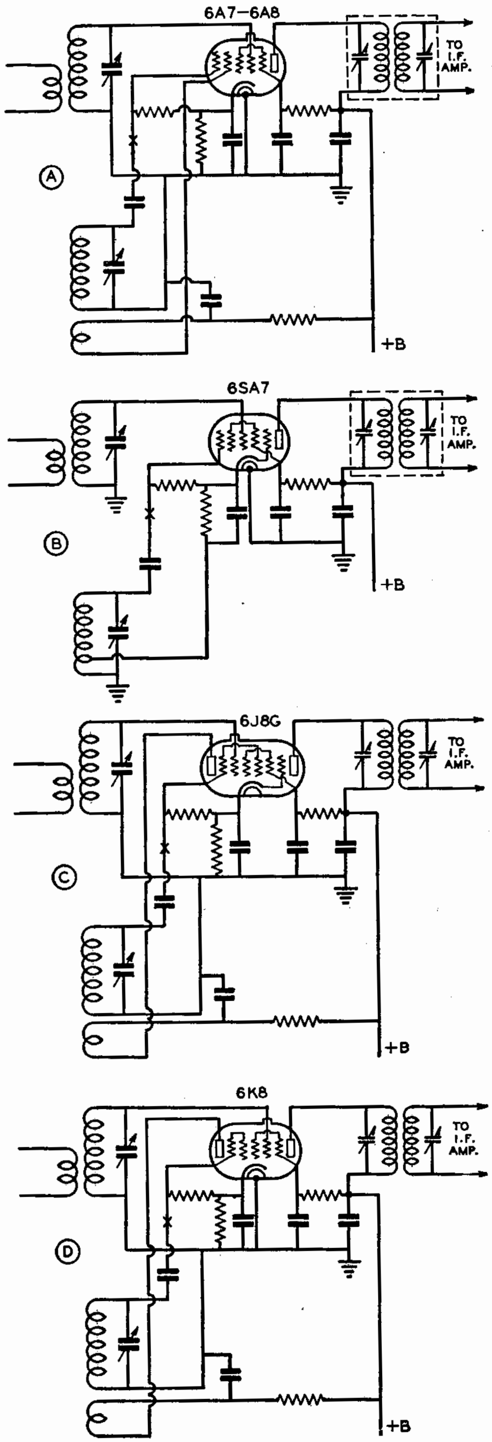


Figure 11.
CONVERTER CIRCUITS.
A and B are for "pentagrid" tubes and C and D for "triode-heptode" and "triode-hexode" tubes.

6K8, 6J8G and 6SA7 perform particularly well when used in this manner. A circuit of this type for use with a 6K8 is shown in figure 12. The points marked "X" in figure 11 show the proper place to inject r.f. from a separate oscillator with the other combination type converter tubes. When the 6A7 and 6A8 types are used with a separate oscillator the unused oscillator anode-grid is connected directly to the screen.

Mixer Noise and Images

The effects of *mixer noise* and *images* are troubles common to all superheterodynes, and since both these effects can largely be obviated by the same remedy, they will be considered together.

Mixer Noise. Mixer noise of the shot-effect type, which is evidenced by a hiss in the audio output of the receiver, is caused by exceedingly small irregularities in the plate current in the mixer stage. Noise of an identical nature is generated in the amplifier stages of the receiver, but due to a certain extent to the fact that the gain in the mixer stage is considerably lower than in an amplifier stage using the same tube, the proportion of inherent noise present in a mixer usually is considerably greater than in an amplifier stage.

Although this noise cannot be eliminated, its effects can be greatly minimized by placing sufficient signal-frequency amplification having a high signal-to-noise ratio ahead of the mixer. This remedy causes the signal output from the mixer to be large in proportion to the noise. Increasing the gain after the mixer will be of little advantage in eliminating mixer noise difficulties; greater selectivity after the mixer will help to a certain extent but cannot be carried too far since this type of selectivity decreases the i.f. bandpass and reduces the strength of the high-frequency components of modulated signals.

Images. Images are a result of frequency conversion. They are a consequence of the fact that there are two signal frequencies which will combine with a single oscillator frequency to produce the same difference frequency. For example: a superheterodyne with its oscillator operating on a higher frequency than the signal, which is common practice in present superheterodynes, is tuned to

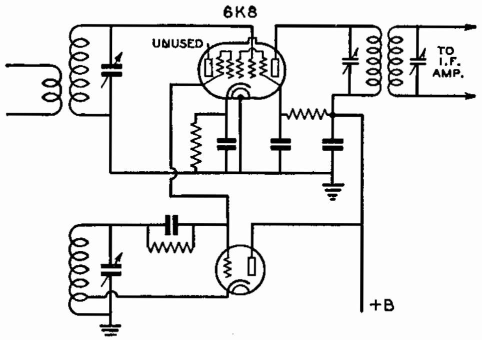


Figure 12.
USING A SEPARATE OSCILLATOR WITH A DUAL-PURPOSE CONVERTER TUBE.
A separate oscillator may also be connected into the mixer circuits shown in figure 11 at the points marked "X."

receive a signal at 14,100 kc. Assuming an i.f.-amplifier frequency of 450 kc., the mixer input circuit will be tuned to 14,100 kc. and the oscillator to 14,100 plus 450, or 14,550 kc. Now, a strong signal at the oscillator plus the intermediate frequency (14,550 plus 450, or 15,000 kc.) will also give a difference frequency of 450 kc. in the mixer output and will be received just as though it were actually on 14,100 kc., the frequency of the desired signal. The image is always *twice* the intermediate frequency away from the desired signal.

The only way that the *image* could be eliminated in this particular case would be to make the selectivity of the mixer input circuit and any circuits preceding it great enough so that the 15,000-kc. signal would be eliminated with these circuits tuned to 14,100 kc.

For any particular intermediate frequency, image interference troubles become increasingly greater as the frequency to which the signal-frequency portion of the receiver is tuned is increased. This is due to the fact that the percentage difference between the desired frequency and the image frequency decreases as the receiver is tuned to a higher frequency. The ratio of strength between a signal at the image frequency and a signal at the frequency to which the receiver is tuned required to give equal output is known as the *image ratio*. The higher this ratio, the better the receiver in regard to image-interference troubles.

With but a single tuned circuit between the mixer grid and the antenna, and with 400–500 kc. i.f. amplifiers image ratios of one hundred and over are easily obtainable up to frequencies around 5000 kc. Above this frequency greater selectivity in the mixer grid circuit (through the use of regeneration) or additional tuned circuits between the mixer and the antenna are necessary if a good image ratio is to be maintained.

R.F. Stages. Since the necessary tuned circuits between the mixer and the antenna can be combined with tubes to form r.f. amplifier stages, the reduction of the effects of mixer noise and the increasing of the image ratio can be accomplished in a single section of the receiver. When incorporated in the receiver this section is known simply as an *r.f. amplifier;* when it is a separate unit with a separate tuning control it is known as a *preselector*. Either one or two stages are commonly used in the preselector or r.f. amplifier. Some single-stage preselectors and a few two-stage units use regeneration to obtain still greater amplification and selectivity.

Double Conversion. As previously mentioned, the use of a higher intermediate frequency will also improve the image ratio, at the expense of i.f. selectivity, by placing the desired signal and the image farther apart. To give both good image ratio at the higher frequencies and good selectivity in the i.f. amplifier, a system known as *double conversion* is sometimes employed. In this system the incoming signal is first converted to a rather high intermediate frequency, such as 1600 kc., and then amplified and again converted, this time to a much lower frequency, such as 175 kc. The first i.f. frequency supplies the necessary wide separation between the image and the desired signal while the second one supplies the bulk of the i.f. selectivity.

Regenerative Preselectors. R.f. amplifiers for wave-lengths down to 30 meters can be made to operate efficiently in a nonregenerative condition. The amplification and selectivity are ample over this range. For higher frequencies, on the other hand (wavelengths below 30 meters), *controlled regeneration* in the r.f. amplifier is often desirable for the purpose of increasing the gain and selectivity.

The input impedance of the grid circuit of a radio-frequency amplifier tube consists of a very high capacitive reactance which becomes part of the tuning capacity for longer wavelengths. However, in very short wave receivers the input impedance of a tube may drop to very low values, such as a few thousand ohms. This low impedance across the input tuned circuit reduces the amount of amplification that can be obtained from the complete r.f. stage to a very low value.

A small amount of r.f. feedback can be introduced to compensate for this tube loss.

Regeneration can be carried to the point of actually creating the effect of negative resistance in the grid circuit, and thereby balancing the resistance introduced across the tuned circuit by the relatively low parallel tube resistance. Excessive regeneration will result in too much negative resistance, which will cause the r.f. amplifier to oscillate. Operation should always be below the point of self-oscillation.

As previously discussed, a disadvantage of the regenerative r.f. amplifier is the need for an additional regeneration control, and the difficulty of maintaining alignment between this circuit and the following tuned circuits. Resonant effects of antenna systems usually must be taken into account; a variable antenna coupling device can sometimes be used to compensate for this effect, however. Another disadvantage is the increase in hiss, or internal noise.

The reason for using regeneration at the higher frequencies and not at the medium and low frequencies can be explained as follows: The signal-to-noise ratio (output signal) of the average r.f. amplifier is reduced slightly by the incorporation of regeneration, but the signal-to-noise ratio of the *receiver as a whole* is improved at the very high frequencies because of the extra gain provided ahead of the mixer, this extra gain tending to make the signal output a larger portion of the total signal-plus-noise output of the receiver.

Signal-Frequency Tuned Circuits

The signal-frequency tuned circuits in superheterodynes and tuned radio frequency types of receivers consist of coils of either the solenoid or universal-wound types shunted by variable condensers. It is in these tuned circuits that the causes of success or failure of a receiver often lie. The universal-wound type coils usually are used at frequencies below 2000 kc.; above this frequency the single-layer solenoid type of coil is more satisfactory.

Impedance and Q. The two factors most affecting the tuned circuits are impedance and Q, which, as explained in Chapter 2, is the ratio of reactance to resistance in the circuit. Since the resistance of modern condensers is low at ordinary frequencies, the resistance usually can be considered to be concentrated in the coil. The resistance to be considered in making Q determinations is the r.f. resistance, not the d.c. resistance of the wire in the coil. The latter ordinarily is low enough that it may be neglected. This r.f. resistance is influenced by such factors as wire size and type and the proximity of metallic objects or poor insulators, such as coil forms with high losses. It may be seen from the curves shown in Chapter 2 that higher values of Q lead to better selectivity and increased r.f. voltage across the tuned circuit. The increase in voltage is due to an increase in the circuit impedance with the higher values of Q.

Frequently it is possible to secure an increase in impedance in a resonant circuit, and consequently an increase in gain from an amplifier stage, by increasing the reactance through the use of larger coils and smaller tuning condensers (higher L/C ratio). The Q of the coil probably will be lowered by this process, but the impedance, which is a function of both reactance and Q, will be greater because for small increases in reactances the reactance will increase faster than the Q decreases. The selectivity will be poorer, but in superheterodyne receivers selectivity in the signal-frequency circuits is of minor importance where signals on adjacent channels are concerned. On the other hand, the t.r.f. type of receiver requires good selectivity in the tuned circuits, and a compromise between impedance and Q must be made.

Input Resistance. Another factor which influences the operation of tuned circuits is the decrease with increasing frequency of input resistance of the tubes placed across these circuits. At broadcast frequencies the input resistance of most tubes is high enough so that it is not bothersome. As the frequency is increased, however, the input resistance becomes lower because the transit time required by an electron traveling between the cathode and grid becomes an appreciable portion of the time required for an r.f. cycle of the signal voltage. The result of this effect is similar to that which would be caused by placing a resistance between the grid and cathode.

Because of the lower input resistance of tubes at the higher frequencies, there is a limit to the maximum impedance necessary to obtain maximum voltage across the tuned circuits when these circuits are shunted by the tube's input resistance. These considerations often make it advisable to design the concentric tuned circuits often used at the higher frequencies for maximum Q rather than for maximum impedance. The tube input resistance remains constant, and increasing the tuned circuit impedance beyond two or three times the input resistance will have but little effect on the net grid-to-ground impedance of the amplifier stage.

The limiting factor in r.f. stage gain is the ratio of input conductance to the tube transconductance. When the input conductance

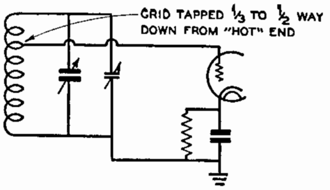


Figure 13.
CIRCUIT FOR REDUCING GRID LOADING EFFECTS.
Tapping the grid down on the coil will increase the gain and selectivity obtained with high-transconductance tubes at high frequencies.

becomes so great that it equals the transconductance, the tube no longer can act as an amplifier. There are two ways of increasing the ratio of transconductance to input conductance. One of these methods is exemplified by the "acorn" type tube, in which the input conductance is reduced through the use of a smaller element structure while the transconductance remains nearly the same as that of tubes ordinarily used at lower frequencies. Another method of accomplishing an increase in transconductance-input conductance ratio is by greatly increasing the transconductance at the expense of a proportionately small increase in input conductance. The latter method is exemplified by the so-called "television pentodes," which have extremely high transconductance and an input conductance several times that of the acorn tubes.

The difficulties presented by input-resistance effects may be partially obviated by tapping the grid down on the coil, as shown in figure 13. This circuit is commonly employed with high-transconductance tubes when operating on the 28–30 Mc. amateur band, and nearly always with such tubes on the 56–60 Mc. band. Acorn tubes, due to their smaller dimensions and lower capacities, are considerably better than the conventional types at ultra-high frequencies and it usually will not be found necessary to tap their grids down on the tuned circuit until frequencies around 200 Mc. are reached.

Superheterodyne Tracking. Because the detector (and r.f. stages, if any) and the oscillator operate on different frequencies in superheterodynes, in some cases it is necessary to make special provisions to allow the oscillator to track with the other tuned circuits when similar tuning condensers are used. The usual method of obtaining good tracking is to operate the oscillator on the high-frequency side of the mixer and use a series "tracking condenser" to slow down the tuning rate of the oscillator. The oscillator tuning rate must be slower because it covers a smaller range than

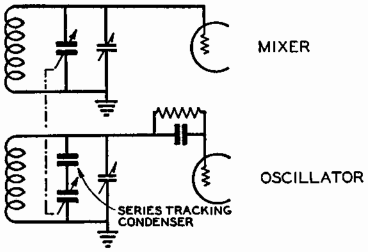


Figure 14.
OSCILLATOR SERIES TRACKING CONDENSER ARRANGEMENT.
The series condenser allows the oscillator to tune at a slower rate of capacity change than the mixer.

does the mixer when both ranges are expressed as a percentage of frequency. At frequencies above 7000 kc. and with ordinary i.f. frequencies, the difference in percentage between the two tuning ranges is so small that it may be disregarded in receivers designed to cover only a small range, such as an amateur band.

A mixer and oscillator tuning arrangement in which a series tracking condenser is provided is shown in figure 14. The value of the tracking condenser varies considerably with different intermediate frequencies and tuning ranges, capacities as low as .0001 μfd. being used at the lower tuning-range frequencies, and values up to .01 μfd. being used at the higher frequencies.

Bandspread Tuning. The frequency to which a receiver responds may be varied by changing the size of either the coils or the condensers in the tuning circuits, or both. In short-wave receivers a combination of both methods is usually employed, the coils being changed from one band to another and variable condensers being used to tune the receiver across each band. In practical receivers, coils may be changed by one of two methods: A switch, controllable from the front panel, may be used to switch coils of different sizes into the tuning circuits or, alternatively, coils of different sizes may be plugged manually into the receiver, the connection into the tuning circuits being made by suitable plugs on the coils. Where there are several "plug-in" coils for each band they are sometimes arranged on a single mounting strip, allowing them all to be plugged in simultaneously.

In receivers using large tuning condensers to cover the short-wave spectrum with a minimum of coils, tuning is liable to be quite difficult owing to the large frequency range covered by a small rotation of the variable condensers. To alleviate this condition, some method of slowing down the tuning rate, or *bandspreading* must be used.

Quantitatively, bandspread is usually designated as being inversely proportional to the range covered. Thus, a *large* amount of bandspread indicates that a *small* frequency range is covered by the bandspread control. Conversely, a *small* amount of bandspread is taken to mean that a *large* frequency range is covered by the bandspread dial.

Types of Bandspread. Bandspreading systems are of two general types: electrical and mechanical. Mechanical systems are exemplified by high-ratio dials in which the tuning condensers rotate much more slowly than the dial knob. In this system there is often a separate scale or pointer either connected or geared to the dial knob to facilitate accurate dial readings. However, there is a limit to the amount of mechanical bandspread which can be obtained in an inexpensive dial before the speed-reduction unit develops backlash, which makes tuning difficult. To overcome this problem most receivers employ a combination of both electrical and mechanical bandspread. In this system a moderate reduction in the tuning is obtained in the dial and the rest of the reduction obtained by *electrical bandspreading*.

Parallel Bandspread. Electrical bandspreading takes two general forms. In one, two tuning condensers are used in parallel across each coil, one of rather high capacity to cover a large tuning range and another of small capacity to cover a small range around the frequency to which the large condenser is set. These condensers are usually controlled by separate dials or knobs, the large condenser being known as the *bandsetting* condenser, and the smaller one being the bandspread condenser. Where there is more than one tuned circuit in the receiver, a bandsetting and a bandspread condenser are used across *each* coil and all the condensers serving in each capacity are mechanically connected together, or *ganged,* thus allowing a single dial to be used for each purpose even though there may be several tuned circuits.

Since the tuning range of a tuned circuit is proportional to the ratio of minimum to maximum capacity across it, a wide variation in the amount of bandspreading is made possible by a proper choice of the two capacities. The greater the capacity of the bandsetting condenser in proportion to the bandspread condenser, the greater will be the bandspread.

The bandspreading method described above is usually known as the *parallel* system. This system, as applied to a single tuned circuit, is diagrammed in figure 15A. The large tuning, or bandsetting, condenser, C_1, usually has a maximum capacity of from 100 to 370 $\mu\mu$fd. C_2, the bandspread condenser, usually has a value of from 10 to 50 $\mu\mu$fd., depending upon the design of the receiver.

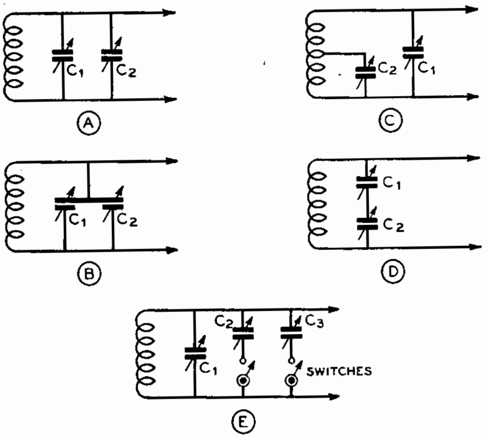


Figure 15.
BANDSPREAD CIRCUITS.
The operation of each of these circuits is described in the text.

Dual-Rotor Bandspread. A special form of the parallel bandspread method is used in some manufactured tuning assemblies. In this system a single set of stationary plates (stator) in the tuning condenser is acted upon by two separate rotors, one of large capacity for bandsetting and the other of small capacity for bandspread. Each rotor is operated by a separate dial. This system allows the bandsetting and bandspread functions to be combined in a single tuning-condenser unit. A variation of this method is sometimes used in which the same dial is used for both bandsetting and bandspreading purposes, the change from one function to the other being accomplished by a "gear-shifting" mechanism built into the dial. The schematic of this bandspread system is shown in figure 15B.

The parallel system of bandspreading has one major disadvantage, especially for amateur-band usage. This disadvantage lies in the fact that if the bandspreading condenser is made large enough to cover the lower-frequency amateur bands with optimum capacity being used across the coil in the bandsetting condenser, an extremely large bandsetting condenser is needed to give an equal amount of bandspread on the high-frequency bands. The high capacity across the coils reduces the impedance of the tuned circuits on the high-frequency bands, where impedance is most needed.

Tapped-Coil System. To allow equal bandspread on the amateur bands and still not use extremely high bandsetting capacities on the higher frequencies, the variation of the parallel system shown in figure 15C is often employed. As the bandspread condenser is connected across part of the coil, this method is usually known as the *tapped coil* system.

The theory upon which the tapped-coil system operates is quite simple. The effectiveness of the bandspread condenser in tuning the coil depends upon the amount of the coil included across the bandspread condenser terminals. As the number of turns between the bandspread condenser terminals is decreased the amount of bandspread increases.

In most amateur-band receivers employing the tapped-coil system of bandspreading, a separate bandsetting condenser is permanently connected across each coil. These condensers are either mounted within the coils, in the plug-in-coil system, or alongside the coils in the bandswitching system.

The tapped-coil bandspread method is quite widely used in modern amateur-band receivers, especially in home constructed sets. Its principal advantage is that it allows equal bandspread, to any degree desired, over several amateur bands. Another advantage is that it facilitates accurate tracking in ganged tuning circuits; the coil taps are adjusted until the circuits track identically.

The bandspread condenser, C_2, may have a maximum capacity of from 25 to 50 $\mu\mu$fd. for amateur band usage, while the bandsetting condenser, C_1, should have a maximum capacity of 30 to 150 $\mu\mu$fd. for amateur bands from 10 to 160 meters. Although it is possible to use almost any combination of capacities at C_1 and C_2, too little capacity at C_1 is liable to lead to cross modulation and image interference, while too great a capacity at C_2 will cause uneven bandspread, the high-frequency end of the tuning range being more crowded than the low-frequency end.

Series System. Another bandspread system is shown in figure 15D. This system, which was widely used in the past, and is still employed to some extent, is known as *series bandspread.* In this system the bandspread condenser, C_2, usually has a capacity of 100 to 150 $\mu\mu$fd., while the bandsetting condenser, C_1, may have a capacity of 25 to 50 $\mu\mu$fd. The principle upon which the circuit operates is that while the *minimum* capacity across the coil varies but little for any setting of the bandsetting condenser, the *maximum* capacity available may be varied considerably.

Condenser Switching System. In figure 15E is illustrated another method of equalizing the degree of bandspread over a wide range of frequencies. C_1 is the large 350-$\mu\mu$fd. tuning condenser; two bandspread condensers C_2 and C_3, of 50$\mu\mu$fd. and 15 $\mu\mu$fd. respectively, are switched across the large condenser for bandspreading the short-wave bands. The 50-$\mu\mu$fd. condenser is suitable for bandspread tuning in the range from 75 to 200 meters, and the smaller condenser is suitable from 10 to 75 meters. The disadvantage of this circuit lies in the switching arrangement, which may require relatively long connecting leads; the minimum capacity of the circuit would then be rather high, and the lumped inductance low at the higher frequencies.

Circuit Capacity. In this book and in other radio literature mention is sometimes made of "stray" or *circuit capacity.* This capacity is in the usual sense defined as the capacity remaining across a coil when all the tuning, bandspread, and padding condensers across the circuit are at their minimum capacity setting. Circuit capacity can be attributed to two general sources. One source, which is fixed for any particular type of tube, is that due to the "cold" input capacitance of the tube when its cathode is not heated. The input capacitance varies somewhat from the fixed value when the tube is in actual operation. Such factors as plate load impedance, grid bias, and frequency will cause a change in input capacitance. However, in all except the extremely high-transconductance tubes the published measured input capacitance is quite close to the effective value. In the high-transconductance types however, the effective capacitance does vary considerably from the published figures, under different operating conditions.

The second source of circuit capacity and that which is more easily controllable is that contributed by the minimum capacity of the variable condensers across the circuit and that due to capacity between the wiring and ground. In well-designed high-frequency receivers every effort is made to keep this portion of the circuit capacity at a minimum, since a large capacity reduces the tuning range available with a given coil and prevents a good L/C ratio, and consequently a high-impedance tuned circuit, from being obtained.

Typical values of circuit capacity may run from 10 to 75 $\mu\mu$fd. in high-frequency receivers, the first figure representing concentric-line receivers with acorn tubes and extremely small tuning condensers, and the latter representing all-wave sets with bandswitching, large tuning condensers, and conventional tubes.

I.F. Tuned Circuits

All i.f. amplifiers employ bandpass circuits of some sort. A bandpass circuit is exactly what the name implies—a circuit for passing a band of frequencies. Bandpass arrangements can be designed for almost any degree of selectivity, the type used in any particular application depending upon the use to which the i.f. amplifier is to be put.

Bandpass Circuits. Bandpass circuits consist essentially of two or more tuned circuits and some method of coupling the tuned circuits together. Some representative arrangements are shown in figure 16. The circuit shown at A is the conventional i.f. transformer with the coupling, M, between the tuned circuits being provided by inductive coupling from one coil to the other. As the coupling is increased, the selectivity curve becomes less peaked, and when a condition of over-coupling is reached the top of the curve flattens out. When the coupling is increased still more, a dip occurs in the top of the curve. The windings for this type of i.f. transformer, as well as most others, nearly always consist of small, flat universal-wound pies mounted either on a piece of dowel to provide an air core or on powdered-iron impregnated bakelite for "iron core" i.f. transformers. The iron-core transformers generally have somewhat more gain and better selectivity than equivalent air-core units between 175 and 2000 kc.

The circuits shown at B and C are quite similar. Their only difference is the type of mutual coupling used, an inductance being used at B and a capacitance at C. The operation of both circuits is similar. Three resonant circuits are formed by the components. In B, for example, one resonant circuit is formed by L_1, C_1, C_2, and L_2 all in series. The frequency of this resonant circuit is just the same as that of a single one of the coils and condensers, since the coils and condensers are similar in both sides of the circuit and the resonant frequency of the two condensers and the two coils all in series is the same as that of a single coil and condenser. The second resonant frequency of the complete circuit is determined by the characteristics of each half of the circuit containing the mutual coupling device. In B, this second frequency will be lower than the first since the resonant frequency of L_1, C_1 and the inductance, M, or L_2, C_2 and M is lower than that of a single

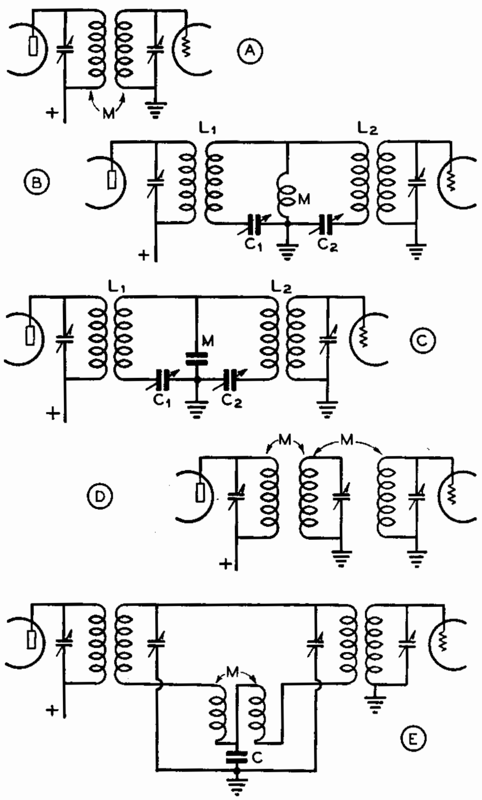


Figure 16.
I.F. AMPLIFIER BAND-PASS CIRCUITS.
The ordinary i.f. transformer circuit is shown at A. The other circuits are intended to give a straight-sided, flat-topped selectivity characteristic to the i.f. amplifier.

coil and condenser, due to the inductance of M being added to the circuit. The opposite effect takes place at C, where the common coupling impedance is a condenser. Thus at C the second resonant frequency is higher than the first. In either case, however, the circuit has two resonant frequencies, resulting in a flat-topped selectivity curve. The width of the top of the curve is controlled by the reactance of the mutual coupling component. As this reactance is increased (inductance made greater, capacity made smaller) the two resonant frequencies become farther apart and the curve is broadened.

The circuit of figure 16D is often used where a fairly high degree of bandpass action is required and the number of i.f. transformers used must be kept at a minimum. In this circuit there is inductive coupling between the center coil and each of the outer coils. The

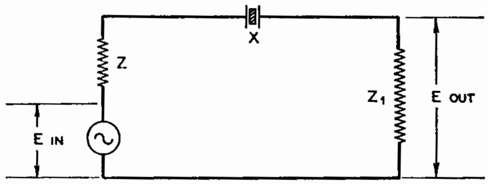


Figure 17.
CRYSTAL FILTER EQUIVALENT CIRCUIT.
With a constant input voltage, the r.f. voltage developed across Z_1 depends upon the impedances of Z, X and Z_1.

result of this arrangement is that the center coil acts as a sharply tuned coupler between the other two. A signal somewhat off the resonant frequency of the transformer will not induce as much voltage in the center coil as will a signal of the correct frequency. When a smaller voltage is induced in the center coil, it in turn transfers a still smaller voltage to the output coil. In other words the coupling of the three coils increases as the resonant frequency is approached and remains nearly constant over a small range and then decreases again as the resonant band is passed.

Another very satisfactory bandpass arrangement which gives a very straight-sided, flat-topped curve is the negative-mutual arrangement shown at E. Energy is transferred between the input and output circuits in this arrangement by both the negative-mutual coils, M, and the common capacitive reactance, C. The negative-mutual coils are interwound on the same form and connected "backward," as shown.

Crystal Filters. The selectivity of the intermediate-frequency amplifier may be increased greatly through the use of an extremely high Q piezo-electric series resonant circuit. The piezo-electric quartz crystal, together with its coupling arrangement, is generally known as a *crystal filter*. The electrical equivalent of the basic crystal filter circuit is shown in figure 17, while the electrical equivalent of the crystal itself is shown in figure 18.

At its resonant frequency, the crystal, X, may be replaced by a very small resistance, and thus at this frequency the current flowing through the circuit, Z, X, Z_1 reaches a maximum and the output voltage E_{out} is also at its maximum value. At frequencies slightly off resonance the crystal impedance becomes quite high and the current flowing through the circuit, and consequently the voltage E_{out} developed across Z_1, drops to a low value. It is the ratio of E_{out} at resonance to this voltage at frequencies away from resonance that determines the selectivity characteristic of the crystal filter. This ratio may be shown to depend upon the values of the impedances Z and Z_1. These impedances remain nearly constant for frequencies near resonance, and the selectivity of the filter circuit as a whole may be altered by changing the resonant frequency values. The variable selectivity crystal filter circuits quite often used in communications superheterodynes operate on this principle.

Practical Filters. In practical crystal filters is is necessary to balance out the capacity across the crystal holder (C_1 in figure 18) to prevent by-passing around the crystal of undesired signals off the crystal resonant frequency. The balancing is done by a *phasing* circuit which takes out-of-phase voltage from

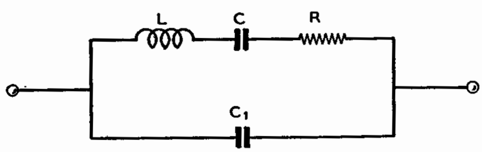
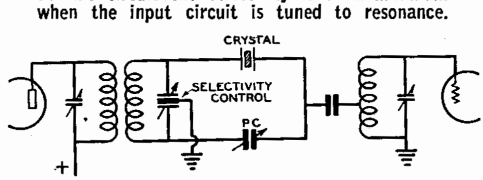


Figure 18.
CRYSTAL EQUIVALENT.
The crystal is equivalent to a very large inductance in series with a very small resistor and condenser.

Figure 19.
VARIABLE-SELECTIVITY CRYSTAL CIRCUIT.
In this circuit the selectivity is at a minimum when the input circuit is tuned to resonance.



a balanced input circuit and passes it to the output side of the crystal in proper phase to neutralize that passed through the holder capacity. A representative practical filter arrangement is shown in figure 19. The phasing condenser is indicated in the diagram by PC. The balanced input circuit may be obtained either through the use of a split-stator condenser as shown or by the use of a center-tapped input coil.

Variable-Selectivity Filters. In the circuit of figure 19 the selectivity is minimum with the crystal input circuit tuned to resonance, since at resonance the input circuit is a pure resistance effectively in series with the voltage applied to the crystal. As the input circuit is detuned from resonance, however, the resistive component of the input impedance decreases and the selectivity becomes greater. In this circuit the output from the crystal filter is tapped down on the i.f. stage grid winding to provide a better match and lower the impedance in series with the crystal.

The circuit shown in figure 20 also achieves variable selectivity by adding an impedance in series with the crystal circuit. In this case the variable impedance is in series with the crystal output circuit. The impedance of the output tuned circuit is varied by varying the Q. As the Q is reduced (by adding re-

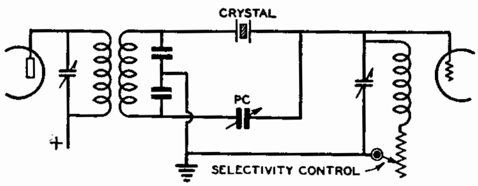
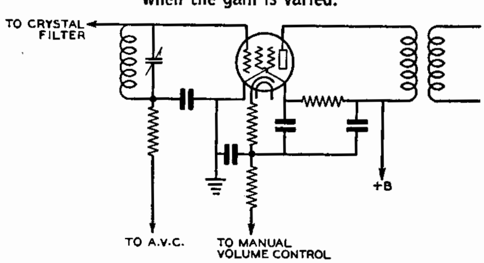


Figure 20.
WIDE-RANGE VARIABLE-SELECTIVITY CRYSTAL FILTER.
The selectivity is varied by changing the impedance of the output circuit by changing its Q.

Figure 21.
DEGENERATIVE I.F. STAGE.
Degeneration in the i.f. stage following the crystal filter is desirable to avoid input capacity changes when the gain is varied.



sistance in series with the coil) the impedance decreases and the selectivity becomes greater.

A variation of the circuit shown at figure 20 consists of placing the variable resistance across the coil and condenser, rather than in series with them. The result of adding the resistor is a reduction of the output impedance and an increase in selectivity. The circuit behaves oppositely to that of figure 20, however; as the resistance is lowered the selectivity becomes greater.

Interference Rejection. The crystal filter phasing condenser can be adjusted so that parallel resonance between it and the crystal causes a sharp dip in the response curve at some desired point, such as 2 kc. from the desired signal peak. This effect can be utilized to eliminate completely the unwanted sideband 1 kc. away from zero beat for c.w. reception. The b.f.o. then provides a true single signal effect, that is, a single beat frequency note. This effectively increases the number of c.w. channels that can be used in any short-wave band.

1600-Kc. Crystal Filters. Since the selectivity of a series crystal resonator varies approximately directly with frequency, crystal filters for use with i.f. amplifiers in the 1500- to 1600-kc. range are approximately three times as broad as their maximum selectivity setting as 465-kc. crystal circuits. This is no great disadvantage, as a well-designed 1600-kc. filter may be made to have 300-cycle selectivity at its maximum setting. For radiotelephone reception the 1600-kc. filter actually is advantageous, because its minimum selectivity permits a much wider band than a 465-kc. unit. The wider available pass band allows the crystal to be left in the circuit at all times and the selectivity merely varied to suit the kind of reception desired. Variable-selectivity circuits of the type shown in figure 19 require special consideration when used with 1600-kc. crystals, however. This is due to the fact that the capacity across the crystal holder, and consequently the capacity of the phasing condenser, is much higher, due to the thinner crystal required at 1600 kc.

As the phasing condenser and the crystal are actually in series across the input circuit and selectivity control, any change in setting of the phasing condenser will alter the selectivity. This difficulty may be eliminated by using a special form of phasing condenser which acts as a capacity potentiometer and maintains equal capacity across the input circuit and at the same time varies the capacity in the phasing branch.

Reducing Input Capacity Variations. As the previous discussion on crystal filters has indicated, the selectivity of the crystal filter can be altered by changing the impedance of the crystal output circuit. Since the impedance at crystal frequency of the output circuit can be varied by detuning it as well as by varying its Q, it is important that the input capacity of the tube following the filter remain constant when the gain of this stage is varied. The input capacity may be stabilized with respect to changes in the tube's amplification by employing a small amount of degeneration, as illustrated in figure 21. The amount of degeneration which can be used

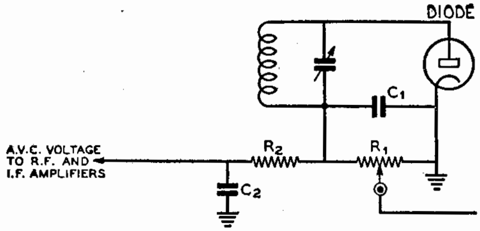


Figure 22.
DIODE A.V.C. CIRCUIT.
This circuit will be found in many superheterodynes. The diode also acts as a detector, audio voltage appearing across the volume control, R_1.

will depend upon the amount of gain which can be sacrificed in the i.f. stage following the crystal filter. Values for R will ordinarily fall between one-third and two-thirds of the total resistance in the cathode circuit, exclusive of the manual gain control.

Detector, Audio and Control Circuits

Detectors. Second detectors for use in superheterodynes are usually of the diode, plate, or infinite impedance types, which were described in detail in Chapter 3. Occasionally, grid-leak detectors are used in receivers using one i.f. stage or none at all, when the second detector is regenerative.

Diodes are the most popular second detectors because they allow a simple method of obtaining automatic volume control to be used. Diodes load the tuned circuit to which they are connected, however, and thus reduce the selectivity slightly. Special i.f. transformers are used for the purpose of providing a low-impedance input circuit to the diode detector.

Automatic Volume Control. An elementary circuit of an automatic volume control (a.v.c.) system is shown in figure 22. A diode tube is used as a rectifier of the carrier signal. The radio- (or intermediate) frequency circuit to the diode is completed through the small condenser C_1, which is too low in value to by-pass audio frequencies. The carrier signal is detected or rectified, and the resulting current flows through the diode circuit and the resistance R_1. This rectified current develops a voltage across R_1, which is more negative at the ungrounded end.

A simple R-C (resistance-capacity) filter in the form of R_2-C_2 may be connected to the diode circuit in order to utilize the d.c. voltage for automatic volume control purposes. The filter irons out the audio frequencies and allows pure direct current to be obtained. The negative voltage developed across R_1 and C_2 has a value directly proportional to the incoming carrier signal. This voltage is used to bias the control grids of some or all of the r.f. and i.f. amplifier stages. An increased negative bias on these stages will reduce the amplification of the receiver so that a strong carrier furnishes approximately the same audio-frequency output signal as would be obtained from a weak carrier. Automatic volume control has the further advantage of maintaining the audio signal at a fairly constant level, even though the signal from a distant station may be fading or varying in amplitude.

A great many different circuits are used for obtaining a.v.c., and it is obviously impossible to show them all here. Essentially, most of these circuits consist of some kind of rectifier for rectifying the signal and using it for bias on the preceding stages or else some sort of an amplifier biased near the cutoff point which draws more current through a resistance when a signal is applied, the drop across the resistance being used in one of several possible ways to bias the amplifier stages.

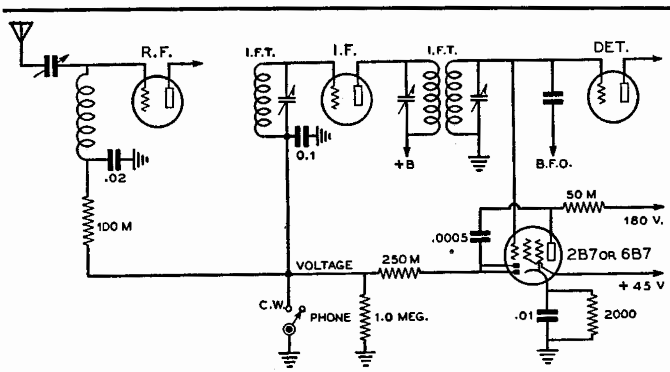


Figure 23.
A.V.C. CIRCUIT FOR ANY SUPERHETERODYNE.
This circuit may be added to a receiver not equipped with a.v.c. The 2B7 or 6B7 acts as an a.v.c. amplifier and diode rectifier.

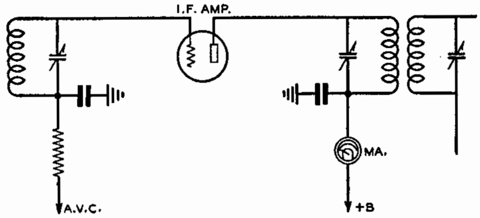


Figure 24.
USING A LOW-RANGE MILLIAMMETER AS A TUNING OR SIGNAL STRENGTH INDICATOR.
The plate current to an i.f. stage varies as the a.v.c. bias changes. A 0-10 d.c. milliammeter will serve in most cases. The meter reads "backwards" in this circuit, strong signals causing the current to decrease more than weak ones.

Figure 25.
ELECTRON-RAY TUNING INDICATOR.
Other "eye" tubes such as the 6N5, 6U5, and 6G5 may also be used in this circuit.

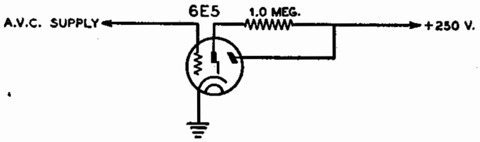


Figure 23 shows a typical automatic volume control circuit which can be applied to almost any superheterodyne receiver.

The resistors and condensers in the various i.f. and r.f. grid-return circuits constitute a time-delay filter. The time constant of the a.v.c. circuit may be reduced by using smaller condensers or resistors or increased by using larger ones.

Signal Strength Indicators. A visual means for determining whether or not the receiver is properly tuned, as well as an indication of the relative signal strength, are both provided by means of ***tuning indicators*** of the meter or vacuum-tube types. Direct current milliammeters can be connected in the plate return circuit of an r.f. amplifier as shown in figure 24 so that the change in plate current, due to the a.v.c. voltage which is supplied to that tube, will indicate proper tuning or *resonance*. Sometimes these d.c. meters are built in such a manner as to produce a shadow of varying width. Vacuum-tube tuning indicators are designed so that an electron-ray "eye" pattern changes its size when the input circuit of the tube is connected across all or part of the a.v.c. voltage. The basic circuit for this type of indicator is illustrated in figure 25.

Unfortunately, when an ordinary meter is used in the plate circuit of a stage for the purpose of indicating signal strength, the meter reads backward with respect to strength. This is caused by increased a.v.c. bias on stronger signals resulting in lowered plate current through the meter. For this reason special meters which indicate zero at the right-hand end of the scale are often used for signal strength indicators in this type of circuit. Alternatively, the meter may be mounted upside down so that the needle moves toward the right with increased signal strength.

A circuit which allows an ordinary meter to be used, and which gives conventional right-hand movement of the needle with increased signal strength is shown in figure 26. The plate (or plate and screen) current to the stages receiving a.v.c. bias is fed through one-half of a bridge network. The meter, M, is usually a 0–1 milliammeter. The resistor values shown are average ones; it may be necessary to change them slightly, depending upon the number of stages drawing current through the network. Using a lower value at R will give greater "swing" for a given signal strength, while larger values will reduce the swing. The variable 1000-ohm resistor is

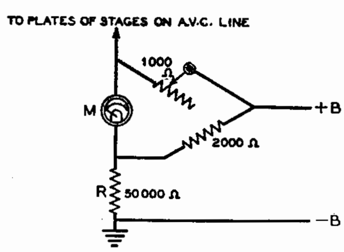
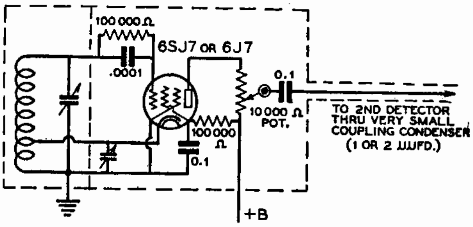


Figure 26.
FORWARD READING SIGNAL STRENGTH METER CIRCUIT.
Placing the meter in a bridge circuit allows it to read in a "forward" direction in respect to signal strength. The meter is usually a 0-1 milliammeter.

Figure 27.
VARIABLE-OUTPUT B.F.O. CIRCUIT.
Being able to vary the output of the b.f.o. is sometimes helpful when receiving weak signals.



used to set the meter for minimum indication when no signal is being received.

Beat-Frequency Oscillators. The beat-frequency oscillator, usually called the *b.f.o.*, is a necessary adjunct for reception of c.w. telegraph signals on superheterodynes which do not use regenerative detectors. The oscillator is coupled into the second detector circuit and supplies a weak signal of nearly the same frequency as that of the desired signal from the i.f. amplifier. If the i.f. amplifier is tuned to 465 kc., for example, the b.f.o. is tuned to approximately 464 or 466 kc. in order to produce a 1000-cycle beat note in the output of the second detector of the receiver. The carrier signal would otherwise be inaudible. The b.f.o. is not used for voice reception, except as an aid in searching for weak stations.

The b.f.o. input to the second detector need only be sufficient to give a good beat note on an average signal. Too much coupling into the second detector will give an excessively high hiss level, masking weak signals by the high noise background.

A method of manually adjusting the b.f.o. output to correspond with the strength of received signals is shown in figure 27. A variable b.f.o. output control of this sort is a useful adjunct to any superheterodyne, since it allows sufficient b.f.o. output to be obtained to give a "beat" with strong signals and at the same time permits the b.f.o. output, and consequently the hiss, to be reduced when attempting to receive weak signals. The circuit shown is somewhat better than those in which one of the electrode voltages on the b.f.o. tube is changed, as the latter usually change the frequency of the b.f.o. at the same time they change the strength, making it necessary to reset the trimmer each time the output is adjusted.

In nearly all receivers in which both a.v.c. and a b.f.o. are used it is necessary to disconnect the a.v.c. circuit and manually control the gain when the b.f.o. is turned on. This is because the b.f.o. acts exactly like a strong signal and puts a.v.c. bias on the stages on the a.v.c. line, thereby lowering the gain of the receiver.

Noise Suppression

The problem of noise suppression confronts the listener who is located in such places where interference from power lines, electrical appliances and automobile ignition systems is troublesome. This noise is often of such intensity as to swamp out signals from desired stations.

There are three principal methods for reducing this noise:

(1) A.c. line filters at the source of interference if the noise is created by an electrical appliance.
(2) Noise-balancing circuits for the reduction of power-leak interference.
(3) Noise-limiting circuits for the reduction, in the receiver itself, of interference of the type caused by automobile ignition systems.

Power Line Filters. Numerous household appliances, such as electric mixers, heating pads, vacuum sweepers, refrigerators, oil burners, sewing machines, doorbells, etc., create an interference of an intermittent nature. The insertion of a line filter near the source of interference often will effect a complete cure. Filters for small appliances can consist of a 0.1-μfd. condenser connected across the 110-volt a.c. line. Two condensers in series across the line, with the midpoint

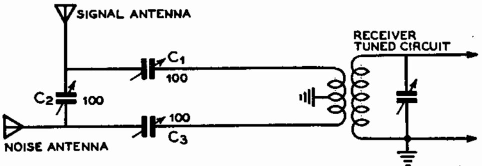


Figure 28.
JONES NOISE-BALANCING CIRCUIT.
This circuit, when properly adjusted, reduces the intensity of power-leak and similar interference.

connected to ground, can be used in conjunction with ultra-violet ray machines, refrigerators, oil burner furnaces and other more stubborn offenders. In severe cases of interference, additional filters in the form of heavy-duty r.f. choke coils must be connected in series with the 110-volt a.c. line on both sides of the line.

Noise Balancing. Power line noise interference can be greatly reduced by the installation of a *noise-balancing* circuit ahead of the receiver, as shown in figure 28. The noise-balancing circuit adds the noise components from a separate noise antenna in such a manner that this noise antenna will buck the noise picked up by the regular receiving antenna. The noise antenna can consist of a connection to one side of the a.c. line, in some cases, while at other times an additional wire, 20 to 50 feet in length, can be run parallel to the a.c. house supply line. The noise antenna should pick up as much noise as possible in comparison with the amount of signal pickup. The regular receiving antenna should be a good-sized out-door antenna, so that the signal to noise ratio will be as high as possible. When the noise components are balanced out in the circuit ahead of the receiver, the signals will not be appreciably attenuated.

This type of noise balancing is not a simple process; it requires a bit of experimentation in order to obtain good results. However when proper adjustments have been made, it is possible to reduce the power leak noise from 3 to 5 R points without reducing the signal strength more than one R point, and in some cases there will be no reduction in signal strength whatsoever. This means that fairly weak signals can be received through terrific power leak interference. Hash type interference from electrical appliances can be reduced to a very low value by means of the same circuits.

The coil should be center-tapped and connected to the receiver ground connection in most cases. The pickup coil consists of four turns of hookup wire 2″ in diameter which can be slipped over the first r.f. tuned coil in most radio receivers. A two-turn coil is more appropriate for 10- and 20-meter operation, though the four-turn coil is suitable if care is taken in adjusting the condensers to avoid 10-meter resonance (unless very loose inductive coupling is used).

Adjustment of C_1 will generally allow a noise balance to be obtained when varying C_2 and C_3 in nearly any location. One antenna, then the other, can be removed to check for noise in the receiver. When properly balanced, the usual power line buzz can be balanced down nearly to zero without attenuating the desired signal more than 50%. This may result in the reception of an intelligible distant signal through extremely bad power line noise. Sometimes an incorrect adjustment will result in balancing out the signal as well as the noise. A good high antenna for signal reception will ordinarily overcome this effect.

With this circuit some readjustment is necessary from band to band in the short-wave spectrum; noise-balancing systems require a good deal of patience and experimenting at each particular receiving location.

Noise-Limiting Circuits. Several different noise-limiting circuits have become popular. These circuits are beneficial in overcoming automobile ignition interference. They operate on the principle that each individual noise pulse is of very short duration, yet of extremely high amplitude. The popping or clicking type of noise from electrical ignition systems may produce a signal ten to twenty times as great as the incoming radio signal.

As the duration of this type of noise peak is short, the receiver can be made inoperative during the noise peak without the human ear detecting the total loss of signal. Some noise limiters, or eliminators, actually *punch a hole* in the signal, while others merely *limit* the maximum peak signal which reaches the headphones or loudspeaker.

The noise peak is of such short duration that it would not be objectionable except for the fact that it produces an overloading effect on the receiver, which increases its time constant. A sharp voltage peak will give a kick to the diaphragm of the headphones or speaker, and the momentum or inertia keeps the diaphragm in motion until the dampening of the diaphragm stops it. This movement produces a popping sound which may completely obliterate the desired signal. If the noise peak can be limited to an amplitude equal to that of the desired signal, the resulting interference is practically negligible.

A.F. Peak Limiters. Remarkably good noise suppression can be obtained in the audio amplifier of a radio receiver by using a delayed push-pull diode suppressor. Any twin diode tube can be used, though the type 84 high vacuum full-wave rectifier tube seems to be the most effective.

The circuit in figure 29 can be used to describe the operation of this general type of noise suppressor or limiter. Each diode works on opposite noise voltages; that is, both sides of the noise voltage (+ and — portions of the a.c. components) are applied to diodes which short-circuit the load whenever the applied voltage is greater than the delay voltage. The delay bias voltage prevents diode current from flowing for low-level audio voltages, and so the noise circuit has no effect on the desired signals except during the short interval of noise peaks. This interval is usually so short that the human ear will not notice a drop in signal during the small time that the load (headphones) is short-circuited by the diodes.

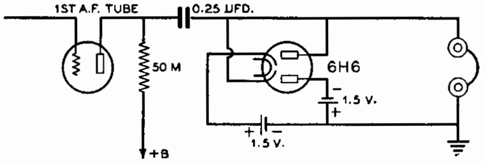


Figure 29.
A.F. NOISE LIMITER.
A limiter such as this is effective in reducing short-duration noise pulses, such as automobile ignition interference.

Delay bias voltage of 1½ volts from a small flashlight cell will allow any signal voltage to operate the headphones which has a peak of less than about 1½ volts. Noise peaks often have values of from 5 to 20 times as great as the desired signal; so these peaks operate the diodes, causing current to flow and a sudden drop in impedance across the headphones.

Diodes have nearly infinite impedance when no diode current is flowing; however, as soon as current starts, the impedance will drop to a very few hundred ohms, which tends to damp out or short circuit the audio output. The final result is that the noise level from automobile ignition is limited to values no greater than the desired signal. This is low enough to cause no trouble in understanding the voice or c.w. signals.

A push-pull diode circuit is necessary because the noise peaks are of an a.c. nature and are not symmetrical with respect to the zero a.c. voltage reference level. The negative peaks may be greater than the positive peaks, depending on the bias and overload characteristics of the audio amplifier tube. If a single diode is used, only the positive (or negative) peaks could be suppressed. In figure 29 the two bias dry-cells are arranged to place a negative bias on each diode plate of 1½ volts. A positive noise voltage peak at the plate of the audio amplifier tube will overcome this negative bias on the top diode plate and cause diode current to flow and lower the impedance. A negative noise voltage peak will overcome the positive bias on the other diode cathode and cause this diode to act as a noise suppressor. A positive bias on the cathode is the same as a negative bias on the diode plate. The 6H6 has two separate cathodes and plates, hence lends itself readily to the simple circuit illustrated in figure 29.

Circuits of this type are very effective for short-pulse noise elimination because they tend to punch a hole in the signal for the duration of a strong noise voltage peak. A peak that will cause a loudspeaker or headphones to rattle with a loud pop will be reduced to a faint pop by the noise-suppression system. The delay bias prevents any attenuation of the desired signal as long as the signal voltage is less than the bias.

With this type of noise limiter it is possible to adjust the audio or sensitivity gain controls so that the auto ignition QRM seems to drop out, leaving only the desired signal with a small amount of distortion. Lower gain settings will allow some noise to get through but will eliminate audio distortion on voice or music reception. At high levels the speech or music peaks will be attenuated whenever they exceed the d.c. delay bias voltage. Faint ignition rattle will always be audible in the background with any noise-suppressor circuit since some noise peaks are too small to operate the systems, yet are still audible as a weak rattle or series of pops in the headphones.

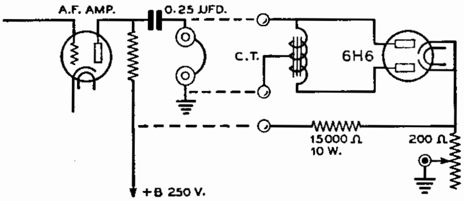


Figure 30.
ADJUSTABLE NOISE LIMITER.
With this circuit the bias on the limiter diodes is adjustable for different noise levels. The center-tapped choke may be the primary of a small pentode output transformer.

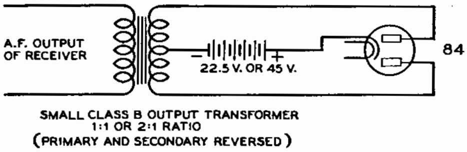


Figure 31.
NOISE LIMITER FOR USE WITH LOUDSPEAKER.
The high bias on this dual-diode noise limiter allows it to be used on high-level audio stages.

Figures 30 and 31 show two noise-limiter circuits which can be used as separate units for connection to any receiver. The unit shown in figure 30 can be connected across any headphone output as long as there is no direct current flowing through the phones. A blocking condenser can be connected in series with it if necessary, though better noise suppression results when the blocking condenser is in series with the plate lead to the headphones. Delay bias is obtained from the plus B supply through a 15,000-ohm 10-watt resistor and a 200-ohm wire-wound variable resistor. The cathode or cathodes are made a volt or so positive with respect to ground and minus B connection.

The diode plates are connected through a center-tapped low resistance choke to ground as far as bias voltage is concerned. Any push-pull to voice coil output transformer can be used for the center-tapped choke in figure 30. The secondary can be left open. The delay bias is adjustable from 0 up to about 3 volts and once set for some noise level, can be left in that position.

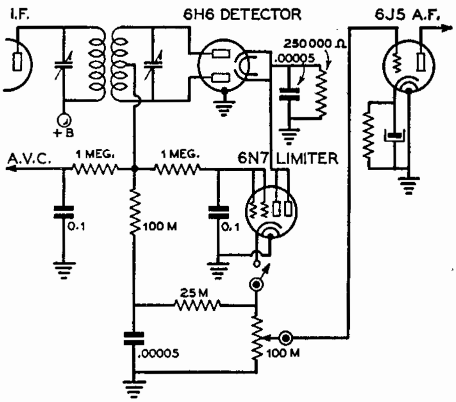


Figure 32.
DICKERT AUTOMATIC LIMITER.
This limiter will automatically adjust itself to various amounts of carrier strength. The recommended values of components are shown.

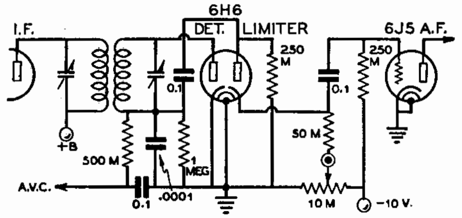


Figure 33.
BACON SERIES LIMITER.
The series type of limiter breaks the circuit between the detector and first audio stage on noise peaks.

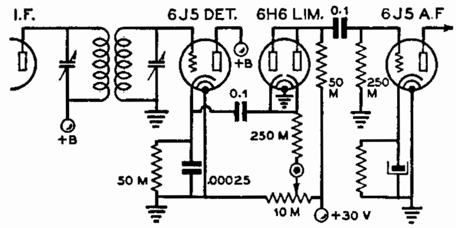


Figure 34.
SERIES LIMITER WITH INFINITE-IMPEDANCE DETECTOR.
This arrangement of the series limiter must be used when the detector gives positive output voltage. It is applicable to both infinite impedance and power detectors.

The unit illustrated in figure 31 can be connected across any audio amplifier stage, even the output stage which drives a loudspeaker. Any bias from 1½ to 90 volts or more can be connected in series with the center tap and 84 tube cathode. The higher values of delay bias would be needed for high output levels from the loudspeaker. Generally, 22½- to 45-volts bias will allow enough delay to allow moderate room volume reception of the desired voice signals without leveling off and distortion. As low a delay bias should be used as possible without distortion, in order to obtain effective noise suppression.

Second-Detector Noise Limiters. There are numerous arrangements for noise limiting in the second detector circuit. Tests conducted with a great many of these circuits have indicated that the ones shown in figures 32, 33 and 34 are the most practical and desirable for use in amateur communications receivers. The noise-silencing action of these limiters is obtained either by shorting the noise pulses to ground or by opening an "electronic switch" in series with the audio current on each noise pulse. The circuit of figure 32 is an example of the first method, while those of figures 33 and 34 are of the latter type.

The *Dickert* noise limiter circuit shown in figure 32 makes use of a diode detector and a small class B triode such as the 6A6, 6N7, or 79 as the noise limiter tube. The latter tubes are used because at zero or negative grid voltage and a small amount of plate potential they draw very little plate current.

Under normal operation with a received carrier the grid of the 6N7 is biased negatively by an amount slightly less than half the rectified carrier voltage. This means that for modulation percentages up to nearly 100 per cent the resistance of the 6N7 will remain very high due to its grid always remaining negative with respect to the cathode. Note also that the grid is supplied with d.c. through a filter circuit with a comparatively high time constant so that the actual grid potential varies but very slowly with changing external conditions.

But with the reception of a noise pulse the cathode of the 6N7 is instantaneously driven highly negative while the control grid maintains the moderate carrier-level bias due to the time constant of the filter feeding it. Another way of stating that the cathode goes negative with respect to the grid is, of course, to say that the control grid is driven positive. Also, at the same time that the control grid goes positive the same noise pulse drives the plate of the 6N7 more positive due to the common resistance between it and the cathode of the detector, and ground. This of course means that the current due to the noise pulse flows almost entirely between the cathode and plate of the 6N7 instead of taking its normal course through the audio volume control.

The circuit is completely self-adjusting as to received carrier strength and gives equal suppression regardless of the carrier level.

Series-Valve Limiters. In the *Bacon* series-tube limiter circuits the normal signal is carried by the cathode-to-plate current of an additional diode connected into the circuit. This cathode-to-plate current can only flow as long as the plate is positive with respect to the cathode of the diode. Hence, by limiting the range of input signal voltages over which this plate current will flow in conformity with the polarity of the noise pulses as they will appear in the output of the detector, noise limiting will be obtained by adjusting the voltages to such a point that all incoming pulses greater than those produced by 100 per cent modulation of the incoming carrier will cause the plate to go negative with respect to the cathode of the noise diode. The strong noise pulses will then find an open circuit in their path from detector to audio amplifier although noise pulses up to and including the amplitude of the incoming signal (and the incoming signal) will be passed on to the audio stages.

In a conventional diode detector the noise pulses will be increasingly negative with respect to normal signal levels so it is necessary to feed the audio into the plate of the limiter diode and to run the cathode of this diode negative with respect to the plate. This arrangement is shown in figure 33. The amount of bias is adjusted manually so that all normal signal strengths will be handled but that pulses in excess of this strength will cause the plate to go negative with respect to the cathode and cause the pulse to be limited in amplitude.

In a power detector or infinite-impedance detector the noise pulses are positive with respect to normal signals. In this case it is necessary to feed the detector output into the cathode of the diode limiter and to bias the plate a certain fixed amount positive with respect to the cathode, as shown in figure 34. Then, with noise pulses which exceed the positive bias which has been manually adjusted to appear on the plate, the cathode will go positive with respect to the plate and the continuity of the signal will be stopped.

A disadvantage of all series-tube noise limiters is that the signal strength output of the detector is reduced by a considerable amount, often as much as 8 to 10 db, which sometimes requires an additional audio stage or a high-gain stage in place of a low-gain one.

A more detailed and comprehensive discussion of noise balancing and noise limiting systems will be found in the Radio *Noise Reduction Handbook.*

Receiver Adjustment

The simplest type of regenerative receiver requires little adjustment other than those necessary to insure correct tuning and smooth regeneration over some desired range. Receivers of the tuned radio-frequency type and superheterodynes require precise alignment to obtain the highest possible degree of selectivity and sensitivity.

Good results can only be obtained from a receiver when it is properly aligned and adjusted. The most practical technique for making these adjustments is given in the following discussion.

Instruments. A very small number of instruments will suffice to check and align any multitube receiver, the most important of these testing units being a modulated oscillator and a d.c. and a.c. voltmeter. The meters are essential in checking the voltage applied at *each* circuit point from the power supply. If the a.c. voltmeter is of the oxide-rectifier type, it can be used, in addition, as an output meter when connected across the receiver output when tuning to a modulated signal. If the signal is a steady tone, such as from a test oscillator, the output meter will indicate the value of the detected signal. In this manner, lineup adjustments may be visually noted on the meter rather than by increases or decreases of sound intensity as detected by ear.

T.R.F. Receiver Alignment. The alignment procedure in a multi-stage t.r.f. receiver is exactly the same as aligning a single stage. If the detector is regenerative, each preceding stage is successively aligned while keeping the detector circuit tuned to the test signal, the latter being a station signal or one locally generated by a test oscillator loosely coupled to the antenna lead. During these adjustments, the r.f. amplifier gain control is adjusted for maximum sensitivity, assuming that the r.f. amplifier is stable and does not oscillate. Oscillation is indicative of improper by-passing or shielding. Often a sensitive receiver can be roughly aligned by tuning for maximum noise pickup, such as parasitic oscillations originating from static or electrical machinery.

Superheterodyne Alignment. Aligning a superhet is a detailed task requiring a great amount of care and patience. It should never be undertaken without a thorough understanding of the involved job to be done and then only when there is abundant time to devote to the operation. There are no short cuts; every circuit must be adjusted individually and accurately if the receiver is to give peak performance. The precision of each adjustment is dependent upon the accuracy with which the preceding one was made.

Superhet alignment requires (1) a good signal generator (modulated oscillator) covering the radio and intermediate frequencies and equipped with an attenuator and B-plus switch; (2) the necessary socket wrenches, screwdrivers, or "neutralizing tools" to adjust the various i.f. and r.f. trimmer condensers, and (3) some convenient type of tuning indicator, such as a copper-oxide or electronic voltmeter.

Throughout the alignment process, unless specifically stated otherwise, the a.f. and r.f. gain controls must be set for maximum output, the beat oscillator switched off, the R-meter cut out, the crystal filter set for minimum selectivity and the a.v.c. turned off. If no provision is made for a.v.c. switching, the signal generator output must be reduced to the proper level by means of the attenuator. When the signal output of the receiver is excessive, either the attenuator or the a.f. gain control may be turned down, but never the r.f. gain control.

I.F. Alignment. After the receiver has been given a rigid electrical and mechanical inspection and any faults which may have been found in wiring or the selection and assembly of parts corrected, the i.f. amplifier may be aligned as the first step in the checking operations.

The coils for the r.f. (if any), first detector and high-frequency oscillator stages must be in place. It is immaterial which coils are inserted, since they will serve during the i.f. alignment only to prevent open-grid oscillation.

With the signal generator set to give a modulated signal on the frequency at which the i.f. amplifier is to operate, clip the output leads from the generator to the last i.f. stage; "hot" end through a small fixed condenser to the control grid, "cold" end to the receiver ground. Adjust both trimmer condensers in the last i.f. transformer to resonance as indicated by signal peak in the headphones or speaker and maximum deflection of the output meter.

Each i.f. stage is adjusted in the same manner, moving the hot lead, stage by stage, back toward the front end of the receiver and backing off the attenuator as the signal strength increases in each new position. The last adjustment will be made to the first i.f. transformer with the hot lead connected to the control grid of the first detector. Occasionally, it is necessary to disconnect the 1st detector grid lead from the coil, grounding it through a 1,000- or 5,000-ohm grid leak and coupling the signal generator through a small capacitance to the grid.

When the last i.f. adjustment has been completed, it is good practice to go back through the i.f. channel, re-peaking all of the transformers. It is imperative that this recheck be made in sets which do not include a crystal filter and where necessarily the simple alignment of the i.f. amplifier to the generator is final.

I.F. with Crystal Filter. There are several ways of aligning an i.f. channel which contains a crystal-filter circuit. However, the following method is one which has been found to give satisfactory results in every case:

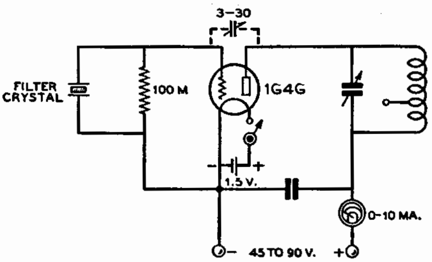


Figure 35.
CRYSTAL TEST OSCILLATOR CIRCUIT.
The receiver's crystal may be placed in this oscillator for a rough alignment of the i.f. amplifier to the crystal frequency. The tank circuit is made up of a winding from a b.f.o. transformer and a 350-$\mu\mu$fd. broadcast condenser.

If the i.f. channel is known to be far out of alignment or if the initial alignment of a new receiver is being attempted, the crystal itself should first be used to control the frequency of a test oscillator. The circuit shown in figure 35 can be used. A b.f.o. coil, as shown in the diagram, can be used for the plate inductance. If none is handy one winding of an i.f. transformer may be used. In either case, it is necessary to disconnect the trimmer across the winding unless it has sufficient maximum capacity to be used in place of the 350-$\mu\mu$fd. tuning condenser indicated in the diagram.

A milliammeter inserted in the plate circuit will indicate oscillation, the plate current dipping as the condenser tunes the inductance to the resonant frequency of the crystal. Some crystals will require additional grid-plate capacity for oscillation; if so, a 30-$\mu\mu$fd. mica trimmer may be connected from plate to grid of the oscillator tube. The oscillator is then used as a line-up oscillator as described in the preceding section by using a.c. for plate supply instead of batteries. The a.c. plate supply gives a modulated signal suitable for the preliminary lining-up process.

For the final i.f. alignment the crystal should be replaced in the receiver and the phasing condenser set at the "phased" setting, if this is known. If the proper setting of the phasing condenser is unknown it can be set at half capacity to start with. Next, a signal generator should be connected across the mixer grid and ground and, with the receiver's a.v.c. circuit operating and the beat oscillator turned "off," the signal generator slowly tuned across the i.f. amplifier frequency.

As the generator is tuned through the crystal frequency, the receiver's signal strength meter will give a sudden kick. Should the receiver not be provided with a signal-strength meter, a vacuum-tube voltmeter, such as shown in Chapter 22, can be connected across the a.v.c. line; if the receiver has neither a.v.c. nor a tuning meter, the vacuum-tube voltmeter may be connected between the second detector grid and ground. In any case a kick of either the tuning meter or the vacuum-tube voltmeter will indicate crystal resonance. It is quite probable that more than one resonance point will be found if the receiver is far out of alignment. The additional points of resonance are spurious crystal peaks; the strongest peak should be chosen and the signal generator left tuned to this frequency.

The phasing condenser should next be adjusted for *minimum* hiss or noise in the receiver output and the selectivity control, if any is provided, set for maximum selectivity. From this point on, the alignment of the i.f. amplifier follows conventional practice, except that the a.v.c. circuit is used as an alignment indicator, each circuit being adjusted for maximum output. If the receiver is of the type having no a.v.c. or tuning indicator, and the vacuum-tube voltmeter must be connected across the second-detector grid circuit, it will be necessary to remove the vacuum-tube voltmeter and make the final adjustment on the last i.f. transformer by ear after the other transformers have been aligned.

B. F. O. Adjustment. Adjusting the beat oscillator is relatively simple. It is only necessary to tune the receiver to resonance with any signal, as indicated by the tuning indicator, and then turn on the b.f.o. and set its trimmer (or trimmers) to produce the desired beat note. Setting the beat oscillator in this way will result in the beat note being stronger on one "side" of the signal than on the other, which is what is desired for maximum selectivity. The b.f.o. should *not* be set to "zero beat" with the receiver tuned to resonance with the signal as this will cause an equally strong beat to be obtained on both sides or resonance.

Front-End Alignment. The alignment of the "front end" of a manufactured receiver is a somewhat involved process and varies considerably from one receiver to another and for that reason will not be discussed here. Those interested in the alignment of such receivers usually will find full instructions in the operating manual or instruction book supplied with the receiver. Likewise full alignment data are always given when an "all wave" tuning assembly for incorporation in home-built receivers is purchased.

In aligning the front end of a home-constructed superheterodyne which covers only the amateur bands the principal problems are those of securing proper bandspread in the oscillator, and then tracking the signal-frequency circuits with the oscillator. The simplest method of adjusting the oscillator for proper bandspread is to tune in the oscillator on an "all wave" receiver and adjust its bandspread so that it covers a frequency range equal to that of the tuning range desired in the receiver but over a range of frequencies equal to the desired signal range plus the intermediate frequency. For example: If the receiver is to tune from 13,950 to 14,450 kc. to cover the 14-Mc. amateur band with a 50-kc. leeway at each end, and the intermediate frequency is 465 kc., the oscillator should tune from 13,950+465 kc. to 14,450+465 kc., or from 14,415 to 14,915 kc.

(Note: The foregoing assumes that the oscillator will be operated on the high-frequency side of the signal, which is the usual condition. It is quite possible, however, to have the oscillator on the low-frequency side of the signal, and if this is desired the intermediate frequency is simply *subtracted* from the signal frequency, rather than added, to give the required oscillator frequency).

If no calibrated auxiliary receiver is available the following procedure should be used to adjust the oscillator to its proper tuning range: A modulated signal from the signal generator is fed into the mixer grid, with mixer grid coil for the band being used in place, and with the signal generator set for the highest frequency in the desired tuning range and the bandspread condenser in the receiver set at minimum capacity, the oscillator bandsetting condenser is slowly decreased from maximum capacity until a strong signal from the signal generator is picked up. The first strong signal picked up will be when the oscillator is on the low-frequency side of the signal. If it is desired to use this beat, the oscillator bandsetting condenser need not be adjusted further. However, if it is intended to operate the oscillator on the high-frequency side of the signal in accordance with usual practice, the bandsetting condenser should be decreased in capacity until the second strong signal is heard. When the signal is properly located the mixer grid should be next tuned to resonance by adjusting its padder condenser for maximum signal strength.

After the high-frequency end of the band has thus been located the receiver bandspread condenser should be set at maximum capacity and the signal generator slowly tuned toward the low-frequency end of its range until its signal is again picked up. If the bandspread adjustment happens to be correctly made, which is not probable, the signal generator calibration will show that it is at the low-frequency end of the desired tuning range. If calibration shows that the low-frequency end of the tuning range falls either higher or lower than what is desired, it will be necessary to make the required changes in the bandspread circuit described under the section on *Bandspread* and repeat the checking process until the tuning range is correct.

Tracking. After the oscillator has been set so that it covers the correct range, the tracking of the mixer tuning may be tackled. With the signal generator set to the high-frequency end of the tuning range and *loosely* coupled to the mixer grid the signal from the generator should be tuned in on the receiver and the mixer padding condenser adjusted for maximum output. Next, both the receiver and the signal generator should be tuned to the low-frequency end of the receiver's range and a check made to see if it is necessary to reset the mixer padder to secure maximum output. If the tracking is correct it will be found that no change in the padder capacity will be necessary. If, however, it is found that the output may be increased by retuning the padder it will be necessary to readjust the mixer bandspread.

An increase in signal strength with an increase in padding capacity indicates that the bandspread is too great and it will be necessary to increase the tuning range of the mixer. An increase in signal strength with a decrease in padding capacity shows that the mixer tuning range is too great and the bandspread will have to be increased.

When the mixer bandspread has been adjusted so that the tracking is correct at both ends of a range as narrow as an amateur band, it may be assumed that the tracking is nearly correct over the whole band. The signal generator should then be transferred to the grid of the r.f. stage, if the receiver has one, and the procedure described for tracking the mixer carried out in the r.f. stage.

Series Tracking Condensers. The above discussion applies solely to receivers in which a small tuning range is covered with each set of coils and where the ranges covered by the oscillator and mixer circuits represent nearly equal percentages of their operating frequencies, i.e., the intermediate frequency is low. When these conditions are not satisfied, such as in continuous-coverage receivers and in receivers in which the intermediate frequency is a large proportion of the signal frequency, it becomes necessary to make special provisions for oscillator tracking. These provisions usually consist of ganged tuning condensers in which the oscillator section plates are shaped differently and have a different capacity range than those used across the other tuned circuits, or the addition of a "tracking condenser" in series with the oscillator tuning condenser in conjunction with a smaller coil.

While series tracking condensers are seldom used in home-constructed receivers, it may sometimes be necessary to employ one, as in, for example, a receiver using a 1600-kc. i.f. channel and covering the 3500–4000 kc. amateur band. The purpose of the series tracking condenser is to slow down the oscillator's tuning rate when it operates on the high-frequency side of the signal. This method allows perfect tracking at three points throughout the tuning range. The three points usually chosen for the perfect tracking are at the two ends and center of the tuning range; between these points the tracking will be close enough for all practical purposes.

In home-constructed sets the adjustment of the tracking condenser and oscillator coil inductance is largely a matter of cut-and-try, requiring a large amount of patience and an understanding of the results to be expected when the series capacity and the oscillator inductance are changed.

Receivers with A.V.C. When lining up a receiver which has automatic volume control (a.v.c.), it is considered good practice to keep the test oscillator signal near the threshold sensitivity at all times to give the effect of a very weak signal relative to the audio amplifier output with the audio gain control on maximum setting.

Testing. In checking over a receiver, certain troubles are often difficult to locate. By making voltage or continuity tests, blown-out condensers, or burned-out resistors, coils or transformers may usually be located. Oscillators are usually checked by means of a d.c. voltmeter connected from ground to screen or plate-return circuits. Short-circuiting the tuning condenser plates usually should produce a change in voltmeter reading. A vacuum-tube-type voltmeter is very handy for the purpose of measuring the correct amount of oscillator r.f. voltage supplied to the first detector circuit. The proper value of the r.f. voltage is approximately one volt less than the fixed grid bias on the first detector when the voltage is introduced into either the grid or the cathode circuit.

Incorrect voltages, poor resistors or leaky by-pass or blocking condensers will ruin the audio tone of the receiver. Defective tubes can be checked in a tube tester. Loud-speaker rattle is not always a defect in the voice coil or spider support, or metallic filings in its air gap; more often the distortion is caused by overloading the audio amplifier. An i.f. amplifier can also impair splendid tone due to a defective tube or overloading.

It is a good idea to have all tubes in a receiver checked periodically, because if a tube slowly becomes noisy, soft, or deficient in emission, the operator may not realize that the performance is not up to the full capabilities of the receiver. Any tube which does not test up to the equivalent of a new tube should be replaced, as a tube that once starts to "go" cannot possibly give very many more hours of useful service.

On the other hand, there is little point in replacing all tubes periodically, because tests have shown that a tube that has been in use for three or four years, if it still is giving satisfactory service, is just as likely to provide another year of uninterrupted service as is a brand new tube.

It should be borne in mind that electrolytic condensers, even of the best quality, have a limited life—the length of useful service depending upon the quality and application of the condenser. Unlike tubes, electrolytic condensers seldom give any trouble in the first three years of use (if of good quality and not overloaded). However, they seldom last more than five years, unless they are the less commonly used "wet" type. For this reason it is advisable to replace all electrolytic condensers every four years or so if reliability of service is important.