SECTION 13

FREQUENCY (HETERODYNE) CONVERTER CIRCUITS

PART A. ELECTRON-TUBE CIRCUITS

MIXERS.

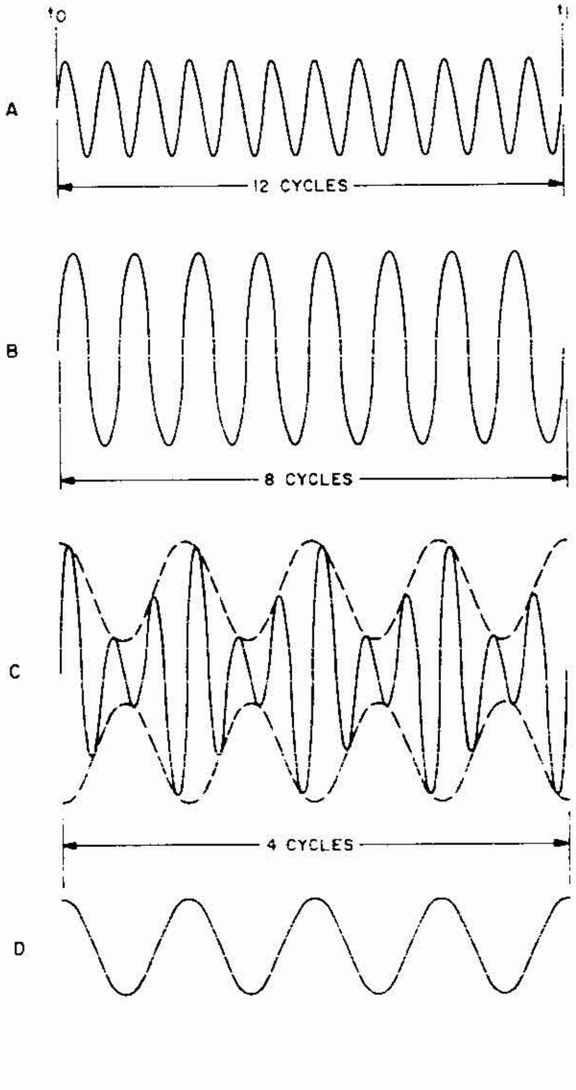
The frequency-conversion function in a superheterodyne receiver is accomplished either by a mixer circuit with a separate local oscillator or by a pentagrid converter circuit (described later in this section).

The term **mixer** used in this section should not be confused with the term **audio mixer**, which designates the linear circuit used to combine audio signals. The term **mixer**, as used in this section, designates a nonlinear circuit that heterodynes radio-frequency and local-oscillator signals in a superheterodyne receiver to produce an intermediate-frequency signal.

In receiver design practice, it is desirable to convert the received r-f signal to an intermediate frequency before further amplification takes place. The principle of frequency conversion and subsequent amplification at an intermediate frequency results in excellent selectivity and over-all gain characteristics for the receiver. The frequency conversion is obtained by the **heterodyne** process, which is the combining of an incoming radio-frequency signal with a locally generated signal in a nonlinear device, to produce frequencies equal to the sum and difference of the two combining frequencies. The mixer stage sometimes referred to as the **first detector** in the superheterodyne receiver, performs only the frequency conversion function, and must be supplied a heterodyning r-f voltage generated by a separate local-oscillator circuit. The output frequencies of the mixer stage, in addition to the frequencies of the input voltages, are primarily the sum and difference of the signal-input frequency and an integral multiple of the local-oscillator frequency. The output circuit of the mixer stage is tuned to select only one frequency, which is usually a beat frequency equal to the difference between the signal-input frequency and the local-oscillator frequency. This difference, or beat, frequency is known as the **intermediate freqency.**

At this time a brief discussion of the heterodyne principle is helpful in order to better understand the production of beats in a superheterodyne receiver. The accompanying illustration shows graphically how a beat (intermediate) frequency is produced when two different signal frequencies of **unequal** amplitude are combined. If the two waveforms, parts A and B, are superimposed, the waveform given in part C results; this waveform shows amplitude fluctuations with respect to the time axis. At each instant, the two signal frequencies (A and B) combine to produce a resultant amplitude which is equal in value to the algebraic sum (A + B) of the individual signal values. The amplitude variations, represented in part C as the dotted lines forming an envelope for the resultant, are called **beats**, and vary in amplitude at a frequency that is equal to the difference between the frequencies of the two signals being combined. Thus, from a study of the combined waveform given in part C, it can be seen that during the time interval between t_0 and t_1 the number of beats per second is equal to the **difference** between the two frequencies given in parts A and B.

For simplicity, frequencies of 12 and 8 cycles are given in parts A and B, respectively. The envelope of the resulting waveform in part C is shown as 4 cycles per second. The output signal which results after the combined signals are acted upon by a nonlinear device in the mixer stage is shown in part D as the intermediate (beat) frequency. Although the frequencies (12, 8, and 4 cycles) used in the illustration are extremely low, the heterodyne principle would be the same for other corresponding frequencies, such as 1200, 800, and 400 kilocycles, or 12, 8, and 4 megacycles. Thus part A can be thought of as the

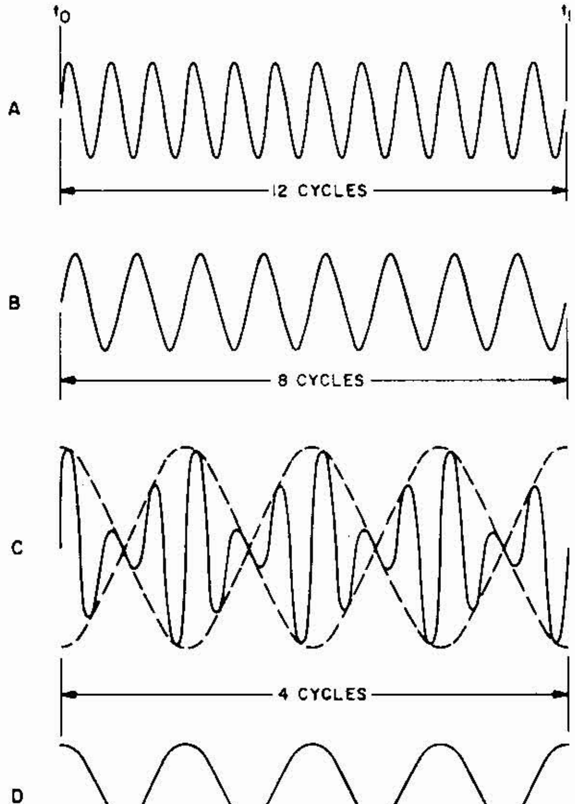


Heterodyning of Two Signals of Unequal Amplitude received r-f signal, part B as the local-oscillator signal, and part D as the intermediate-frequency (beat-frequency) output of the mixer stage after demodulation.

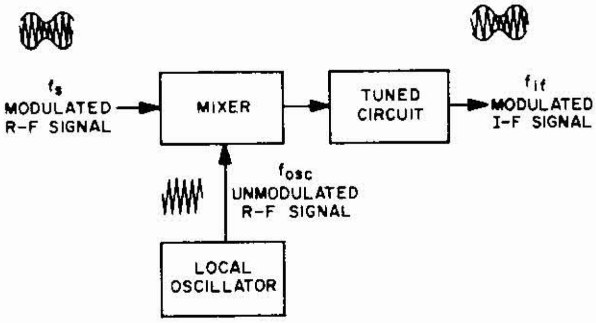
To produce an output which has very little distortion, the amplitude of the locally generated signal must be larger (usually at least ten times larger) than that of the received r-f signal. This principle is shown by the previous illustration representing the heterodyning of two signals of **unequal** amplitude. The accompanying illustration shows the heterodyning of two signals of **equal** amplitude, and the distortion which results. Note that the envelope of the waveform shown in part C drops to zero, and that there is resulting distortion in the demodulated waveform shown in part D.

If one of the two frequencies (A or B) being heterodyned is modulated, the same action as previously described will occur, except that the resultant waveform shown in part D will vary in amplitude according to the modulation component of the original input frequency (A or B).

The accompanying block diagram illustrates the heterodyne principle of a frequency converter consisting of a mixer and local oscillator. Two voltages of different frequency are each fed to the input of the mixer; one voltage is the r-f signal voltage, and the other is the voltage generated by the local oscillator. These two voltages beat, or heterodyne, within the mixer to produce an output having, in addition to the frequencies of the two input voltages, many sum-and-difference frequencies. The output of the mixer includes a tuned circuit to select the desired beat frequency. The beat frequency is generally chosen to be a frequency which is the difference between the two mixer-input frequencies.



Heterodyning of Two Signals of Equal Amplitude With Resulting Distortion



Block Diagram of Mixer and Local Oscillator

In the block diagram, a modulated r-f signal is applied to the mixer stage; an unmodulated r-f signal of constant amplitude from the local-oscillator circuit is also applied to the mixer stage. The heterodyning, or mixing, of these two signals produces, in the mixer output, an intermediate-frequency signal which contains all of the modulation characteristics of the original modulated r-f signal. The undesired sum-and-difference frequencies and the two mixer-input frequencies (r-f and oscillator signals) are rejected by the tuned circuit in the output of the mixer; only the desired intermediate (difference or beat) frequency is permitted to pass through the tuned circuit. This intermediate-frequency signal is then amplified and detected in succeeding stages of the receiver.

The local-oscillator frequency differs from the frequency of the received r-f signal by an amount equal to the intermediate frequency; therefore, the local-oscillator frequency can be either **above** or **below** the received r-f signal and, in either case, produce the desired intermediate frequency. Depending upon the design requirements of the receiver and the frequencies involved, the local oscillator is tuned to a frequency either higher or lower than the r-f signal frequency. When the local-oscillator frequency is **below** the received r-f signal, the following formula applies:

$$f_{if} = f_s - f_{osc}$$

where: f_{if} = intermediate frequency
f_s = received r-f signal frequency
f_{osc} = local-oscillator frequency

When the local-oscillator frequency is **above** the received r-f signal, the following formula applies:

$$f_{if} = f_{osc} - f_s$$

The mixer circuit includes a nonlinear element, consisting of either an electron-tube or semiconductor device; if an electron tube is used, the nonlinear element can be a simple rectifier (diode), a triode, or a multigrid tube. When a triode, tetrode, or pentode electron tube is used as the nonlinear circuit element, the tube is biased at or near cutoff, or otherwise operated on a nonlinear portion of its characteristic curve. Triode and multigrid electron tubes used as the mixer in superheterodyne receivers generally produce some signal amplification (conversion gain), in addition to the desired frequency conversion. A discussion of similar nonlinear elements is given in Section 11, Detector (Demodulator) Circuits.

Mixer-local oscillator combination circuits can provide reasonable frequency stability in superheterodyne receivers up to approximately 500 mc. The mixer circuits described in this section are representative of typical electron-tube mixers found in many communication-electronic equipments.

DIODE MIXER.

APPLICATION.

The diode mixer is used in superheterodyne receiver circuits to combine, or "mix", the r-f signal from a local oscillator with the incoming r-f signal, in order to produce the desired i-f (intermediate-frequency) output signal. The electron-tube diode mixer is generally used in applications where signal-to-noise ratio is an important consideration or where the transit time at very high frequencies becomes critical for other types of electron-tube mixers.

CHARACTERISTICS.

Requires a separate local-oscillator circuit to supply the heterodyning voltage.

Utilizes the principle of rectification by a nonlinear device.

Output circuit is tuned to the difference frequency, or intermediate frequency.

Conversion gain is less than unity.

Signal-to-noise ratio is good.

CIRCUIT ANALYSIS.

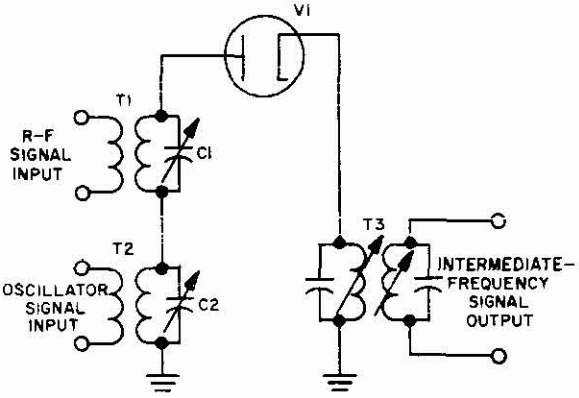
General. The diode mixer is one of the simplest types of mixer circuits employed as a frequency converter. In this application, voltages of the two input frequencies to be heterodyned are applied in series to the diode, and the mixer-output voltage is obtained from a tuned transformer or impedance-coupling arrangement. The output circuit is tuned to the difference frequency (intermediate frequency) so that it will pass this frequency on to the succeeding intermediate-frequency amplifier stages but will attenuate (reject) all other frequencies.

The electron-tube diode used as a mixer is subject to transit-time effects; therefore, its use as a mixer at very high frequencies is somewhat limited. When transit-time effects are important, the crystal diode is frequently used as a mixer in preference to the electron-tube diode.

Circuit Operation. A simple diode mixer circuit is illustrated in the accompanying circuit schematic. Transformer T1 consists of an untuned primary winding and a tuned secondary winding; capacitor C1 and the secondary winding of T1 form a resonant circuit at the frequency of the r-f signal to be received. Transformer T2 is similar to T1, except that capacitor C2 and the secondary winding T2 form a resonant circuit at the frequency of the local-oscillator signal. The resonant circuits, shown in the schematic as T1, C1 and T2, C2, are actual L-C circuits composed of inductors and capacitors at all radio frequencies up to the ultra high frequencies. At the ultra high frequencies and above, the tuned circuits may be in the form of tuned lines or resonant cavities.

Electron tube V1 is a cathode-type diode; the filament (heater) circuit is not shown on the schematic.

Transformer T3 is a double-tuned transformer, with the primary and secondary circuits resonant to the output (intermediate) frequency. This transformer exhibits a bandpass characteristic and thereby discriminates against frequencies above and below the desired output frequency.



Diode Mixer Circuit

When no r-f signal is applied to the input of transformer T1, but the local-oscillator signal is applied to the input (primary) of transformer T2, diode V1 acts only as a rectifier. For this input condition, the current pulsations passing through the primary winding of the double-tuned transformer, T3, are those of the local-oscillator frequency; however, the tuning of transformer T3 does not permit the local-oscillator frequency to reach the output because of the bandpass characteristic of the transformer.

When the r-f signal and the local-oscillator signal are simultaneously applied to their respective tuned circuits (T1 and T2), the two signal voltages are applied in series to the mixer diode, V1.

Since the two applied signals differ in frequency, the voltages are not always in phase with each other. Periodically these two voltages algebraically add or subtract to produce an amplitude variation at regular intervals; it is this periodic amplitude variation in the form of a beat-frequency voltage which is of greatest importance. The beat frequency is actually the difference frequency produced by the instantaneous signal voltages as they combine to increase amplitude when approaching an in-phase relationship and to decrease amplitude when approaching an out-of-phase relationship.

Because the two sine-wave frequencies are superimposed, the mixer diode rectifies, or detects, both frequencies. As a result, pulsating currents which vary in amplitude at the beat-frequency rate are produced in the primary of transformer T3. Thus, a carrier envelope is formed which varies in accordance with the difference frequency. The pulsating currents forming the carrier envelope flow through the primary winding of transformer T3. Since the primary circuit is tuned, it presents a high impedance to the difference (intermediate) frequency. Consequently, this frequency is passed by transformer T3, and a voltage is induced in the secondary winding which varies in amplitude in accordance with the amplitude of the original r-f signal.

If the received r-f signal contains amplitude-modulation components, the beat difference will also contain amplitude-modulation components, which vary in accordance with the audio frequencies modulating the original r-f signal. If the received r-f signal is frequency-modulated, the beat difference will deviate at the same rates as the original r-f signal. Thus, it is seen that the characteristics of the intermediate-frequency signal are the same as those of the original received signal, except that the frequency of the received signal has been "converted" to a lower frequency.

The output signal voltage developed across the secondary tuned circuit of transformer T3 is applied to succeeding intermediate-frequency amplifier stages and is subsequently detected, or demodulated.

FAILURE ANALYSIS.

General. Since the circuit of the diode mixer is relatively simple, failure of the circuit to operate can be resolved to one of several possibilities. The diode, V1, should be checked to determine whether it is in satisfacary condition and whether the correct filament (heater) voltage is applied to the tube.

The presence of an r-f signal (or a test signal) and the local-oscillator signal must be determined, since no output can be obtained from the mixer circuit unless both signals are applied to the mixer input. Resonant circuits T1, C1 and T2, C2 must be properly aligned, each to its specified frequency. The double-tuned output transformer, T3, must also be correctly tuned to the desired intermediate frequency. Since one or more open windings in the tuned circuits (T1, T2, and T3) can cause a lack of output, these windings should be checked with an ohmmeter to determine whether continuity exists.

TRIODE MIXER.

APPLICATION.

The triode mixer is used in receiver circuits to combine or "mix" the r-f signal from the local oscillator with the incoming r-f signal, to produce the desired intermediate frequency (I-F) output.

CHARACTERISTICS.

Requires a separate local oscillator circuit to supply the heterodyning voltage.

I-F frequency remains the same for any selected input frequency.

Operates on the non-linear portion of the Eg-Ip curve.

Has an amplification factor, which is referred to as conversion gain.

CIRCUIT ANALYSIS.

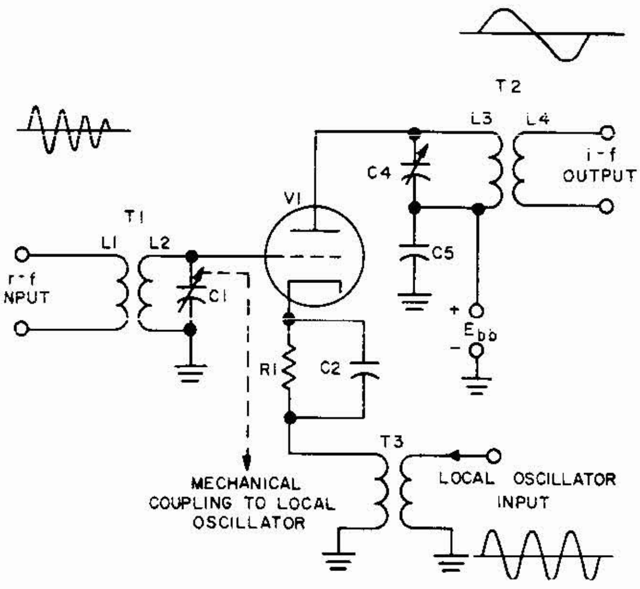
General. The purpose of the mixer stage is to convert the incoming r-f frequency, usually into a lower frequency, which contains the same characteristics (modulation) as the original r-f frequency. This lower output frequency, called the intermediate or i-f frequency, remains the same, regardless of the frequency of the r-f signal received.

By operating over the non-linear portion of the tube's characteristic Eg-Ip curve, harmonic distortion is produced in the plate circuit, and as a result of this harmonic distortion, new frequencies, which are harmonics of the input, are introduced. By proper selection of the local oscillator frequency, specific output frequencies can be obtained. This mixing of frequencies is called heterodyning, and the result at the plate is the presence of four basic frequencies: Namely, the sum and the difference of the two inputs, and the two original inputs (various other beats are also produced but are not often used particularly because of the small amplitude remaining as compared with the basic outputs). A resonant tank in the plate circuit is tuned to the selected difference frequency, so that it will pass only this frequency on to the succeeding i-f amplifier stages and thus effectively attenuate all of the other beat frequencies.

Circuit Operation. The accompanying circuit diagram illustrates a typical triode mixer.

L2, the secondary of T1, together with C1, forms a tank circuit tuned to the desired r-f frequency, and this selected r-f signal is applied directly to the control grid of tube V1. The tube is biased class "C" by the use of C2 and R1, which form a cathode bias circuit, and it is for this reason that the tube operates on the non-linear portion of the Eg-Ip curve. The signal from the local oscillator is coupled through transformer T3 to the cathode circuit of the tube, and because the tube operates on the non-linear portion of the characteristic curve, the two input signals are mixed. The result at the plate is a signal containing the sum and difference of the two inputs, plus each of the two originally applied signals. The primary, L3, of T2, together with C4, forms a tank circuit tuned to the difference, or i-f frequency, and capacitor C5 bypassed the unwanted r-f frequencies to ground.

With no r-f signal applied, and with the signal from the local oscillator applied to the cathode circuit, tube V1 conducts. The current through the cathode starts charging capacitor C2, but because of its long time constant, the cycle ends before the capacitor can charge to the peak value of the input. The charge is slow to leak off, however, because of the value of R1, and within a few cycles, the cathode circuit stabilizes at a voltage which determines



Typical Triode Mixer

the operating bias of the tube. For additional information on cathode bias, refer to section 2, paragraph 2.2.1 of the Handbook. Because of the large cathode bias, the tube operates class "C", and thus over the nonlinear portion of the Eg-Ip curve.

Capacitor C1 and the tuning capacitor in the local oscillator are mechanically connected, so that whenever the value of C1 is changed to operate the r-f tank at a particular frequency, the local oscillator tank is also changed automatically by the same amount. This results in the local oscillator frequency and the r-f frequency always being separated by the same amount at any frequency which may be selected at the input. The amplitude of the local oscillator voltage is approximately ten times as great as the r-f signal amplitude, for efficient mixing and the frequency is selected either above or below the r-f frequency, depending upon the application of the circuit, by an amount which is equal to the i-f frequency.

Under actual operating conditions, the following action takes place. The input r-f frequency and the local oscillator frequency are simultaneously applied to the grid and cathode circuits, respectively. As previously mentioned, these two inputs are of different frequencies, and consequently, they periodically vary in their phase relationships with each other. For this reason, they add or subtract algebraically at regular intervals, and the result at the plate is a new signal whose amplitude varies at a steady rate. This variation in amplitude is of primary importance, and is known as the "beat-frequency". This "beat-frequency" is in reality, the difference frequency which results from the algebraic addition of the two inputs as they approach an in-phase relationship, and their subtraction as they approach an out-of-phase relationship. This beat frequency is equal to the desired i-f frequency.

The resulting plate current pulses, whose amplitudes vary at the beat-frequency rate, arrive at the primary of transformer T2, and a carrier envelope which varies at the beat (i-f) frequency is developed. Since the primary of T2 is tuned to this i-f frequency by the use of C4, it presents a maximum load to the plate at the i-f frequency and the changing field that is developed around the primary winding induces an output in the secondary. All other beat frequencies present in the primary are not developed, because the impedance to these frequencies is at a minimum. For a detailed description of the heterodyning action, refer to the introduction to this section of the Handbook.

If the received r-f signal contains amplitude modulated components, the beat frequency also contains similar amplitude modulated components, which vary in accordance with the audio frequencies modulating the original r-f signal. If the received r-f signal is frequency modulated, the beat difference will deviate in frequency at the same rate as the original r-f signal. Thus, the characteristics of the i-f signal are the same as those of the original received signal, except that the frequency of the received signal is converted to a lower frequency.

A commonly used circuit variation of the triode mixer applies both the local oscillator and r-f signals to the grid of the tube. There is little operational difference, but cathode injection provides better oscillator stability, since the load impedance presented to the oscillator is lower.

The advantage of the triode mixer lies in its relative simplicity and relatively high signal to noise ratio. The conversion gain is about one third of that of the same tube used as an amplifier.

The use of the triode mixer, however, is limited to the VHF spectrum or lower. Above these frequencies, the effect of the interelectrode capacitance of the tube elements becomes too great, and the low output is not practical.

FAILURE ANALYSIS.

No Output. A defective tube, an open or shorted C1, C4, or C5, or a defective T1 or T2 can cause a no-output condition to exist. If no output exists, check the plate of V1 with a voltmeter for the presence of plate voltage. If plate voltage is not present, check L3 for a possible open and C5 for a short, with an ohmmeter. If no output still exists check C2, C4, and C5 with an ohmmeter for shorts or opens, also check T1 and T2 for continuity or possible shorts. Check the secondary of T3 also for a possible open circuit. If the above checks fail to locate the trouble, check all capacitors for value with an in-circuit capacitor checker.

Low or Distorted Output. A defective tube, or low plate supply voltage can cause a low output condition to exist. Check the plate supply voltage with a voltmeter for the proper voltage. Check the output of the local oscillator with an oscilloscope to make sure that it is of proper amplitude.

A distorted output can be caused by a defect in nearly any component in the circuit. Check for the presence of the r-f signal on the grid of V1 with an oscilloscope. If no signal is present, check for a signal on the primary of T1. If the signal is present on the primary, check the transformer windings with an ohmmeter for an open or short, and capacitor C1 for a possible short. If no signal is present on the primary, the trouble lies in the preceeding r-f amplifier stages, and the mixer is probably not defective. Check for presence of the local oscillator signal on the cathode. If not present, check for its presence on the primary of transformer T3. If not on the primary, the trouble lies in the oscillator circuit, and the mixer is probably not at fault. If the signal is present on the primary, check the secondary of the transformer for a short or an open, and check R1 and C2 for proper value. If both the local oscillator and the input r-f signals are present at the grid and cathode of the tube, the trouble is in the plate circuit. Make certain that the plate tank circuit is tuned to the proper i-f frequency. Check C5 with an in-circuit capacitor checker to determine if it has changed in value. Check the windings of T2 for a partial short, as this can change the resonant frequency of the tank.

PENTODE MIXER.

APPLICATION.

The pentode electron tube is used as a mixer in superheterodyne receivers to combine, or "mix", the r-f signal from a local oscillator with the incoming r-f signal, in order to produce the desired intermediate frequency (i-f) output signal.

CHARACTERISTICS.

Requires a separate local oscillator circuit to supply the heterodyning voltage.

Output circuit is tuned to resonate at i-f frequency.

Plate resistance and transconductance are fairly high.

Operates on non-linear portion of Eg-Ip curve.

Output frequency (i-f) remains constant under normal operating conditions.

Has a relatively high conversion gain and signal to noise ratio.

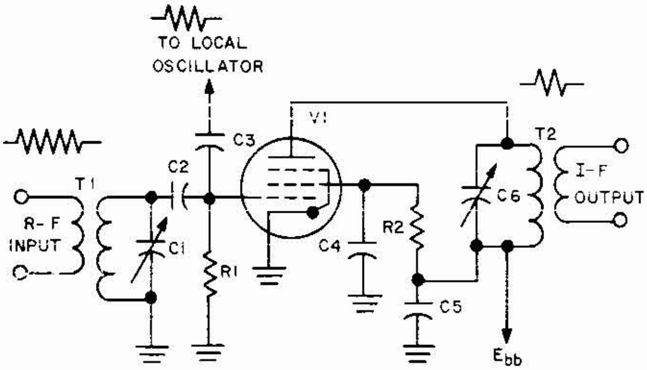
CIRCUIT ANALYSIS.

General. The pentode mixer is frequently used in f-m equipment for the v-h-f band. At frequencies where the screen grid is effective, the pentode mixer provides good isolation between the input and output circuits. This means reduced input loading and elimination of possible instability as compared with a triode mixer. The oscillator and signal voltages are usually applied to the control grid simultaneously. In this way, a noise figure is obtained which exceeds that of a normal pentode amplifier, but which is much lower than in any of the multigrid mixers.

The pentode has an extremely high conversion transconductance and permits high voltage gain in the mixer stage. The equivalent noise voltage produced by the tube is twice that of a triode mixer of the same transconductance. Because of the high obtainable transconductance of pentodes, the overall performance can exceed that of most triodes. Since the triode has a certain amount of stray coupling between grid and plate circuits, it is at a disadvantage in this respect when compared with the pentode. At the signal frequency, the i-f circuit is capacitive, and this, because of **Miller effect**, results in a reflected low resistance in the grid circuit. The screen in a pentode effectively stops this loading. With a pentode, cathode injection of the oscillator signal is possible, but this mode of injection increases the effective cathode inductance. Since the input load is proportional to the cathode inductance, cathode injection lowers the voltage gain of the input circuit and also the noise performance. The stability of the oscillator, however, is improved at very-high frequencies, where a low-impedance oscillator load is needed. Unless the oscillator and mixer are loosely coupled, interaction and pulling becomes severe. Interaction of the oscillator and the signal is greatest when they are both applied to the same grid. Similarly, oscillator radiation becomes a greater problem; however, the high transconductance of the pentode permits the use of small oscillator voltages, and radiation is not as great a problem as in a triode.

In operation, the use of a pentode as a mixer is similar to the use of a triode as a mixer. However, the use of a single grid for both the carrier and local oscillator signals sometimes gives rise to difficulties resulting from coupling between the carrier input circuit and the local oscillator circuit. Using the pentode as a mixer, one signal may be applied to the suppressor grid and the other signal to the control grid. By applying the input signals to separate grids, it provides some isolation between the local-oscillator and r-f signals. The value of the cathode resistor is chosen so that it will cause the tube to operate on the non-linear portion of the Eg-Ip curve (the lower bend of the reponse curve). The plate current of the tube then contains the two original input frequencies as well as the sum and difference frequencies of the two original signals. The signal from the local oscillator is normally made much stronger than the r-f input signal so that the percentage of modulation is kept low. The low percentage of modulation required for frequency conversion can be produced in several ways. The method most frequently used depends on the transfer characteristic of a tube or other circuit element. The transfer characteristic expresses the relationship between the signal applied to the input of a device and the signal obtained from its output. The transfer characteristic of a vacuum tube is not a straight line, since the relationship of Eg to Ip usually is curved at low values of plate current. Therefore, the vacuum tube is a non-linear device. When the voltage on the grid of a vacuum tube becomes more negative and reaches the plate current cut-off value, no current flows in the plate circuit. Consequently, for an entire range of voltages no current flows in the input circuit. Therefore, the vacuum tube is non-linear, even if its transfer characteristic is perfectly straight.

Circuit Operation. The schematic of a typical pentode mixer circuit is shown in the accompanying illustration.



Typical Pentode Mixer Circuit

Transformer T1 consists of an untuned primary winding and a tuned secondary winding; capacitor C1 and the secondary winding of T1 form a resonant circuit at the frequency of the r-f signal to be received. Electron tube V1 is a pentode; the filament (heater) circuit is not shown on the schematic.

After being amplified in the step-up transformer T1, the r-f signal is applied to the grid of mixer tube V1 along with the local oscillator signal which is applied through coupling capacitor C3. Blocking capacitor C2 isolates the contact bias resistor R1 from the signal source. Screen bypass capacitor C4 has a low enough reactance to place the screen at ground potential. Dropping resistor R2 determines the screen voltage on the screen grid of V1. An r-f bypass to ground is provided by capacitor C5; and the primary winding of transformer T2 in parallel with tuning capacitor C6 provides a resonant tank circuit for tuning the desired i-f output signal.

With no r-f input, the control grid of V1 has only contact bias. That is, some of the electrons in the space charge have enough velocity to reach the grid. This flow of electrons from cathode to grid causes a small grid current to flow. By making the value of R1 a high resistance (approximately 1 megohm) the resulting voltage drop across it provides a negative bias on the tube, which is called contact-potential bias. Capacitor C2 charges to the voltage developed across R1, holding the tube near cutoff.

Varying capacitor C1 tunes the tank circuit to the desired incoming r-f signal. This signal is amplified in step-up transformer T1, and is applied to the control grid of V1, along with the local oscillator signal. The amplitude of the local oscillator voltage is approximately 10 times the value of the incoming r-f signal voltage. The local oscillator frequency is either above or below the desired i-f frequency (depending on the circuit application), by an amount which is equal to the desired i-f frequency.

Since the two applied signals differ in frequency, their voltages are not always in phase with each other. Periodically these two voltages algebraically add or subtract to produce an amplitude variation at regular intervals; it is this periodic amplitude variation in the form of a beat frequency voltage which is of greatest importance. The beat frequency is actually the difference frequency produced by the instantaneous signal voltages as they combine to increase amplitude when approaching an in-phase relationship, and to decrease when approaching an out-of-phase relationship.

If the incoming r-f signal contains amplitude modulated information, the resulting beat frequency will also contain the same amplitude modulated information. This information varies in accordance with the audio frequency modulating the incoming r-f signal. If the receiver r-f signal contains frequency modulated information, the beat frequency difference will deviate at the same rate as the incoming r-f signal frequency. Thus the characteristics of the resulting i-f are the same as those of the original r-f signal, except that the frequency of the received signal has been converted to a lower or higher frequency depending upon the application.

As a result of the heterodyning action taking place within the elements of the tube, the output signals present at the plate of V1 are: the sum of the two input signals, the difference of the two input signals, and the two input signals themselves. Since the primary winding of transformer T2 is tuned, it will present a high impedance to the desired i-f frequency. This frequency is passed by the tank circuit consisting of the primary winding of T2 and variable capacitor C6, and a voltage is induced in the secondary winding which varies in amplitude in accordance with the amplitude of the original r-f signal. All other signals are bypassed to ground through capacitor C5. The output signal voltage developed across the secondary windings of T2 then contains all of the information present on the desired r-f input signal.

One variation of the pentode mixer circuit is to use cathode injection of the local oscillator signal, but using this mode will increase the effective cathode inductance. Because the input is proportional to the cathode inductance, cathode injection will lower the voltage gain of the input circuit and also the noise performance. Another variation of the pentode mixer circuit uses the suppressor grid for one of the inputs and the control grid for the other. This provides a slight amount of isolation between the two inputs.

FAILURE ANALYSIS.

No Output. A defective tube, an open or shorted C2, C5, or C6, or a defective T1 or T2 can cause a no-output condition. Check the plate of V1 with a high resistance voltmeter. If plate voltage is not present, use an ohmmeter to check the continuity of the primary winding of T2 and to check C1, C5, and C6 for a shorted or open condition. If the previous checks fail to locate the trouble, the circuit supplying the plate voltage is probably at fault.

Low Output. A low output would normally be caused by a defective or weak V1, or a low filament or plate voltage, or if the i-f and r-f tank circuits are not tuned to the proper frequencies. A weak local oscillator voltage can cause a low output. Check the filament and plate voltages with a VTVM. If they are not normal, refer to the procedure in the previous paragraph. If they are normal, check the amplitude of the local oscillator signal. If it is low, check C3 with an in-circuit capacitor checker. If the output is still low, the trouble is probably in the local oscillator circuit.

Distorted Output. A distorted output can be caused by a defect in nearly any component in the circuit. With an oscilloscope, check for an r-f signal on the secondary winding to T1. If the r-f signal is not present, check the windings of T1 with an ohmmeter for continuity. Should the windings not be defective, the trouble lies in the preceeding stages and the mixer is probably not defective. If the signal is present on the secondary winding of T1, check for the presence of the local oscillator signal on the high side of C3. If it is not present, the local oscillator is at fault. If it is present, both the r-f and local oscillator signals should be present on the control grid of V1. If the local oscillator signal is not present, C3 is defective. If the r-f signal is not present, C2 is defective. If both the r-f and local oscillator signals are present on the control grid of V1, Tube V1 is probably defective. If the output is still distorted, check the plate and screen voltages with a VTVM. If both voltages are low, check the output of the plate voltage supply. If it is low, the trouble lies in the plate supply. If it is normal, and the screen voltage is low, check R2 with an ohmmeter, and C4 and C5 with an in-circuit capacitor checker. If the plate voltage is low, check C6 with an in-circuit capacitor checker and the primary winding of T2 with an ohmmeter. If the output is still not present, check the secondary winding of T2 with an ohmmeter.

PENTAGRID MIXER

APPLICATION.

The pentagrid mixer is used in modern superheterodyne receivers as a frequency converter. Incoming r-f signals are combined with signals from a local oscillator to produce an intermediate frequency (i-f).

CHARACTERISTICS.

Offers good selectivity.

Serves both as a frequency converter and a high gain amplifier.

Signal-to-noise ratio is poor.

Requires a separate local oscillator to supply the heterodyning voltage.

Uses two input control grids to provide electron coupling.

Operates with either cathode-self, fixed, or avc bias voltage.

CIRCUIT ANALYSIS.

General. The functional operation of the pentagrid mixer is very similar to that of other mixer circuits discussed previously in this handbook. R-f and oscillator voltages are injected into the tube and added algebraically. The fundamental frequencies, along with their sum and difference frequencies, appear across the output circuit. The output circuit is a parallel resonant tank, tuned to the i-f. The desired i-f signal is transformer coupled into the next stage.

The primary difference between the pentagrid mixer circuit and other mixer circuits is the input arrangement. In the diode, triode, and pentode mixer the r-f and oscillator voltages are inserted on the same tube element, allowing for greater interaction between input signals. In the pentagrid mixer, r-f and oscillator signals are inserted on separate control grids, isolated from each other and the plate by screen grids. Consequently, the frequency pulling effects and signal interaction, common to other mixer circuits, is virtually eliminated.

Circuit Operation. Before discussing operation of the pentagrid mixer it will be helpful to review the operation of the pentagrid tube.

The pentagrid tube consists of a plate, cathode, filaments and five grids, hence the name pentagrid. Two of the grids are used as control grids (G1 and G3), two are used as screen grids (G2 and G4), and the fifth is used as a suppressor grid. For all practical purposes the gain of the pentagrid tube is comparable to that of the pentode, however the introduction of an extra screen grid increases the partition noise, and consequently, the circuit noise.

The screen grids are operated at a positive voltage and serve as the accelerating anodes for electrons leaving the cathode. However, the electrons strike the plate of the tube with such force that they bounce off (secondary emission) and form a space charge around the positive screen grid (G4).

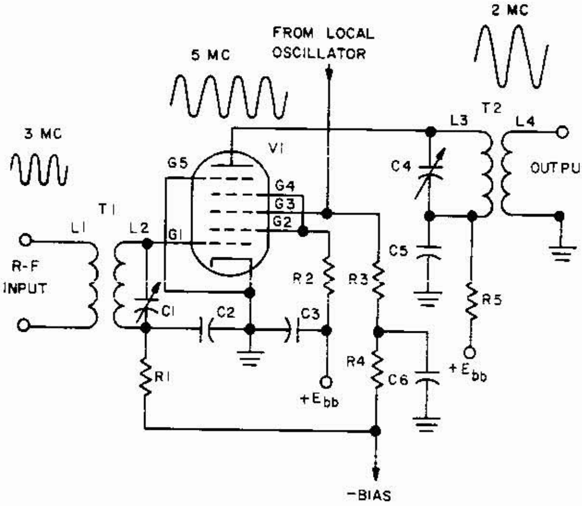
The space charge greatly limits the plate voltage swing, so a negative grid (G5) is placed between screen and plate, and its negative charge diverts electrons back to the plate.

By following the above discussion it can be seen that the pentagrid tube plate current is made independent of plate voltage. In fact, the plate voltage may swing as low as, or lower than, the screen voltage without serious loss of amplifier gain capabilities. In mixer circuits gain (gm) is referred to as "conversion transconductance" and represents the quotient of i-f output current divided by r-f input voltage; or, conversion transconductance = I_{if}/E_{rf}. In pentagrid tubes conversion transconductance may run as high as 500 micromhos.

In the mixer circuits previously discussed, such as the triode and pentode mixer, the r-f and oscillator signals are injected on the same control grid. Thus the r-f input circuit is "seen" by both inputs and stray coupling induces oscillator detuning, or frequency pulling. In pentagrid mixers, r-f and oscillator signals are simultaneously injected on separate control grids (G1 and G3). As stated previously in this discussion, G2 acts as an electrostatic shield between the input elements, and is effectively grounded at r-f frequencies by capacitor C3. Thus, the input circuits are shielded from each other, and interaction caused by stray capacitive coupling is virtually eliminated. Hence the instability of operation and frequency pulling effects common to other mixers is not experienced in the pentagrid circuit.

Thus, in the pentagrid mixer the gain is high, and a small amount of r-f voltage produces a high r-f output, and the input grids are also isolated creating a stable circuit free from frequency pulling effects.

A typical pentagrid mixer circuit is illustrated in the accompanying schematic diagram.



Pentagrid Mixer

Fixed bias from an external bias supply is applied to the control grid G1 through decoupling resistors R1 and coil L2 and to G3 grid via R3 and R4. The tube is biased below cutoff with no input from the r-f and local oscillator, so that in the absence of a signal the tube will not conduct. Capacitors C2 and C6 are r-f bypass capacitors which prevent r-f signals from entering the bias supply.

Dc voltage is applied to the plate and screen through plate decoupling resistor R5 and coil L3, and through screen resistor R2. Capacitors C3 and C5 are also r-f bypass capacitors to prevent r-f from entering the power supply.

With no r-f signal applied to G1, and oscillator voltage applied to G3 the tube begins to conduct, with the plate current varying at the oscillator frequency; however, due to the highly selective tuning of the output tank comprised of L3 and C4, the current variations are by-passed through the tank to ground via C5 and no output is realized at L4.

As the receiver is tuned to the desired r-f frequency the r-f signal is impressed across coil L1. Transformer action takes place and the signal is transferred inductively from the primary to secondary winding L2. Coil L2 and capacitor C1 form a parallel resonant tank between the control grid (G1) and cathode, tuned to the selected r-f frequency. Capacitor C2 by-passes extraneous frequencies to ground and prevents their entering the bias supply.

As r-f and oscillator signals appear simultaneously on G1 and G3, respectively, plate current increases and the tube operates just above cutoff on the non-linear portion of the E_g-I_p curve (the lower bend in the response curve).

Harmonic distortion, caused by operating the tube non-linearly, results in mixing action within the tube. The two original frequencies, plus their sum and difference frequencies, appear between the plate and ground across L3, and C4. The parallel resonant tank, formed by L3 and C4, selects the difference frequency and transformer action occurs between the primary or secondary of T2, resulting in the i-f appearing across L4. The unwanted frequencies (the two originals and their sum) are bypassed through C5 to ground. Capacitor C5 is of a circuit value which will bypass the high frequency components in the plate, but not the relatively low frequency i-f. Since the i-f tank offers a high primary load impedance, only the i-f signal is developed across it and is inductively coupled to the secondary or output winding. The output then consists of a signal at the intermediate frequency which contains all the original signal modulation and any hum modulation from the local oscillator, if not adequately plate filtered.

FAILURE ANALYSIS.

No Output. Before troubleshooting the mixer stage it is necessary to ascertain that r-f and local oscillator signals of proper amplitude and frequency are present at the inputs to the mixer circuit. The operation of the mixer circuit depends upon the heterodyning of these two signals and if either is absent an i-f output will not appear across L4. An oscilloscope, equipped with a high frequency—high impedance probe, must be used to check the presence of r-f and oscillator signals on L1 and G3 respectively.

After assuring the presence of input signals, check the dc and bias supply output voltage for nominal output and ripple as directed in the equipment handbook.

If power supply voltages are present and of correct amplitude, check each component visually for signs of overheating. Also check connections for good electrical and mechanical contact.

Use a vacuum tube voltmeter to check each tube element on the base of the socket. If plate, filament, or screen voltage is absent the tube will not conduct, resulting in no output. Remove power and check power supply plate decoupling resistors R2 and R5 and coil L3 for correct dc resistance. Also check capacitors C3 and C5 with a in-circuit capacitor checker to determine if they are shorted or leaky. If bias voltage is appreciably off value the tube will either be cutoff (increased bias) or saturated (decreased bias). Check bias resistors R1, R3, and R4 and coil L2 for correct dc resistance. Use an in-circuit capacitor checker to check capacitors C2 and C6 for a shorted or leaky condition.

If all circuit components are within tolerance and the presence of both r-f and oscillator signals is verified, the tube is most likely at fault.

If still no output is obtained, check the tuning of the input and output circuits as directed in the equipment handbook. If either tank will not tune, carefully check the capacitor and coil associated with the tank. Remove power and use an ohmmeter to check the primary and secondary windings of T1 and T2 for the correct dc resistance. If the resistance has increased the Q of the circuit will be decreased and output at the desired frequency may be impossible to obtain.

Low or Distorted Output. Check the r-f and oscillator input circuits for proper amplitude and frequency with an oscilloscope. Be especially watchful for distorted input waveforms caused by noise, hum, defective coupling, etc. If input waveforms are correct and free from distortion, check the waveform at the plate of V1 (use a 30-100 pf, 250 v dc blocking capacitor in series with the probe).

If the waveform appearing on the plate is clipped or small in amplitude, check for correct dc operating voltages on the tube elements. Check bias voltage first, as increased bias will cause abnormal plate voltage due to decrease conduction. If bias voltage is incorrect check resistors R1, R3 and R4 and coil L2 for correct dc resisttance. Check r-f by-pass capacitors, C2 and C6, for shorts using an in-circuit capacitor checker.

If bias voltage is correct and plate voltage is low check the dc resistance of R5 and L3. Also check C5 for a shorted or leaky condition.

If all voltages are correct and the output of the tube is still weak, the tube is probably defective.

If the output of V1 appears normal and the output of the mixer stage is still weak or distorted, check the tuning of the output tank circuit. If the tuning of capacitor C4 has shifted appreciably the band pass of the tank circuit will be greatly reduced and the i-f frequency will be suppressed.

BALANCED MIXER.

APPLICATION.

The balanced mixer is used in receiver circuits to combine or "mix" the r-f signal from the local oscillator with the incoming r-f signal, to produce the desired intermediate frequency (i-f) output.

CHARACTERISTICS.

Uses two triodes connected in push-pull.

Fixed, class "C" bias is used.

Requires a separate local oscillator circuit to supply the heterodyning voltage.

Provides amplification, which is referred to as conversion gain.

I-F frequency remains the same for any selected input frequency.

CIRCUIT ANALYSIS.

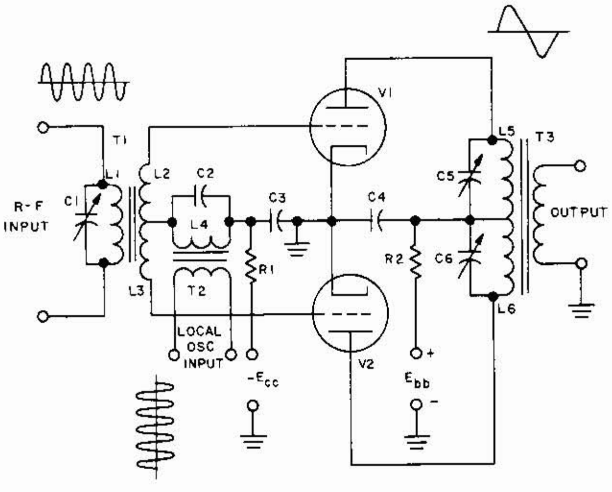
General. The purpose of the mixer stage is to convert the incoming r-f frequency, usually into a lower frequency, which contains the same characteristics (modulation) as the original r-f frequency. This lower output frequency, called the intermediate, or i-f frequency, remains the same, regardless of the frequency of the r-f signal received.

The local oscillator signal is applied in parallel to the grids of tubes V1 and V2 while the r-f signal input is applied in series with the local oscillator input so that the r-f input alternately aids and opposes the local oscillator signal.

By operating both tubes class "C", and by applying two different frequencies to the input of the tubes, a mixing, or heterodyning action occurs, and the result at the plates is a number of different frequencies, which consist primarily of the sum and the difference of the two inputs, and the two originally applied signals.

Since the tubes are connected for push-pull operation, the outputs aid each other at the output transformer, which is usually tuned to the difference frequency, and for this reason, a higher amplification factor is obtained.

Circuit Operation. This accompanying circuit diagram illustrates a typical balanced mixer.



Typical Balanced Mixer

The input r-f signal, applied to the primary of T1, is selected with tuning capacitor C1, which is mechanically connected to the tuning capacitor in the local oscillator. The secondary of T1 is split, and the local oscillator signal is applied through transformer T2 to the center tap of the split secondary. Capacitor C2 provides an effective ground for the center tap of the split secondary, and C3 provides a ground return for the secondary of T2 and keeps r-f out of the bias supply. Resistor R1 establishes Class C bias on tubes V1 and V2, and capacitor C4 is an r-f bypass to ground. Resistor R2 is a plate voltage dropping resistor which establishes the plate voltage for the tubes. Capacitors C5 and C6 in the output circuit are used to tune the primary of the output transformer, T3, to the desired difference frequency.

With no r-f signal applied at transformer T1, and the signal from the local oscillator applied at transformer T2, the voltages applied to the grids of V1 and V2 are in phase with each other.

By applying a signal at the input transformer T1, voltages are developed in the secondary windings L2 and L3, which are equal and opposite with respect to each other, because of the grounded center tap arrangement. Thus, when the grid of V1 is positive with respect to its cathode, the grid of V2 is negative with respect to its cathode, and conversely.

Capacitor C1 and the tuning capacitor in the local oscillator are mechanically connected, so that whenever the value of C1 is changed to operate the r-f tank at a particular frequency, the local oscillator tank is also changed automatically by the same amount. This results in the local oscillator frequency and the r-f frequency always being separated by the same amount at any frequency which may be selected at the input. The amplitude of the local oscillator voltage is approximately ten times as great as the r-f signal amplitude, for efficient mixing, and the frequency is selected either above or below the r-f frequency, depending upon the application of the circuit, by an amount which is equal to the i-f frequency.

When both the local oscillator and the r-f inputs are applied simultaneously, the following action results.

Assume that the local oscillator signal and the r-f input signals on the grid of V1 are positive and in phase. A voltage is developed in the plate circuit which is the algebraic sum of the two applied signals. At the same instant, a positive local oscillator signal and a negative r-f input signal is applied to the grid of V2. The result in the plate circuit of V2, therefore, is also a signal which is the algebraic sum of the two inputs. Since the two inputs are 180 degrees out of phase with each other, they subtract, and the signal at the plate of V2 is smaller in amplitude than the signal at the plate of V1. Because the tubes are connected in push-pull, the two out-of-phase r-f signal inputs add in the primary of T3, and the two in-phase local oscillator components subtract. The local oscillator components are of equal amplitude, and of opposite polarity at the plate, so their algebraic difference is 0 volts. The two r-f signals are in phase, and they add in the plate circuit, the result being a positive going signal.

Let us consider the opposite set of circumstances. As the polarities of the local oscillator and the r-f signals at the grids of the tubes change, the signal in the plate circuit also changes. When the signal from the local oscillator becomes negative on the grids of the tubes, and the r-f signal input is such that it applies a negative signal on the grid of V1, and a positive signal on the grid of V2, the following results occur. Because both of the signals on the grid of V1 are in phase, they add algebraically, and the result at the plate of V1 is a negative going signal which is the sum of the two input signals. The two signals on the grid of V2, however, are out of phase, and the result at the plate is the algebraic difference. Because the local oscillator component is cancelled out in the plate tank circuits, the resultant output is a negative going signal which is the algebraic sum of the two r-f inputs.

The local oscillator signal is of a different frequency than the r-f input, so their phase relationship with each other is constantly varying. The closer they are in phase with each other, the greater is the output, and the further out of phase they are, the smaller the output. These variations in the amplitude of the plate current occurs at the desired difference frequency, and it is this difference frequency or i-f to which the plate tank circuits are tuned. Since the tanks present a high impedance to the i-f, a changing field is developed around the primary winding, which induces an output in the secondary winding.

The local oscillator component is eliminated in the plate circuit because they are of opposite polarity, and since they always are equal in amplitude and opposite in polarity, they cancel. All other frequencies in the plate circuit are bypassed to ground through capacitor C4 without being developed. For a detailed description of heterodyning action, refer to the introduction to this section of the Handbook.

If the received r-f signal contains amplitude modulated components, the beat frequency also contains similar amplitude modulated components, which vary in accordance with the audio frequencies modulating the original r-f signal. If the received r-f signal is frequency modulated, the beat difference will deviate in frequency at the same rate as the original r-f signal. Thus, the characteristics of the i-f signal are the same as those of the original received signal, except that the frequency of the received signal is converted to a lower frequency.

FAILURE ANALYSIS.

No Output. The only components which will cause a no output condition to exist is an open R2, a shorted C4, or a defective T3. Check the value of R2 with an ohmmeter, and check C4 for an open or a short with an ohmmeter. Check the windings of T3 for continuity. Note that one defective tube will not cause a no-output condition to exist. Both tubes must be defective.

Low Output and Other Conditions. If the output appears to be low when observed on an oscilloscope, it could be simply a heterodyned signal of insufficient amplitude, or an output which is the result of one or the other of the input signals being coupled through the mixer stage without being mixed, and thus useless. Determine first of all whether or not the mixer is at fault by checking for the r-f input and the local oscillator input on their respective transformer primaries. Remember to disable the r-f amplifier when checking the local oscillator input, and the local oscillator input when checking the r-f input. If either one of them are not present, the mixer stage is probably not faulty, and the output will most likely be restored with the renewal of the missing input signal. If each signal is present on its respective primary, check the continuity from the grid of V1 to the grid of V2 with an ohmmeter. If it is an open circuit, the secondary of T1 is probably open. Also check the secondary of T2 for continuity with an ohmmeter. Check C2 for a possible short, as this would place a short across the secondary of T2. Check C3 for an open, and R1 for proper value with an ohmmeter. If the above components check good, and the proper signals are applied to their respective primaries, these signals should be present on the grids of the tubes. If the trouble still exists, one of the transformers is probably defective.

If both signals are present on each grid, and the output is low, the tubes are probably defective. Do not overlook the possibility of the tuned circuits being misaligned. If the low output still exists, check the bias supply and the plate voltage supply to be certain that voltages are normal. Check R1 and R2 with an ohmmeter for proper value. Check C4, C5, and C6 for an open or a short with an ohmmeter, and the primary and secondary of transformer T3 for continuity. If above checks fail to locate the trouble, check all capacitors with an in-circuit capacitor checker, and double check all transformers.

PENTAGRID CONVERTER.

APPLICATION.

The pentagrid converter is used in modern superheterodyne receivers to convert radio frequencies (r-f) to intermediate frequencies (i-f) by heterodyning (mixing) the received r-f signal with a locally generated signal.

CHARACTERISTICS.

One tube functions as both oscillator and mixer.

Output is stable up to and including the h-f band.

Signal-to-noise ratio is poor.

Offers high gain (conversion transconductance).

Oscillator section is electron-coupled and isolated from input signals to minimize "pulling effects".

Circuit cost is lower than that of two separate tubes.

General. The pentagrid converter is a low cost, high gain, frequency converter with excellent stability, commonly used for frequencies up to and including the h-f band. Perhaps the most frequent application of the pentagrid converter is in the standard ac-dc house-hold receiver where, due to the high gain characteristics of the pentagrid tube, an r-f amplification stage is not required. By combining the r-f amplifier, local oscillator and mixer into one tube the over-all cost of the receiver is greatly reduced without sacrificing quality; however, in more sophisticated receivers where greater sensitivity and selectivity are desired, the pentagrid converter is usually preceded by at least one stage of amplification.

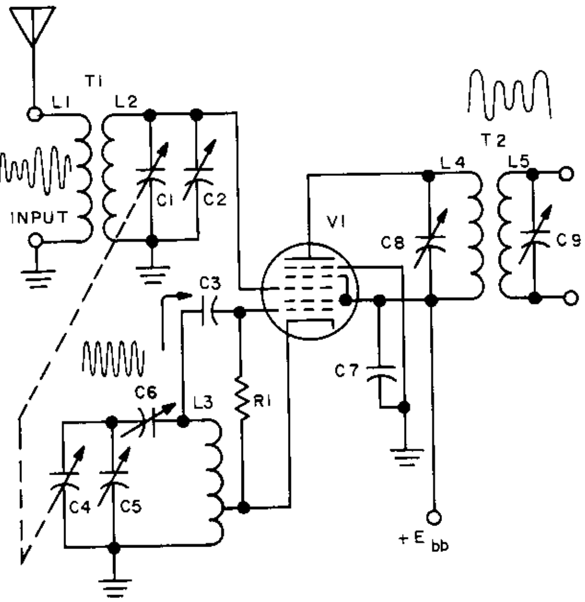
Basically, the pentagrid converter can be divided into two separate circuits; an electron-coupled oscillator (formed by the cathode, inner control grid, and screen grid) and a conventional pentagrid mixer with separate grid injection.

The tube is biased below cutout by a shunt grid leak bias network, and plate current only flows when the oscillator signal is large enough to overcome the heavy negative bias. Thus, conduction takes place for the small amount of time that the oscillator signal is at its peak amplitude. This breaks the plate current into pulses varying at the oscillator frequency. As the receiver is tuned to the desired r-f frequency, the r-f voltage injected on the outer control grid is added algebraically with the oscillator signal so that plate current now follows their combined sum voltage.

Operating the tube just above cutoff on the non-linear portion of the Eg-Ip curve causes harmonic distortion. Consequently, in addition to the two original frequencies, their sum and difference frequencies are now present in the plate circuit.

A parallel resonant tank circuit is placed in the plate circuit and is tuned to the desired i-f, which can be either the sum or difference of the two original frequencies. Transformer action transfers the selected i-f to the input of the next stage. The two original frequencies and their sum or difference (depending upon which frequency was selected for the r-f) are by-passed to ground through the relatively low impedance offered by the screen bypass capacitor.

Circuit Operation. A typical pentagrid converter circuit is illustrated in the accompanying schematic diagram. Pentagrid converters are occasionally modified to function in special circuits, consequently, circuit arrangements which vary from the accompanying schematic may be incorporated in different receivers; however, the functional operation remains basically the same.



Pentagrid Converter

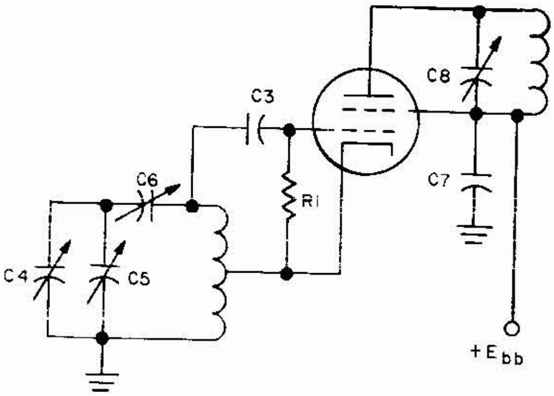
R-f signals arriving at the antenna are impressed across L1 and coupled across transformer T1 to the secondary tuned tank formed by inductor L2 and capacitor C1. C2 is a trimmer capacitor used to track the high frequency end of C1 during alignment. The selected r-f frequency is inserted into the converter tube on the outer control grid, G3.

Oscillator signals are developed in the grid tuned tank formed by inductor L3 and capacitor C4. C5 is a trimmer capacitor used for tracking the high frequency end of the main tuning capacitor C4, and C6 is a padder capacitor used to track the low end of C4. The oscillator signals are coupled to inner control grid G1 through coupling capacitor C3 which, working in conjunction with R1, develops the shunt grid leak bias voltage for the tube.

Conduction takes place when the positive peaks of oscillator signal overcome the class C bias, causing plate current to flow in pulses at oscillator frequency. The pulsed electron stream is further modulated by the r-f signal and both frequencies, plus their sum and difference frequencies appear in the plate circuit. The parallel resonant tuned tank formed by inductor L4 and capacitor C8 acts as a plate load, and is tuned to the desired i-f frequency. Capacitor C7 prevents r-f from entering the power supply.

The output is taken across the parallel tuned tank formed by inductor L5 and capacitor C9 which further selects the desired i-f frequency.

The schematic diagram shown incorporates an electron-coupled Hartley oscillator as the frequency generating section. For illustrative purposes the oscillator portion of the pentagrid converter has been re-drawn in the accompanying schematic diagram. Notice that the screen grids (G2 and G4) form a composite oscillator anode. A detailed operational description of the oscillator section is included in the following paragraphs.

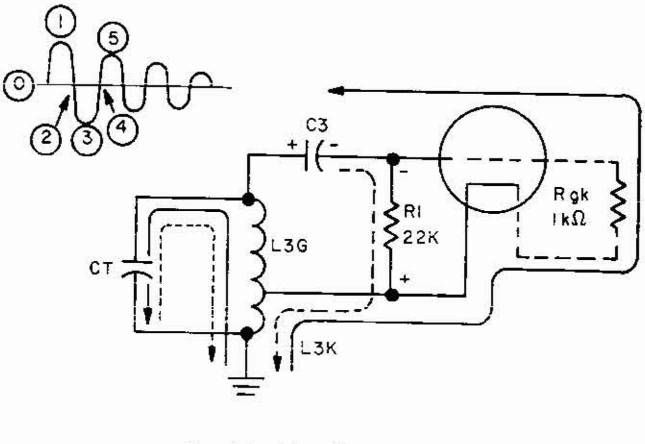


Oscillator Section

In frequency converter circuits it is desirable to have as nearly a stable oscillator injection signal as possible with little variation in frequency or amplitude. In the pentagrid converter this need was intensified by combining two separate functions into one tube envelope. It is known that variation in the plate load of conventional oscillator circuits causes considerable variation of oscillator frequency. Hence, the need for an oscillator whose output circuit is completely isolated from the tuned grid circuit.

In the electron coupled Hartley oscillator, the internally connected screen grids are supplied with a dc potential and act as a composite anode for the oscillator section of the pentagrid converter. Electrons are attracted from the cathode and flow towards the screen grids (anode); however, because of the relatively large spacing between the wires of the screen grid, most of the electrons pass on through to the plate element of the pentagrid tube. Consequently, only a small ammount of screen current flows and the screen voltage remains comparatively constant. It can be seen then that electrons leaving the cathode "see" a relatively constant load because of the stable anode potential on the screen grid, but the actual output circuit of the oscillator is in the pentagrid tube plate. The screen grids are held at r-f ground potential by r-f by-pass capacitor C7 whose impedance is very low at r-f. Thus the only coupling which exists between the input and output circuit is the electron stream, hence the name "electron-coupled" oscillator.

To sustain oscillations in the grid circuit it is necessary to "feedback" an in-phase portion of the output signal. In the electron coupled Hartley the tapped inductor acts as an autotransformer to accomplish this purpose. For illustrative purposes the grid and cathode circuit has been redrawn in the accompanying schematic diagram.



Simplified Oscillator Circuit

The inductor L3 is divided into two sections which will be designated L3k (cathode winding) and L3g (grid winding). It can be seen that the total inductance former by L3, in parallel with the total capacitance of C4, C5 and C6, forms the frequency determining tank circuit. The solid lines represent the initial flow of current (charge path) and the broken lines represent the reverse of current (dis charge path).

At the instant power is applied to the tube, *zero bias* exists on the control grid and the tube readily conducts. For the following discussion it will be helpful to remember that cathode current "follows" plate current. *Increased* cathode current develops a voltage potential across inductor L3 and capacitors C4, C5 and C6, represented by CT, begin to charge (0 to 1 on the sine wave). At point 1, the capacitors have charged to approximately the applied voltage and begin to discharge back through inductor L3, (point 1 to 2) setting up a magnetic field, (point 3). The magnetic field begins to collapse, (point 3 to 4) re-charge capacitor CT (point 5) and the cycle repeats itself; however, notice that the voltage at point 5 is less then that at point 1. This is due to inherent circuit losses (coil resistance,etc.) and eventually, after a few more cycles, the oscillations will dampen out entirely. Thus, it can be seen that an in-phase signal of sufficient amplitude to cancel out circuit losses is necessary to sustain oscillations.

For simplification, bias voltages are disregarded in this discussion and will be discussed later on in the text.

The positive going grid (0 to point 1) causes an increase in plate (and cathode) current, resulting in an increased voltage across inductor L3k, 180° out of phase with the grid signal. The mutual inductive action of the autotransformer L3g and L3k produces another 180° phase shift, so that regenerative (in-phase) feedback is accomplished. The feedback voltage will be relatively small due to the turns ratio of the transformer but it is of sufficient amplitude to reinsert and compensate for any circuit losses. Thus, the flywheel effect of the tuned tank circuit, aided by the mutually induced voltage from L3k, impresses a linear sine wave on capacitor C3, which is part of the shunt grid leak bias circuit.

As has been previously mentioned, it is required that a mixer operate over the nonlinear portion of the E_g-I_p curve, thus the tube must be biased below cutoff. The grid leak bias circuit comprised of resistor R1 and capacitor C3 performs this function and will be discussed in detail in the following paragraphs.

The oscillator input signal arriving from the grid tank circuit is impressed on the tank side of capacitor C3. On the positive swing of the oscillator input signal the grid is driven positive, causing current to flow from cathode to grid through the internal tube grid-cathode resistance, Rgk (The value of Rgk is considerably lower than that of the parallel resistance R1 so the major portion of the current will flow through Rgk) and C3 charges rapidly, placing a negative voltage on the control grid. As the oscillator signal swings negative, grid current ceases to flow and capacitor C3 begins to slowly discharge through resistor R1. The value of R1 is considerably larger than Rgk, so discharge time is longer than charge time. Before C3 can become fully discharged the oscillator signal begins to *swing* positive and grid current flows again, charging C3 to a higher potential and placing more bias voltage on the control grid. Eventually, after a few more cycles of oscillator signal, the charge on C3 becomes stabilized and grid voltage *remains at a constant* level.

If the time constant of the R-C bias network is too long, capacitor C3 will eventually become fully charged, *placing the tube in absolute cutoff* and no current will flow, consequently, oscillations will cease. Hence, the value of grid leak resistor R1 is critical. It must be large enough to **develop a sufficient negative voltage for cutting the tube** off and small enough to allow a partial discharge of C3 before the next oscillator cycle begins. Thus, by using the *correct value of grid leak resistance the circuit* may be designed to cut off for 90% of the time with only 10% (the positive peak) of the signal causing tube conduction.

The positive peaks of the oscillator signal brings the tube out of cutoff and modulates the electron stream in pulses. R-f signals arriving at the antenna are impressed across inductor L1, *the primary winding* of T1. The signals are transformer coupled to the secondary winding, inductor L2. Capacitor C1 and L2 make up a parallel **resonant tank tuned to the *selected r-f frequency*. Notice** that C1 in the r-f section and C4 in the oscillator section are mechanically ganged, and varying one will cause the other to vary by an equal amount, hence *the oscillator and* r-f stage are always, theoretically, separated by the intermediate frequency. However, on the extreme ends of the tuning range the variable capacitors become somewhat nonlinear and if proper tracking is to be acquired it is necessary to insert trimmer and padder capacitors to "fine tune" the local oscillator and r-f sections. Capacitors C2 and C5 are "trimmer" capacitors used to track the low frequency end of C1 and C4 respectively and C6 is a "padder" capacitor used to track the high frequency end of capacitor C4.

The frequency selected by C1 and L2 is applied to the outer control grid, G3. The r-f signal grid is electrostatically shielded from the oscillator grid by screen grid G2 which is at ground potential. Consequently, very little electron coupling exists between the r-f and oscillator circuits and frequency pulling effects are virtually eliminated.

The electron stream, varying at oscillator frequency, is further modulated by the r-f signal and plate current begins flowing at a rate, as determined by the algebraic sum of the two signals. Harmonic distortion, caused by operating the tube non-linearly, produces various frequencies (the original rf and oscillator signals and their sum and different frequencies) in the plate circuit. The fixed tuned output tank comprised of L4 and C8 is tuned to the desired i-f, which is usually the difference frequency, and inductively couples the selected i-f to the secondary winding tuned circuit comprised of L5 and C9.

The unwanted original frequencies and their sum frequency are shunted to ground through r-f by-pass capacitor C7.

FAILURE ANALYSIS.

No Output. Before troubleshooting the converter stage check each component visually for signs of overheating.

Also, check all component connections for good electrical and mechanical contact. Check the mechanical coupling between the ganged capacitors C4 and C1. If the coupler has loosened the oscillator and r-f signals will not be separated by the desired i-f frequency and no output will be obtained from the converter circuit.

The output tuned tank comprised of L4 and C8 is tuned to the desired i-f which is a mixture of the locally generated oscillator signal and the received r-f signal. Thus, if both input signals are not present on their respective control grids the tube will not operate properly, resulting in no output. Before further troubleshooting is accomplished the presence of both input signals must be ascertained. It is important to remember that oscillator signals are dependent upon tube conduction.

To check the r-f signal, connect an oscilloscope (equipped with a high impedance-high frequency probe) between the outer control grid and ground. In receivers where the converter is not preceded by an r-f amplifier the r-f signal may not be of sufficient amplitude to produce an indication on the oscilloscope. If this is the case a signal generator, adjusted to the selected r-f and loosely coupled to the antenna loop, should produce an indication on the oscilloscope. If no signal is obtained after performing the preceding checks, use an ohmmeter to check inductors L1 and L2 for the correct dc resistance. Also, check capacitors C1 and C2 for a shorted condition using an in-circuit capacitor checker. In receivers where an external antenna is used the antenna transmission line must be checked for a short or open.

Since grid leak bias voltage depends upon the applied oscillator input signal, both the bias voltage and oscillator signal may be checked simultaneously by connecting a vacuum tube voltmeter between the inner control grid and ground. If no voltage is present on the control grid, remove power and check the dc resistance of inductor L3 using an ohmmeter. Also check capacitors C4, C5 and C6 for a shorted condition. If the components forming the oscillator tank appear normal, use an in-circuit capacitor checker to check capacitor C3 for a shorted or leaky condition. If C3 is defective the bias on V1 will decrease and the tube will be saturated. Also check resistor R1 using an ohmmeter. If R1 has increased in value the bias on V1 will increase, cutting the tube off.

If both signals are present on the control grids, check the plate and screen elements for the correct dc potential. If plate or screen voltage is abnormal check inductor L4 for nominal dc resistance using an ohmmeter. Also check capacitor C7 using an in-circuit capacitor checker.

If all the circuit components are found to be within tolerance check inductors L4 and L5 for the exact d-c resistance as specified in the equipment handbook. Also, use an in-circuit capacitor checker to check C8 and C9 for a shorted condition.

If it is verified that the circuit components are within tolerance and the correct voltages are applied to the tube elements and a no-output condition still exists, tune the primary and secondary of the output transformer T2 as directed in the equipment handbook.

Low or Distorted Output. A low or distorted output in converter stages could be caused by numerous defective components within the circuit; however, the two most likely causes would be either distorted input signals or improper bias voltage.

First, check the r-f and oscillator signals for correct amplitude and frequency using an oscilloscope equipped with a high impedance-high frequency probe. Be especially watchful for distorted waveforms caused by noise, hum, clipping, etc.

If the quality of the received r-f signal from the antenna (or r-f amplifier) is questionable, disconnect the antenna and inject the signal from an r-f signal generator and recheck the signal applied to the control grid. If the signal is distorted, check the tuning of the grid tank. Also, carefully inspect the grid tank ground connections for good electrical contact. A loose or intermittent ground connection would introduce hum and distort the signal.

If the oscillator signal shows signs of distortion, check the d-c resistance of tapped inductor L3 and resistor R1. Use an in-circuit capacitor checker to check capacitor C3 for a shorted or leaky condition.

If the input waveforms present on the control grids appear to be normal, check the output waveform in the plate circuit. (Use a d-c blocking capacitor in series with the oscilloscope probe). If the output waveform is clipped or small in amplitude, check the cathode and inner control grid for proper operating voltages. A noticeable 60 cycles hum in the output waveform could be caused by a cathode to heater short or high grid leakage.

If the waveform at the plate appears normal, but the output of the converter remains distorted, tune the output transformer T2 as specified in the equipment handbook.

PART B. SEMICONDUCTOR CIRCUITS

MIXERS.

The mixer circuit performs the function of a heterodyne frequency converter. As used in the superheterodyne receiver, the mixer serves to convert the received r-f signal to an intermediate frequency (i-f) which uses a fixed-tuned amplifier to obtain further amplification and selectivity before detection. In this application, two radio-frequency inputs are mixed together, and the output, usually at a lower radio frequency (the i-f), is applied to the intermediate-frequency amplifiers. However, the mixer circuit is not restricted to use in this manner; it can be used wherever it is desired to change, or convert, one frequency to another. The conversion of frequency can be from a lower to a higher frequency (used in VLF and LF receivers), as well as from a higher to a lower frequency (used in medium, HF, VHF, and UHF receivers). In VHF and UHF superheterodynes double, or even triple, conversion may be used to transform the original frequency to a lower i-f more suitable for obtaining the required selectivity with greater amplification than can be obtained at the signal frequency. The general data on mixers discussed in Part A, Electron Tube Circuits, in this section is also generally applicable to semi-conductor mixer circuits, and should be read as background before continuing with this discussion.

Where two r-f signals are applied to a semiconductor and the nonlinear transfer characteristic is used to produce heterodyne action, the circuit functions as a **mixer**. Where a single r-f input is applied to the semiconductor and the semiconductor furnishes a self-generated r-f oscillation for heterodyning, the circuit functions as a **converter**. In both the mixer and the converter, the heterodyning process is used to perform frequency conversion. The terms **mixer** and converter are sometimes used interchangeably, but they really define whether the circuit function involves only mixing or a more complex process.

Mixers in the semiconductor field are divided into two general groups - the diode and the triode (the few other types which exist are specially designed transistors). The diode mixer uses a conventional semiconductor diode to provide mixing without amplification. The triode mixer uses the diode junctions to provide mixing with amplification, and produces a greater output than the simple diode mixer. As presently used, the conventional semiconductor (crystal) mixer provides efficient frequency conversion up to about 1000 mc. For the higher frequencies, special microwave mixers are designed. The microwave crystal diode mixer functions up to the usable limits of the radio-frequency spectrum with a good signal-to-noise ratio (better than that of any other type of mixer). While the early crystal mixers were basically point-contact devices, today's mixers (with the exception of some microwave units) are grown or alloy junctions specially processed for low-noise performance. Tunnel diodes are also used for mixing, but they are generally employed as converters, with their negative-resistance characteristic being used to provide self-oscillation, as well as diode mixing; they will be discussed in a later part of this section, under autodyne converters.

In all of the mixers that are discussed in this section, the heterodyne process of beating together two r-f signals is employed. This heterodyne process has the unique ability to transfer all modulation components (including noise and hum) existing on either of the two signals to the output frequency or frequencies. The heterodyne process does not require signal detection and subsequent addition of the modulation to the new signal frequency. Instead, the conversion from one frequency to another with complete transfer of the modulation from the original frequencies to the output frequency is obtained simply and easily in a single circuit. This is the principle upon which the superheterodyne receiver is based. By heterodyning with the super (higher) frequency (usually obtained from a local oscillator), the original frequency is converted to a much lower frequency by the first detector or mixer. The resultant signal is then amplified, and unwanted signals outside the i-f pass band are removed by the response (selectivity) characteristics of the intermediate-frequency stages, after which it is finally detected in the so-called second detector.

The output of the mixer stage is always tuned to select only one band of frequencies, usually the lower or **intermediate frequency**, from the number of frequencies existing in the output circuit. Several frequencies are present in the output circuit, because the heterodyning, or beating together, of the r-f signal and the local-oscillator signal produces a number of beat-frequency combinations. Thus the output circuit contains the original frequency, the local-oscillator frequency, and the sum and difference of these frequencies, together with a series of other frequencies which are multiples (and submultiples) of these basic frequencies, generated by the heterodyning of the beats with the original signals and the other beat frequencies. Each beat multiple (or submultiple) has a reduced amplitude and need not be considered further. In the case of the first four frequency combinations, which have appreciable amplitude, it is a simple matter to provide a tuned circuit which will select the desired output frequency.

Except for reduced size and power consumption, the semiconductor mixer is comparable to the vacuum-tube mixer. In fact, it offers two important advantages over the vacuum-tube circuit: operation at higher frequencies and a lower noise level at the higher frequencies. The semiconductor mixer can operate at higher frequencies than the electron tube because the electron tube is limited at the higher frequencies by transit time effects (caused by relatively large spacing between the electrodes). Due to the thinness of the PN barrier layer, the diode is not subject to transit time effects until a much higher frequency is reached. Because of the increased random collisions of electrons due to thermal agitation (shot effect) in the electron tube, more noise is produced by a tube mixer than by the relatively cold semiconductor. As a result, semiconductor mixers are invariably used at the higher frequencies. The choice of types and classes of circuits used (diode, triode, etc) is purely a matter of design considerations. The following circuit explanations will discuss these considerations only where they are relevant to an understanding of circuit operation.

DIODE MIXER.

APPLICATION.

The semiconductor diode mixer is used in transistorized superheterodyne receivers in heterodyne frequency converter circuit arrangements to provide the intermediate frequency; and in electron tube high-frequency receivers to provide a low-noise r-f to i-f mixer. Special purpose applications include test equipment, microwave repeaters, and single-sideband transmitters, in which mixers are used for frequency conversion.

CHARACTERISTICS.

Requires a separate source of heterodyning voltage (local oscillator).

Uses nonlinear transfer characteristic of a diode to provide mixing action.

Conversion gain is less than one, and efficiency is high.

Signal-to-noise ratio is high (better than that of an electron tube).

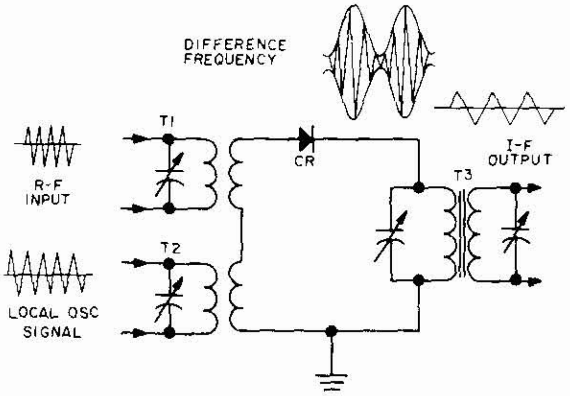
Heterodyne-signal (local oscillator) amplitude must be larger than received-signal amplitude for minimum distortion and best efficiency.

CIRCUIT ANALYSIS.

General. The semiconductor diode mixer is one of the simplest types of mixer circuits employed in frequency conversion. In this application, the two signal voltages to be heterodyned are supplied in series to the diode, and the mixer output voltage is obtained from a tuned-transformer arrangement. The output circuit is tuned to the intermediate frequency, which is usually the difference frequency between the two signals. Thus all other unwanted frequencies are rejected, and the i-f signal (which also contains the modulation components of the input signal) is supplied to the i-f amplifier for further amplification. The preceding discussion concerns the use of the mixer in receivers where the input signal is converted to a lower frequency. In very low frequency receivers, or in a sideband generator where the signal is generated at a low frequency and heterodyned to a higher frequency, the opposite condition exists, and the sum frequency is the output frequency. In each case, the circuit actions are the same, but the frequencies of interest are different.

Circuit Operation. The accompanying circuit schematic shows a simple diode type mixer.

In this circuit, T1 is tuned to the high frequency input signal, and T2 is tuned to the lower-frequency local-oscillator signal. The secondaries of T1 and T2 are connected in series, and the r-f input is superimposed on the local oscillator signal. The combined signals are effectively rectified by crystal diode CR, producing a difference frequency current in the primary of output transformer T3, connected in series between the cathode of the crystal and ground. Since T3 is tuned to the desired intermediate frequency, it offers a high impedance at that frequency, and thus serves as the load across which the output voltage is developed. The secondary of T3 is also tuned to the i-f signal, and together with the tuned primary, it provides a highly selective circuit with bandpass characteristics.



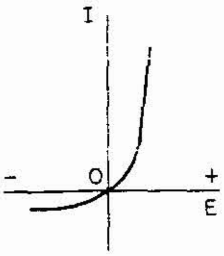
Diode Mixer

When the signal voltages in the secondary of T1 and T2 are in phase, they add and the voltage applied to the crystal is increased. When they are out of phase, the voltages subtract and the crystal input voltage is reduced. Since the two voltages are sinusoidal, the resultant signal will also be sinusoidal, and vary similarly. Because the new signal is a composite signal, its maximum and minimum amplitudes will occur at different times from those of the other signals. Thus the frequency of the new signal will be different from the original frequencies. Any intelligence existing as modulation (either AM or FM) on these carriers will be transferred to the new signal. Since the local-oscillator signal is unmodulated, the new signal will contain the modulation of the high-frequency received signal, together with any unwanted hum or noise components present on the local-oscillator signal.

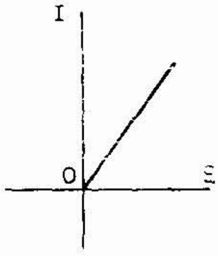
Since the crystal conducts only when its anode is positive with respect to the cathode, only the positive alternations are effective. Pulses of current are produced at the rate of the original signals plus the composite signal. This current flows through the primary of T3 and induces a voltage in the secondary of T3. Since both the primary and secondary of T3 are tuned, the greatest output voltage will occur at the frequency or over a range of frequencies for which the highest impedance is offered. Frequencies outside this band will be offered a low impedance, and little or no output voltage will be developed. Thus only the selected output frequency is obtained.

The basic principle of mixer operation is the use of the nonlinear transfer characteristic of the crystal diode to produce signal voltages in the output which did not exist in the input signal. At the same time, all modulation components present on the original signal must be effectively transferred to the new signals. The desired output frequency is then selected by a tuned circuit and separated from all the other unwanted frequencies. The manner in which this is accomplished is shown in the accompanying illustrations.

First, let us examine the transfer characteristic of a crystal diode and compare it with a linear characteristic, as shown in the accompanying illustrations.



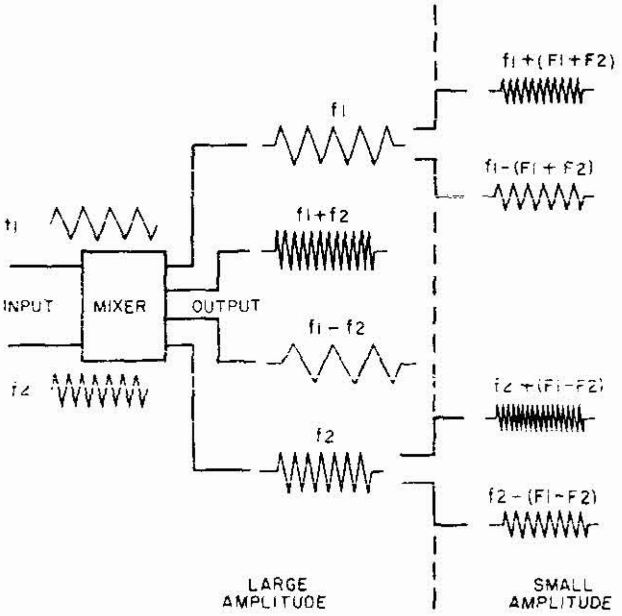
CRYSTAL DIODE
CHARACTERISTIC



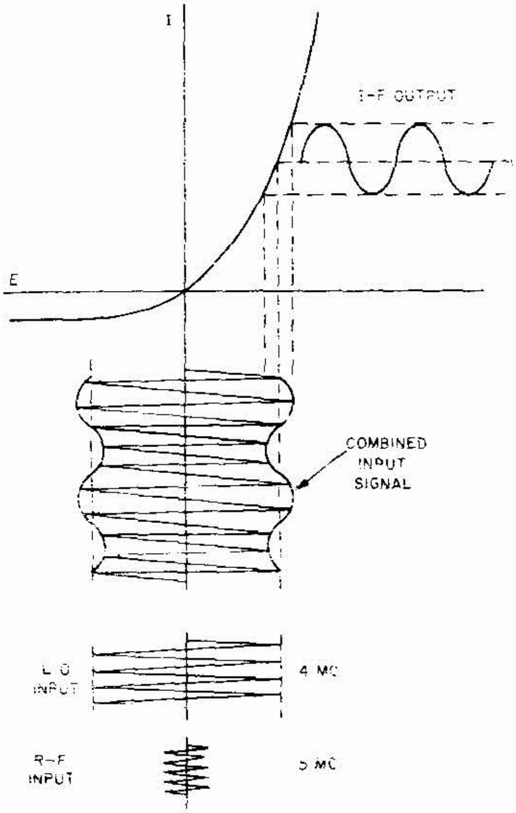
LINEAR
CHARACTERISTIC

As the input voltage to the crystal varies the current also varies, but not equally for all increments of input voltage. On the other hand, the ideal linear curve will result in equal current increments for equal voltage increments. If the diode voltage-current characteristic were linear, the input voltage would produce a current which, when passed through a resistor or load impedance, would produce an output voltage identical to the input voltage. Therefore, if two different voltages were applied as inputs, exactly the same voltages would be obtained in the output (except for a slight loss due to the resistance in the crystal). Thus, frequency conversion could not occur if the diode transfer characteristic were linear. On the other hand, when an input voltage is applied to the nonlinear diode, a distorted output is obtained. The distortion consists of signals which differ in frequency from the original signal. If two different signals are applied to the nonlinear diode, the output circuit contains distortion products for both signals. These extraneous signals are the sum and difference frequencies of the original signals, plus beats between the original signals and the distortion products (which are beat signals themselves), as illustrated below.

To produce the desired conversion with fidelity, one input (usually the input supplied by the local oscillator) must be larger than the other. This is easily accomplished by using the weak high-frequency input signal as the small signal, and the strong local-oscillator signal as the large signal. When the input voltage is large enough to appear at the point of greatest inflection on the diode characteristic curve, the best efficiency is obtained. The following figure illustrates the conversion transfer graphically. In effect, the small input signal at 5 mc modulates the large local-oscillator signal at 4 mc



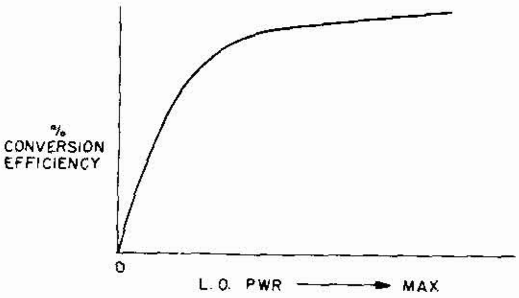
Mixer Output Waveforms



Development of Beat Signal

and produces a 1-mc beat signal, which rides on the local-oscillator carrier somewhat like a ripple voltage. The output circuit contains pulses for each positive cycle of the two input frequencies, plus the beat signal. Selection of the desired output frequency is obtained by using a tuned circuit as the load. The greatest output is developed, of course, at the beat frequency to which the load is tuned, and the other frequencies are effectively rejected.

The manner in which the conversion efficiency varies with local-oscillator signal amplitude is shown graphically in the accompanying figure. As can be seen the best efficiency is obtained for the strongest local-oscillator signal that can be handled by the diode. Since the detector output increases very slowly after the maximum inflection point of the characteristic curve is reached, the efficiency changes very little beyond this point. Thus there is a limit beyond which not much change of efficiency occurs if the local-oscillator power is increased. Note, however, that for very small signals the efficiency is low. In addition to low conversion efficiency when the input signal is of the same amplitude as the local-oscillator signal, extreme distortion is produced, because the beat signal varies from zero to a maximum of twice normal (in effect 100% modulation). In this case the circuit acts somewhat like a square-law detector. Little use is made of this circuit characteristic. Normally, the local-oscillator signal amplitude is fixed at about ten times the amplitude of the received signal.



Conversion Efficiency Variation

It is interesting to observe that the local-oscillator signal is always unmodulated; if both signals were modulated, the linear transfer of modulation would be annulled because of phase cancellation between modulation components. The normal transfer of modulation occurs linearly even though the beat is produced by deliberately distorting the r-f signal. This deviation from the normal rule of avoiding distortion is due to the large separation in frequency between the modulation (usually an audio-frequency signal) and the input and local-oscillator signals (which are always radio-frequency signals). The audio modulation varies at such a relatively slow rate that many r-f cycles can be lost without a noticeable change in fidelity; that is, any change in the amplitude of a single r-f cycle has little effect on the over-all operation.

Since the semiconductor diode will conduct in a reverse direction, it represents a lower-impedance load than the conventional electron tube diode, and it also has a lower forward resistance. Neither parameter, however, has any great effect on the operation of the diode as a mixer.

FAILURE ANALYSIS.

No Output. If the local-oscillator signal or the r-f input is missing, no i-f output will be produced. Both signals must be present to obtain frequency conversion. An open circuit in the input transformer (T1) or the local-oscillator transformer (T2) - either primary or secondary - will also render the circuit inoperative. A defective crystal may be checked by making forward- and reverse-resistance checks of the diode. The reverse resistance should be very much larger than the forward resistance. Since the proper functioning of transformer T3 is necessary to select the output signal, an open circuit in this transformer could also result in no output. Moreover, it is possible that mistuning of the input circuits could cause absence of one of the signals and produce a no-output indication. A resistance or continuity check of the transformers should be made to insure that the circuit is comp[illegible]te, and a test signal should be applied to the input t[illegible]terodyne with the local-oscillator signal while checks [illegible] made for an output signal in T3. It will be necessary t[illegible]se a VTVM with an r-f probe to determine whether the i-f voltage is present. With a modulated input to the mixer, an oscilloscope with an r-f probe can be used to observe whether the modulation appears in the output.

Low Output. A low-output condition can occur if the local-oscillator signal is equal to or less than that of the input signal. Such a condition could be caused by mistuning of T1 or T2. Substituting a test signal in place of the local-oscillator signal will quickly determine whether the oscillator output is low (if the proper value is known, the oscillator voltage can be measured with a VTVM and r-f probe). A similar result could be produced by the local-oscillator being tuned off frequency as a result of improper padding or alinement.

Other Conditions. Defective shielding or lack of proper lead dress after repair may permit the local-oscillator signal to leak into the preceding stages of the receiver and reduce the receiver sensitivity by producing a high avc voltage. Or it may allow the local-oscillator signal to feed back through the i-f and detector stages and cause birdies and unwanted signals. Such troubles will disappear when the local oscillator is temporarily disabled and a well shielded test-signal source is substituted in its place.

TRIODE MIXER

APPLICATION.

The transistor triode mixer is used in transistorized superheterodyne receivers to combine the incoming r-f signal with the local oscillator signal to produce the desired i-f frequency.

CHARACTERISTICS

Provides conversion gain.

Requires a separate local oscillator to provide the heterodyning signal.

Utilizes the nonlinear transfer characteristics of the transistor to provide heterodyning action.

The transistor is biased in the low current region where nonlinearity is high.

A relatively high signal to noise ratio is obtained.

Operates better at higher frequencies because of reduced transit time effects.

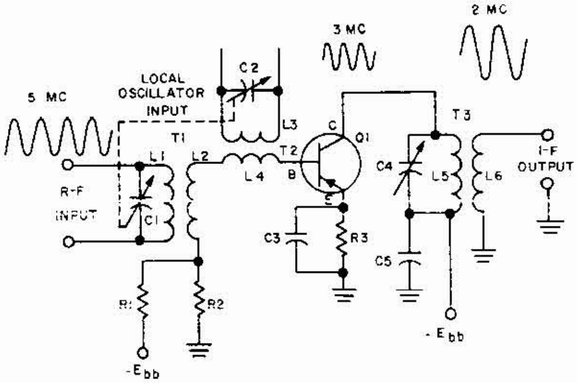
CIRCUIT ANALYSIS.

General. The purpose of the mixer stage is to convert the incoming r-f frequency usually into a lower frequency which contains the same characteristics (modulation) as the original r-f- frequency. This lower output frequency, called the intermediate frequency, or the i-f frequency, must remain the same for any r-f signal received within the range of the receiver for proper operation. The radio frequency is converted to an intermediate frequency by a process called heterodyning. When the input signal, along with another specific frequency referred to as the "local oscillator signal," is injected into the base (or emitter) of a transistor, four basic frequencies are obtained at the collector (although many other beat frequencies are also generated they are seldom used). These are the original two frequencies and the sum and difference of these inputs. A resonant tank in the collector circuit is tuned to the difference frequency, so that it will accept and pass this frequency on to the following stages and effectively attenuate all the other unwanted frequencies present.

There are also applications where an incoming signal is converted to a higher frequency, as in Very Low Frequency receivers and in Single Side Band generators, where the sum frequency instead of the difference frequency is used as the intermediate frequency. Circuit operation is the same for this application, the important change is that the output tank is tuned to the desired (sum) frequency.

The efficiency of frequency conversion in the transistor at lower frequencies is strongly dependent on the alpha rating or maximum usable gain capability of the transistor. Over the medium frequency range conversion output depends primarily on base resistance, and in the high frequency range conversion efficiency is limited by the amount of emitter reverse shunting capacitance, the less the capacitance the better is the performance. Conversion gain also influences the noise factor. At low frequencies the transistor is equal to a crystal diode with a transistor amplifier, while at vhf some gain may still be obtained, the noise is usually higher than that produced by the diode and transistor amplifier combination.

Circuit Operation. The accompanying diagram illustrated a typical common-emitter type triode mixer.



Common-Emitter Triode Mixer

As can be seen from a study of the schematic, resistors R1 and R2 form a voltage divider to provide base bias for Q1. Resistor R3, bypassed by capacitor C3, is a conventional emitter swamping resistor used to prevent temperature changes from altering transistor performance.

Winding L1 is the primary of T1, and, together with capacitor C1, forms a parallel resonant tank circuit tuned to the selected r-f signal frequency. This signal is inductively coupled to secondary L2 of T1. Transformer T2 injects the local oscillator signal on the base of Q1. Transistor Q1 is the nonlinear device used for heterodyning. The primary, L5, of transformer T3 together with C4 forms a parallel resonant tank circuit tuned to the difference (i-f) frequency, and capacitor C5 also shunts the unwanted frequencies remaining in the collector circuit to ground.

The bias voltage divider formed by R1 and R2 together with emitter resistor R3 biases transistor Q1 in the low current region of its dynamic transfer curve. Operation in this region provides good heterodyning action since considerable nonlinearity occurs here.

The received r-f signal is coupled through T1 in series with the local oscillator signal injected through T2, to the base of Q1. Since these two frequencies are different the phase relationship between them is constantly changing. This causes these two signals to constantly add or subtract algebraically so that amplitude variations appear on the collector at regular intervals in the form of a newly developed beat frequency. This beat frequency is the desired product of heterodyning the two signals and is called the intermediate frequency. If the received r-f signal is amplitude modulated the resultant i-f signal will have the same amplitude modulation characteristics (the modulation is transferred linearly from one signal to the other). Likewise, if the received r-f signal is frequency modulated the resultant i-f frequency deviates around a center frequency at the same rate as the original r-f signal deviated. See the introduction to Part A, Section 13 of this Handbook for a detailed discussion of frequency conversion. C1 and the tuning capacitor of the local oscillator are mechanically connected so that whenever C1 is turned to tune the r-f tank to a different frequency, the local oscillator frequency is, likewise, changed a corresponding amount. This results in a constant difference frequency being produced as the receiver is tuned over the entire range. The local oscillator signal amplitude is made approximately ten times that of the incoming r-f signal for efficient mixing. The resonant tank formed by the primary of T3, and consisting of L5 and C4 is tuned to the difference frequency or i-f. This resonant tank presents a high impedance only to the intermediate frequency and a maximum amplitude output signal is developed and inductively coupled to the secondary, (L6), of T3. Capacitor C4 which tunes the output tank circuit also presents a low impedance to the unwanted frequencies in the collector circuit, and they are shunted around L5 and bypassed to ground by C5. Normally this bypassing is sufficient. It has been noted, however, that in strong signal areas, and especially in all-wave types of superheterodyne receivers, that sometimes strong beat harmonic frequencies are generated which are of sufficient amplitude to appear somewhere in the tuning range. Since these signals seem to appear at non-harmonic frequency points on the dial they cause the operator to infer that this station is operating off-frequency. This effect depends upon the choice of the i-f, whether or not it is single or double conversion, and it also depends upon how well the shielding is effective, and varies from model to model. This effect is mentioned here to indicate the importance of selecting only desired frequencies.

FAILURE ANALYSIS.

General. When making voltage checks, use a vacuum-tube voltmeter to avoid low value of multiplier resistance employed on the low voltage ranges of the standard 20,000 ohm per volt meter. Be careful to observe proper polarity when checking continuity with an ohmmeter. Since a forward bias through any of the transistor junctions will cause a false low resistance reading.

No. Output. A no-output condition is usually indicative of a defective transistor, or an open base, emitter, or collector circuit. In the common-emitter circuit a shorted base or collector would also cause no output. These conditions can easily be found by resistance and continuity checks with an ohmmeter. To prevent false readings, be careful to observe proper polarity when checking resistance or continuity. Check the power supply voltage to make certain that loss of output is not due to a blown fuse or a defective power supply.

It should be noted that an i-f frequency could not be produced by the mixer if the local oscillator signal can not reach the base of Q1. Presence of this signal can be determined by simulating this signal with a signal of proper frequency from a signal generator and injecting it into the base of Q1. An output then would indicate a fault in either the local oscillator, or local oscillator coupling transformer T2. Trouble could then be localized to either the local oscillator or T2 by injecting the simulated local oscillator signal in the primary of T2. If this causes an output it would be safe to assume that the local oscillator is at fault. If signal injection into the base of Q1 produced an i-f output and injection into the primary of T2 did not, T2 can be assumed to be at fault. It should also be noted that failure of the local oscillator will cause very little noise to be present at the output of the receiver. In contrast, failure of the r-f stages would not greatly affect the noise present at the receiver output, but would prevent or greatly diminish radio reception.

Presence of the r-f input signal can be determined by utilizing the procedure described above and applying it to transformer T1.

If resistance and continuity checks reveal that all components are good but an output cannot be produced even when injecting frequencies from a signal generator it is possible that the output tank, the primary of T3 is badly mistuned or the trouble probably exists in the secondary of T3. Check the resistance of the secondary of T3 with an ohmmeter. If the trouble persists the defect could possibly be in the input circuits to the following stage.

Low Output. Low output could be caused by a change in bias or a defective transistor. Check DC bias levels with a vacuum tube voltmeter. With power removed, indications of improper bias should be followed up with resistance checks to determine the component at fault.

It should be noted that deterioration with age causing lack of gain may result under high temperature conditions. Unlike vacuum tubes, however, transistors have operated for years without noticeable deterioration under proper operating conditions.

Another possible cause of decreased output would be insufficient local oscillator signal reaching the base of Q1. This condition could be checked by tracing the local oscillator signal through transformer T2 to the base of Q1, with an oscilloscope, noting that the amplitude is sufficient on the primary of T2 and that there is not excessive attenuation through T2. Less likely though a still possible cause of low output would be insufficient r-f signal reaching the base of Q1. This condition could be isolated to the proceeding r-f stages or transformer T1 by using the procedure described above for checking the local oscillator signal. Should all the conditions necessary for proper operation be met, i.e., proper operating bias, good transistor and sufficient amplitude input and local oscillation signals, poor performance could be the result of mistuning of output tank T3. With an r-f input into the receiver try tuning T3 for a peak receiver output.

MICROWAVE DIODE MIXER.

APPLICATION.

The microwave diode mixer is used in superheterodyne radar receivers to combine, or "mix", the incoming r-f microwave signal with the local oscillator signal to produce the desired intermediate frequency (i-f) output signal. The microwave diode mixer is generally used in applications where signal-to-noise ratio is an important consideration or where transit time at very high frequencies becomes critical for other types of semiconductor mixers.

CHARACTERISTICS.

I-f voltage is linearly dependent upon signal amplitude, for signals small compared with the local oscillator power.

Transit time effects are minimized.

Overall noise figure is as low as 7db at frequencies up to 25,000 MHz.

Requires a separate local oscillator to supply the heterodyning voltage.

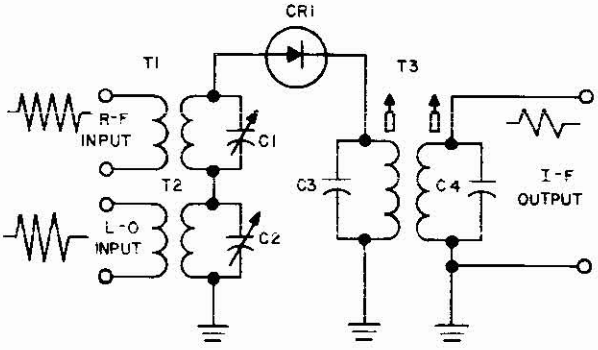
Output circuit is tuned to the i-f frequency.

Conversion gain is less than unity.

CIRCUIT ANALYSIS.

General. The crystal is the most effective element for the superheterodyne receiver at microwave frequencies. The operation of a crystal as a mixer is similar to that of the diode electron tube. Since a crystal is not an amplifier, there can be no conversion gain. The conversion loss is taken as the ratio of the available i-f signal power to the available r-f signal power. It varies with the circuit impedance but is normally about 6 to 10 db. Crystals are easily damaged, and voltages should not be applied which are greater than about 5 volts in the blocking (anode to cathode) direction or which result in more than about 1-vdc in a resistive load. In application, the desired r-f input signal and the local oscillator signal are applied in series to the microwave diode, and the mixer output voltage is obtained from a transformer tuned to the desired i-f signal so that it will pass this frequency and reject all other frequencies.

Circuit Operation. A simplified microwave diode mixer circuit is shown in the accompanying illustration.



Microwave Diode Mixer Equivalent Circuit

Transformer T1 consists of an untuned primary winding and a tuned secondary winding; Capacitor C1 and the secondary winding of T1 form a resonant circuit at the frequency of the received r-f signal. Transformer T2 is similar to T1, except that capacitor C2 and the secondary winding of T2 form a resonant circuit at the frequency of the local oscillator. The resonant circuits, shown in the schematic as T1, C1 and T2, C2, are actual L-C circuits composed of inductors and capacitors at radio frequencies.

Semiconductor CR1 is a point contact crystal diode used at microwave frequencies. Transformer T3 is a double-tuned transformer, with the primary and secondary circuits resonant to the intermediate frequency. This transformer has a bandpass characteristic which discriminates against frequencies above and below the desired output frequency.

When no r-f signal is applied to the input of transformer T1, but the local oscillator signal is applied to the input (primary) of transformer T2, semiconductor CR1 acts only as a rectifier. For this input condition, the current pulsations passing through the primary winding of the double-tuned transformer, T3, are those of the local oscillator frequency; however, the tuning of transformer T3 does not permit the local oscillator frequency to reach the output because of the bandpass characteristic of the transformer.

When the r-f and local oscillator signals are applied simultaneously to their respective tuned circuits, the two signal voltages are applied in series to semiconductor mixer diode CR1.

Since the two applied signals differ in frequency, the voltages are not always in phase with each other. Periodically these two voltages algebraically add or subtract to produce an amplitude variation at regular intervals; it is this periodic amplitude variation in the form of a beat frequency voltage which is of greatest importance. The beat frequency is actually the difference frequency produced by the instantaneous signal voltages as they combine to increase amplitude when approaching an in-phase relationship and to decrease amplitude when approaching an out-of-phase relationship.

Because the two sine-wave frequencies are superimposed, the mixer CR1 rectifies, or detects, both frequencies. As a result, pulsating currents which vary in amplitude at the beat frequency rate are produced in the primary winding of transformer T3. Thus a carrier envelope is formed which varies in accordance with the difference frequency. The pulsating currents forming the carrier envelope flow through the primary winding of transformer T3. Since the primary circuit is tuned, it presents a high impedance to the difference (i-f) frequency. Consequently, this frequency is passed by transformer T3, and the output voltage is induced in the secondary winding which varies in amplitude in accordance with the amplitude of the original r-f signal.

If the received r-f signal contains amplitude-modulation components, the beat difference will deviate at the same rates as the original r-f signal. Thus, the characteristics of the intermediate frequency signal are the same as that of the original r-f signal, except that the received signal has been changed to a lower frequency.

The output (i-f signal) voltage developed across the secondary tuned circuit of transformer T3 is applied to the succeeding stages where it is amplified and demodulated.

FAILURE ANALYSIS.

General. When making voltage checks use a VTVM to avoid the low values of shunting resistance employed on the low ranges of conventional voltohmmeters. Be careful to observe the proper polarity when checking continuity with an ohmmeter, since a forward bias through any of the diode junctions will cause a false low resistance reading.

No Output. Since the circuit of the microwave diode mixer is relatively simple, failure of the circuit to provide an output can be resolved to one of several possibilities. The resonant circuits T1, C1 and T2, C2 must be properly aligned to their respective frequencies. The double-tuned output transformer T3, must also be correctly aligned to the desired intermediate frequency. The presence of the desired r-f and local oscillator frequencies must be determined, since no output can be obtained from the mixer circuit unless both signals are applied to the mixer input circuits. One or more open windings in the transformers T1, T2, or T3 can cause a no-output condition, so these windings should be checked with an ohmmeter to determine whether continuity exists. Capacitors C1, C2, C3, and C4 can be checked with an in-circuit capacitor checker.

Low Output. If the tank circuits are not tuned to the proper frequencies, or if one of the capacitors should become leaky, a low output condition could occur. Check to see if the r-f, local oscillator, and i-f tank circuits are tuned properly, and check all capacitors for a leaky condition.

AUTODYNE CONVERTER.

APPLICATION.

The autodyne converter is generally used in transistorized radio receivers to convert the incoming r-f signal to an intermediate frequency (i-f), and amplify the i-f, for application to succeeding stages.

CHARACTERISTICS.

Uses a single transistor to provide the functions of these stages.

Acts as a local oscillator.

Acts as an i-f amplifier.

Acts as a self-contained mixer.

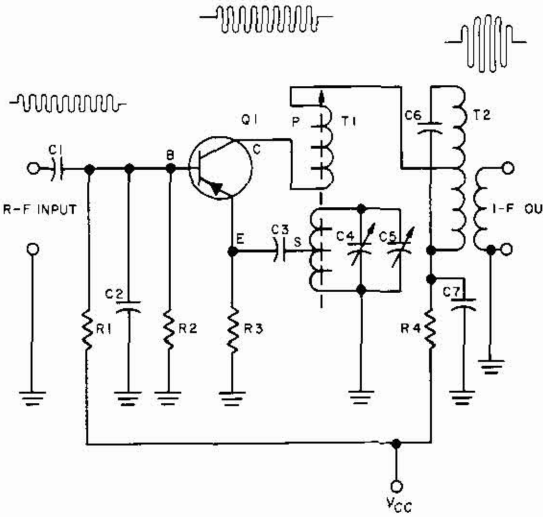
Has lower conversion gain than circuit using a separate oscillator.

CIRCUIT ANALYSIS.

General. The autodyne converter is used as a combination local oscillator, mixer, and i-f amplifier in transistorized radio receivers. In operation, random noise in the oscillator section produces a slight variation in base current which is amplified to a larger variation of collector current. This signal is induced into the secondary winding of a transformer tuned to the oscillator frequency, and is then fed back to the emitter circuit. With the feedback winding of the transformer properly phased, the feedback is positive (regenerative) and of sufficient amplitude to cause sustained oscillations.

In the mixer section, the transistor is biased in a relatively low current region, thus operating on quite non-linear characteristics. As the desired incoming r-f signal is tuned, it mixes with the local oscillator signal and provides at the output the following four signals; the original r-f signal, the local oscillator signal, the sum of the two, and the difference of the two. Because the i-f tank circuit is tuned to the difference of the two signals, it is this signal which is selected, amplified, and applied to the following stage.

Circuit Operation. The schematic of a typical autodyne converter is shown in the accompanying illustration.



Typical Autodyne Converter Circuit

Q1 is a PNP type transistor whose base is capacitively coupled to the r-f input by C1. Fixed base bias is supplied by the voltage divider consisting of R1 and R2 bypassed for r-f by C2 (see paragraph 3.3.1, base biasing, in Section 3 of this Handbook for a detailed explanation of biasing). Capacitor C3 couples the local oscillator tank circuit to the emitter of Q1, and also bypasses emitter swamping resistor R3 to prevent degeneration. The swamping resistor stabilizes the transistor against thermal current changes (see paragraph 3.4.2, bias stabilization, in Section 3 of this handbook for a detailed explanation of emitter swamping action). The secondary winding of T1 together with tuning capacitors C4 and C5 form the oscillator tank circuit, which is inductively coupled to the collector by the primary winding. Thus, feedback is obtained from collector to emitter to sustain oscillation. Another tuned tank circuit resonated at the i-f is formed by the primary of T2 and capacitor C6.

Collector voltage is obtained from the supply through dropping resistor R4, bypassed by C7 for undesired r-f and i-f signals. The secondary winding of T2 is inductively coupled to the primary to furnish the i-f output.

Since the autodyne converter provides three functions using one transistor it is discussed separately by function in the following paragraphs. These three separate functions can be supplied by the single transistor primarily because operation is at three different frequencies. Hence the oscillator is used to provide an i-f beat frequency, which, in turn can be mixed with the r-f input to furnish an amplified i-f output.

In operation, current flows through the transistor as determined by the biasing circuit. Internal noise or thermal variations initially produce a feedback voltage between the collector and the emitter which is in-phase with the input circuit. As the emitter current increases, the collector current also increases, and additional feedback between the windings of T1 further increases the emitter current until it reaches the saturation region, where the emitter current no longer increases. When the current stops increasing, the induced feedback voltage is reduced until there is no longer any voltage fed back to the emitter circuit. At this time, the field around the tank and tickler coils collapses and induces a reverse voltage into the emitter circuit, which causes a decrease in the emitter current, and hence a decrease in the collector current. The decreasing current then induces a larger reverse voltage in the feedback loop, driving the emitter current in the opposite direction, that is, to zero or cutoff. Although the emitter current is cutoff, a small reverse saturation current (Iceo) flows; this current has essentially no effect on the operation of the circuit, but it does represent a loss which lowers the overall efficiency. In this respect, the transistor differs from the electron tube, which has zero current flow at cutoff.

The discharge of the tank capacitor through the primary winding of the transformer causes the voltage applied to the emitter to rise from a reverse-bias value through zero to a forward bias value. Emitter and collector current again flows, and the previous described action repeats itself, resulting in sustained oscillations.

The tuning capacitors in the r-f and local oscillator tank circuits are mechanically connected, so that whenever one is varied, the other is varied by the same amount. This results in the local oscillator frequency and the r-f frequency always being separated by the same amount at any frequency which may be selected at the input. The amplitude of the local oscillator voltage is approximately ten times as great as the amplitude of the r-f signal, for efficient mixing, and the frequency is selected either above or below the r-f frequency, depending upon the application of the circuit, by an amount which is equal to the i-f frequency.

Since the two applied signals differ in frequency, their voltages are not always in phase with each other. Periodically, these two voltages algebraically add or subtract to produce an amplitude variation at regular intervals; it is this periodic amplitude variation in the form of a beat frequency voltage which is of importance. The beat frequency is actually the difference frequency produced by the instantaneous signal voltage as they combine to increase amplitude when approaching an in-phase relationship, and to decrease amplitude when approaching an out-of-phase relationship. When the incoming r-f signal contains amplitude modulated information, the resulting beat frequency also contains the same amplitude modulated information, and varies in accordance with the audio frequency modulating the incoming r-f signal. If the received r-f signal contains frequency modulated information, the beat frequency difference deviates at the same rate as the incoming r-f signal frequency. Thus the characteristics of the resulting i-f are the same as those of the original r-f signal, except that the frequency of the received signal is converted to a lower or higher frequency, depending upon the application.

As a result of the heterodyning action taking place within the elements of the transistor, the output signals present at the collector of Q1 are as follows: the r-f signal, the local oscillator signal, the sum of the two, and the difference of the two. Since the i-f transformer T2 is fixed tuned to the difference frequency, it is this frequency which is induced into the secondary winding and applied to the succeeding stages. All other signals are bypassed to ground through capacitor C7. The output signal present on the secondary winding of T2 contains all of the information that was present sent on the original r-f signal.

FAILURE ANALYSIS.

General. When making voltage checks use a vacuum tube voltmeter to avoid the low values of shunting resistance employed on the lower ranges of conventional voltmeters. Be careful also to observe the proper polarity when checking continuity with an ohmmeter, since a forward bias through any of the transistor junctions will cause a false low-resistance reading.

No Output. A no-output condition can occur from one of the following faults; a defective Q1, an open C1, R4, or R3, open windings on T1 or T2, or if capacitors C2 or C7 are shorted. Be sure that the supply voltage is correct before performing any checks. If Vcc is not correct, the trouble is probably not in the autodyne but in the power supply.

If an r-f signal is present at the input to the circuit, check for the r-f signal at the base of Q1, if the signal is not present, C1 is defective. If the signal is present on the base of Q1, check for the signal on the collector of Q1; if it is not present, Q1 is defective, R3 is open, C3 is shorted, or T1 or T2 has an open winding. Check R3 and T1 and T2 with an ohmmeter. Check C3 with an in-circuit capacitor checker. If the signal is still not present on the collector of Q1, Q1 is probably defective.

Low Output. A low-output condition may arise from the components in the circuit changing value, the oscillator not being tuned properly, shorted turns in the transformers, a change in bias voltages, a defective Q1, or mismatched impedances.

Check for the proper oscillator frequency on the emitter of Q1. If the oscillator frequency is not present, C3 is defective. If the oscillator frequency is incorrect, tune the tank circuit to the proper frequency. Check for the proper bias voltages on Q1. If the bias voltages are incorrect, check the components in the circuit which have an improper bias.