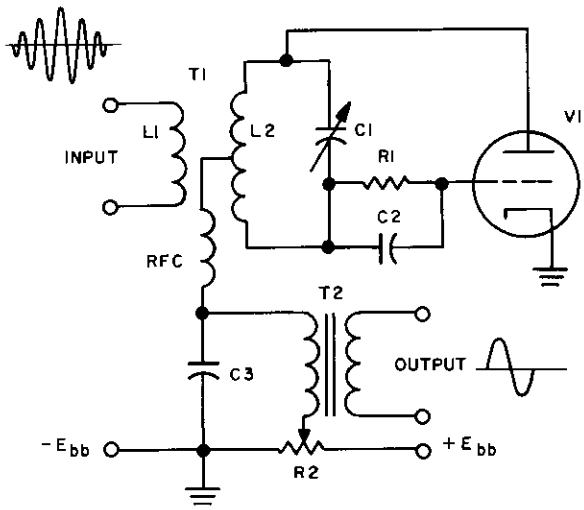
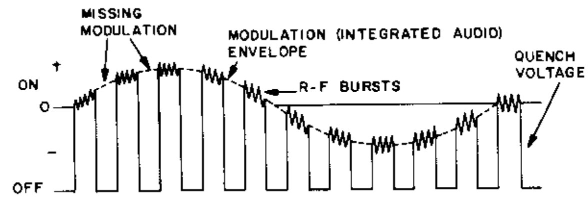


Typical Self-Quenched Super-Regenerative Detector

flows from cathode to grid and back to ground via grid-leak R1, charging grid capacitor C2 negatively. This negative grid bias, in turn, causes a slight reduction in plate current, and a consequent rise in plate voltage. When the carrier is modulated by an audio signal, the grid bias varies at an audio rate in accordance with the modulation. When the grid bias increases, the plate current decreases. So far, this is conventional grid rectification and detection. In the regenerative detector this change of plate current induces a field around tank coil L2 which produces an in-phase voltage in the grid portion of the tank coil. Hence, as the plate current decreases a positive voltage is fed back to the grid, and causes still smaller plate current to flow. In the conventional regenerator, this feedback is limited to an amplitude which is just below the point where continuous oscillations are produced. Consequently, even though this type of regenerative feedback results in a gain, it is not as large a gain as could be obtained if the circuit were prevented from oscillating until a larger feedback amplitude was obtained. Such action is accomplished in the super-regenerator by developing a low frequency oscillation in the grid circuit known as the **quench** voltage. In the self-quenched circuit described above, the quench voltage is obtained by using a large grid-leak resistance and capacitance to provide a long time-constant. Because of the large time-constant very little voltage can leak off capacitor C2 during the negative portions of each r-f input cycle, so a cumulative build-up in negative bias voltage develops as the input signal is applied, until the bias is sufficiently large to drive the grid to plate current cut off and beyond. When C2 is charged to this cut-off voltage, grid and plate current flow ceases while capacitor C2 discharges through the long time-constant grid-leak. During this discharge period the detector circuit is inoperative.

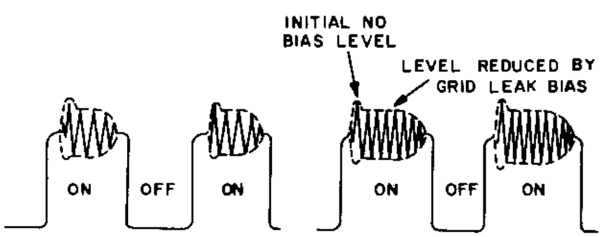


Output Waveforms

Thus, the action consists of an ON period followed by an OFF period. During the ON period the audio output is developed, while during the OFF period no output is developed, although this action results in a signal consisting of chopped up pieces of the original modulation, the modulation frequencies are very low in comparison to the operating frequencies (cycles compared with megacycles), so that only a small portion of the modulation is lost during any one OFF cycle, as shown in the exaggerated waveform in the accompanying illustration. It is evident that the overall waveform shape is retained, but a ripple component at the **quench** frequency is introduced. This ripple of quench voltage is filtered out by capacitor C3 which bypasses it to ground. Thus, only the audio frequencies pass through the primary of output transformer T2, and induce an output voltage in the secondary. Since the output waveform is chopped up and is not exactly the same as the input waveform, distortion is produced (this is in addition to any normal distortion caused by grid-leak detection). Thus, it is evident that the output of the super-regenerator must always contain more distortion than in the ordinary regenerative detector. However, this inherent distortion is somewhat nullified by the large gain possible through super-regeneration. The gain is of the order of one hundred times or more than that of the ordinary regenerative detector.

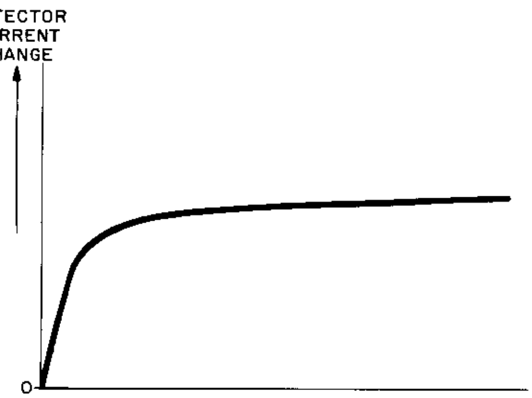
When a separate quench oscillator is used, it is connected in series with either the grid or plate circuit, and the grid-leak values are changed to provide additional gain, since the tube does not have to develop its own quench voltage. However, for the sake of economy and simplicity the single tube self-quenching circuit is usually used. Since the super-regenerator is unique in its action, operating at very high frequencies, at low frequencies and at audio frequencies practically simultaneously, it is necessary to examine the operating sequence more closely to completely understand operation. First consider the quench voltage, regardless of whether or not it is externally supplied, or is generated internally, it primarily serves to gate the grid circuit. During the positive half cycle it permits operation, and during the negative half cycle it reduces operation to almost zero. At the same time, this quench voltage control permits the circuit to oscillate at a very high frequency (the tuned tank frequency) during the conducting half cycles and prevents these oscillations during the non-conducting half cycle. In the self-quencher, the off period allows time for the grid-leak network to discharge, so that a train of r-f pulses may be generated during each on-period. Grid-leak bias is developed by rectifying the positive half cycles of this train of r-f pulses each time they cause a flow of grid current. Thus, the grid-capacitor is charged negatively at an r-f rate, and since the discharge time constant is longer than the charge time constant (the conduction of grid current presents a low resistance charge path), the charge cannot leak off the grid between r-f pulses and, therefore, builds up and eventually reaches cutoff bias. This cut-off bias point in the self-quencher determines the start of the off-period, and the tube is held inoperative during this period until grid capacitor C2 discharges through the large grid-leak resistance.

It is important to note that during the on-period r-f oscillations occur at the tank frequency, regardless of whether or not an input signal is applied. This action occurs because of the large feedback from plate to grid. Thus, in the absence of an input signal, the tank circuit is started oscillating by random current flow in the tube due to noise, which through feedback quickly builds up to a high amplitude and develops a d-c bias across the grid-leak. This grid bias, in turn, reduces the amplitude of the r-f oscillation slightly and maintains it at this value for the remainder of the on-period. When an input signal is applied, the amplitude of the r-f oscillation does not change, but instead, the oscillation starts sooner (it has the signal to help it), and the duration of oscillation for the on-period lasts for a slightly longer time than without an input signal, as shown in the accompanying illustration.



Typical Grid Waveforms

Since a negative grid bias is produced by the rectification of this r-f oscillation, the plate current is decreased slightly when a signal appears. Because the high-frequency oscillations exist even when no input signal is applied, the output response is limited to the average change of plate current which can occur from the start of the on-period to the beginning of quiescent oscillation. The result is that if the incoming signal is strong enough to mask out the hiss noise, there is little difference between weak and strong signals, since the detector output current varies logarithmically as shown in the accompanying graph. As a result, large amplitude noise variations caused by ignition interference, static, and similar impulse sources are also reduced in intensity. What would be a loud crash in the conventional detector appears as a rather small noise in the super-regenerator, and can be more easily tolerated without distraction from the desired signals. In a similar manner, small variations in amplitude caused by low percentages of modulation produce weak and unreadable signals, while the large variations in 100 percent modulated signals are sufficient to produce an appreciable output.



Detector Response Characteristics

The amount of feedback and plate voltage is controlled by potentiometer R2. For larger feedback and greater amplification the plate voltage is increased, while for less amplification and feedback it is reduced. For each setting of the control the r-f oscillations will reach a maximum value limited by the saturation voltage for this operating condition, and fixed by the developed grid-leak bias.

FAILURE ANALYSIS.

No Output. A defective tube, loss of plate voltage, or open or shorted input or output circuits will cause a loss of output. Use a high resistance voltmeter to measure the supply and plate voltages and eliminate the possibility of an inoperative power supply or blown fuse. Since the plate voltage will depend on the position of plate potentiometer R2, it is good practice to vary R2 over its range to determine whether or not an output can be obtained. If R2 is open at some point between the slider and ground, the plate voltage will be higher than normal, if open on the slider side there will be no voltage (provided T2 primary and the RFC and upper half of coil L2 have continuity). No voltage for any setting of R2 indicates that T2 primary, the RFC, or coil L2 is open. Check for continuity with an ohmmeter or measure voltage to ground. If there appears to be sufficient plate voltage present, check the values of the grid-leak resistor and capacitor using a voltohmmeter and an in-circuit capacitance checker. Check L2 for possibility of a defective tuning condenser C1 which will usually create a noise when rotated, if shorted. If still no output exists it is possible that T2 secondary is open or shorted. Place a pair of headphones across the primary winding or couple a speaker to the primary by a coupling capacitor. Any output indicates the secondary of T2 is at fault. Note also, that if C3 is shorted, plate voltage will appear about normal but no output will occur because of the shorted load winding. However, this condition usually is determined at the time that continuity checks are made of L2, T2, and R2. It is important to note that lack of an input signal will not result in a no-output condition, since the circuit will still operate, and produce a hiss.

Low Output. A low or reduced output can be caused by a weak input signal, a partially shorted input circuit, an improperly modulated signal, a defective tube, low plate voltage or a defective output transformer, T2. Signals below the threshold level for detection and those signals with low percentages of modulation (say 50% or less) will not be detected, this is normal operation. If, however, the signal is weak because of an open or a partially shorted input transformer, it can be found by checking the coils with an ohmmeter. Likewise, with a low plate voltage indicated on the voltmeter, both feedback and output will be low. If the trouble is not in the plate supply, most likely bypass capacitor C3 is at fault and leaky, check it with an in-circuit capacitance checker. Check the values of the grid-leak and grid capacitor, using an ohmmeter and capacitance checker. Continued low output indicates L1 is either open or partially shorted.

Distorted Output. The output will normally be somewhat distorted, particularly on voice peaks, however, the signal should be intelligible. If distortion is such that the voice is badly garbled, improper biasing is usually the cause. Check the grid-leak resistor with an ohmmeter and the grid capacitance with an in-circuit capacitance checker. To eliminate the following audio stages from suspicion, place a pair of headphones across the primary of T1. If the distortion disappears, the distortion is caused by the audio amplifier stages after the detector.

PRODUCT DETECTOR.

APPLICATION.

The product detector is universally used as a detector for heterodyning and demodulating single-sideband transmissions in modern communications type receivers.

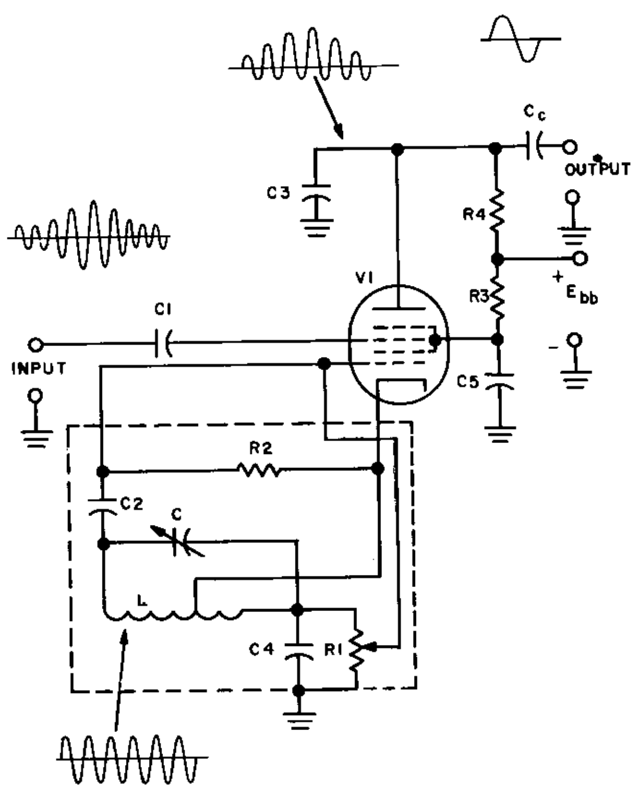
CHARACTERISTICS.

Is usually self-biased.
Operates as a combined heterodyne mixer and detector.
Has excellent selectivity.
Offers a slight improvement in gain.
Is more linear than the diode detector.

CIRCUIT ANALYSIS.

General. The product detector can be considered a form of heterodyne mixer with an audio output instead of the usual r-f output. The purpose of this detector is to mix locally generated low frequency carrier oscillations with the incoming r-f sideband signals to generate beat notes in the audio frequency range. For single-sideband the beat varies in both pitch and amplitude, producing the detected audio. The product detector may also be used for code reception using the beat frequency oscillator (BFO) to produce a single-tone audio beat. The use of mixing to develop the beat signal reduces the tendency to grid-block, when strong signals from a local oscillator are applied to the grid simultaneously with a weak input signal. Ordinary double-sideband AM signals can also be detected with the product detector, provided the BFO is tuned to zero-beat. When used with a strong BFO input and a weak signal input **exalted carrier** reception is simulated. With a strong (exalted) local carrier inserted, phase cancellation of the sideband frequencies during fading is minimized, as the local BFO substitutes for and fills in the carrier. Although during extreme fading this represents an improvement in ordinary AM reception it has the disadvantage that it is usually necessary to continually adjust the local BFO fine tuning control to keep the local oscillator at zero beat. Otherwise, the steady CW beat note produced by the two carriers (input signal and BFO) beating together garbles the signal.

Circuit Operation. While there are a number of product detector circuits, one of the most prevalent in use is the typical pentagrid converter illustrated in the accompanying schematic.



Pentagrid Product Detector

A single pentagrid tube is connected as a heterodyne converter, with the triode portion connected as a simple series-fed Hartley oscillator and operating as the beat frequency oscillator (BFO) to supply a carrier signal. The r-f input with its carrier missing is injected in mixer grid no. 2, which is shielded by the screen construction around it, and the audio output is taken from the plate of the pentode section. Tuned tank L and C is connected in a Hartley circuit with V1, and the lower end of the tank is bypassed to ground by C4, while C2 is the grid capacitor with R2 acting as a shunt grid-leak to supply the bias for the oscillator. The screen receives its supply voltage from dropping resistor R3 from the plate supply. Capacitor C5 bypasses the screen to ground and effectively connects it to the lower end of the tank thereby forming the triode oscillator portion of the circuit. The BFO signal is electron-coupled to the pentode section by electron flow from cathode to screen and plate. The input signal is capacitively coupled through C1 to the mixer grid, and R1 is the d-c return resistor supplying grid bias for the mixer grid. This resistor is made adjustable to set operation at the proper point for complete mixing and reduction of intermodulation distortion from input signals. The BFO signal is thus mixed with the r-f input signal and is heterodyned to produce audio beat signals, which vary in accordance with the modulation of the r-f input signal. Since the plate of V1 is bypassed to ground for rf by C3, only the audio frequency current variations appear in the plate circuit. These audio current variations develop an output voltage in passing through load resistor R4, and thus develop the audio output which is coupled through Cc to the following audio amplifier stage.

With no signal applied, V1 rests in its quiescent state with the triode section oscillating at the i-f (carrier) frequency, and with no input signal there is no output developed. Operation of the BFO is by feedback through tank coil L between the grid and screen (plate) to supply a continuous feedback from screen to grid and produce continuous oscillations at the frequency determined by the tuning of tank capacitor, C. Since C4 has a low r-f reactance to ground, and C5 which grounds the screen also has a low reactance to r-f, the screen is effectively connected to the lower end of the tank. During the oscillation period, grid-leak network C2 and R2 alternately charge and discharge. During the conduction period on positive half-cycles the grid capacitor is negatively charged, and develops a Class C bias on the grid of V1 through grid current flow from the cathode through R2 to ground. On the negative half of the oscillation, grid capacitor C2 discharges to ground through grid-leak R2, so that the bias is reduced to a value which will permit conduction on the next positive r-f excursion. Meanwhile r-f is supplied to the circuit by the tank during the non-conducting period thus producing continuous oscillation at the tank frequency. (See Chapter 7 in this Handbook for a complete discussion of Hartley oscillator operation.)

When an input signal is applied to the mixer grid of V1 through coupling capacitor C1 the input signal appears on the mixer grid. During the positive half-cycle of the input signal plate current flow is increased, and during the negative half-cycle it is decreased. As the electron flow from cathode to plate occurs, the electrons pass through the screen, and the BFO oscillations are heterodyned with the input signal to produce an audio beat note in the plate circuit. A portion of these electrons also flows through the mixer grid and return resistor R1 to provide bias for the mixer grid. Since the pentode section of V1 is connected as an amplifier, this bias fixes the operating point of the number 2 (mixer) grid at the position for maximum undistorted operation (usually in the Class A region). However, when undesired signals close to the tank frequency are strong, the strong signals tend to over-ride the weaker signal and cause response to both signals regardless of the tuning of tank capacitor C. Therefore, if R1 is adjusted to produce clear undistorted reception on the strongest signal, weak signals will not be pulled in frequency and the strong signal will not cause saturation and produce intermodulation distortion. The change in plate current caused by the input signal alternately increasing and decreasing plate current flow through load resistor R4 develops an output voltage across R4. Since C3 bypasses any r-f signal component and any BFO signal component to ground, only the audio beat note will be effective in producing output voltage across the load. Thus, the modulation amplitude variations of the r-f sideband signal, in effect, modulate the oscillating electron stream and produce the output. If the BFO stopped oscillating there would be no output, since there would be no beat note developed between the low frequency i-f signal and the high frequency r-f signal to produce audio variations in the electron stream between cathode and plate.

Although R1 is shown as variable in the schematic, some circuits use a fixed value of resistance which, together with screen resistor R3, is selected to provide optimum operation. In other circuit variations a separate BFO is employed and pentagrid tube V1 is connected as a simple mixer with both control grids biased to operate as amplifiers, so that only a simple mixing function is accomplished. The combined circuit discussed above represents a saving in tubes and economy of circuit components, hence its more prevalent use. Regardless of circuitry, the two signals are always heterodyned to produce a beat output which is in the audio range and thereby demodulates the sideband signal.

FAILURE ANALYSIS.

No Output. Loss of plate or screen voltage, lack of oscillation in the triode section of V1, an open or shorted input or output circuit, as well as a defective tube can produce a loss of output. Check the plate and screen voltages with a high resistance voltmeter, to make certain that a faulty supply or blown fuse is not at fault. If plate voltage is lacking, either R4 is open or C3 is shorted. Likewise, if no screen voltage is present, either R3 is open or C5 is shorted. Measure the resistors with an ohmmeter and check the resistance to ground across the capacitors, or use an in-circuit capacitance checker to check for shorts, leakage, and proper value. Determine if the BFO is oscillating, and if there is an input signal. Use an oscilloscope and an r-f probe connected between the no. 1 grid and ground to check that oscillation occurs. An alternative procedure is to use a high-resistance voltmeter, and place a 1-megohm resistor in series with the probe, and measure the voltage across grid-leak R2. If oscillating, usually a 10-volt or better indication is obtained and, in addition, when grid-leak is shorted with your fingers the oscillation will cease as indicated by a drop in voltage to about 1 volt or less. If oscillations do not occur check coil L for continuity, and tuning capacitor C for a short or leakage (use an in circuit capacitance checker). Check grid-leak R2 for proper resistance value and C2 for leakage and proper value. If still no oscillation, check C4 for an open circuit (if shorted it would still oscillate). With the BFO operating it is still possible that R1 is shorted and is by-passing the input to ground through C4, or for C1 or Cc to be open, check each capacitor with a capacity meter. Usually it is only when the BFO is not oscillating that a true no-output condition occurs, and the set sounds dead. If the BFO is working and only the input signal is missing, there will probably be some hum or occasional noise noticed, except of course if output coupling capacitor Cc is open.

Low Output. Low plate or screen voltage, a defective tube or a change in some parts values can produce a weak output. Measure the plate, screen, and supply voltages with a high resistance voltmeter. Low voltage indicates that C5 or C3 is leaky or that V1 is shorted and drawing larger than normal current. Check the capacitors with a capacity checker. With normal plate and screen voltages check the voltages on both grids with an oscilloscope and an r-f probe. On some detectors it is still possible to get a weak output even though the BFO is not operating. Also check the adjustment of R1 since the signal may be biased off too far and provide a weak output. Normally both the oscillator and incoming signal should be about the same level, but in no case should the BFO voltage be greater than the r-f sideband voltage. Check also the setting of the receiver RF GAIN control since it may be set too low.

Distorted Output. If the input signal is too strong, the detector can be overloaded and cause distortion, make certain the receiver R-F GAIN or AVC system is holding the input signal to the proper level. Also check the adjustment of R1, since if it is set up for weak signal reception the detector will overload and distort on strong signals. When it is adjusted so that the strongest signal is clear, the weaker signals will still be readable. It is also necessary that the receiver be tuned to the proper sideband in single-sideband reception otherwise, the modulation may be present but inverted and be garbled and unintelligible. In this case on a receiver equipped with upper and lower sideband switching, placing the switch to the opposite sideband position will eliminate the distortion. Since it is necessary to keep the inserted carrier within 10 to 12 cycles of the proper frequency, slight frequency instability in the receiver local oscillator may constantly keep the station frequency drifting. This will show up as distortion which disappears as the BFO tuning is slightly readjusted. In the last case the trouble exists in previous receiver stages, not the detector. It is, however, advisable to check the BFO for drift first using a stable primary standard, if available.

FM (OR PM) DETECTORS.

The process of detection (demodulation) removes the modulation (transmitted intelligence) from a received r-f signal and transforms it back to its original form so that it may be used for communications or other purposes. While the AM detectors explained previously in this section of the Handbook are used to demodulate an amplitude-modulated (AM) r-f signal, the FM detectors explained in the following paragraphs are used to demodulate a frequency-modulated (FM) r-f signal. Because of the similarity between a frequency-modulated (FM) signal and a phase-modulated (PM) signal, FM detectors may also be used (with minor circuit changes or adjustments) to demodulate a phase-modulated signal.

Although the circuits used in FM transmission and reception are more complex than those used in AM, FM has a number of advantages which far outweigh this disadvantage. An important advantage of FM over AM is the reduction of distortion due to natural and man-made noise. Most noise occurs in the form of amplitude variations in the r-f signal, and in AM, the intelligence is also carried by the amplitude variations. The AM receiver can not distinguish between the amplitude variations caused by the intelligence and those caused by noise, and consequently reproduces both the noise and the intelligence. In FM however, the intelligence is carried by frequency variations in the r-f signal and the FM receiver is designed so that it does not respond to amplitude variations. Consequently, the noise is not reproduced in the FM receiver output. Another important advantage of FM over AM is the possibility of wide-band transmission. Because of the higher carrier frequencies normally used in frequency modulation, it is possible to use a much wider band of modulating frequencies. This allows FM to be used for such applications as high fidelity transmission (such as in the FM broadcast band) and for multichannel communications (such as in commercial communications). Moreover, FM transmitters can also be designed to produce a narrow-band output signal (comparable to AM band-width) when it is desired to operate many FM transmitters within a small portion of the frequency spectrum.

The FM signal contains the transmitted intelligence in the form of instantaneous frequency variations to a constant amplitude r-f signal. Therefore, to demodulate the received FM signal without distortion, the FM detector must convert these frequency variations into voltage variations which are identical to the variations in the original modulating voltage. Any variations in the amplitude of the received FM signal are the result of unwanted noise or fading, and will result in distortion of the output signal if passed through the FM detector. Therefore, the FM detector must respond to input frequency variations, but not to input amplitude variations.

Three types of FM detectors are presently in common use: discriminators, ratio detectors, and gated-beam detectors. Discriminator circuits exhibit excellent response to frequency variations, but also respond to amplitude variations, and therefore, must be preceded by limiters to ensure that the discriminator input is of constant amplitude. Ratio and gated-beam detector circuits exhibit slightly poorer response to frequency variations than discriminator circuits, but when properly adjusted, do not respond to amplitude variations. Therefore, ratio or gated-beam detectors are used when economy and simplicity are desired, and some distortion can be tolerated. Discriminators are used when an extremely distortionless signal is desired, or precise control of frequency (AFC) is needed.

FOSTER-SEELEY DISCRIMINATOR.

APPLICATION.

The Foster-Seeley discriminator is used as the detector in high quality FM receivers to demodulate the received r-f signal, and in automatic frequency control (AFC) circuits to transform frequency changes into d-c control voltage changes.

CHARACTERISTICS.

Converts instantaneous frequency variations into instantaneous d-c voltage variations.

Employs a double-tuned transformer and two diodes.

Has very low inherent distortion.

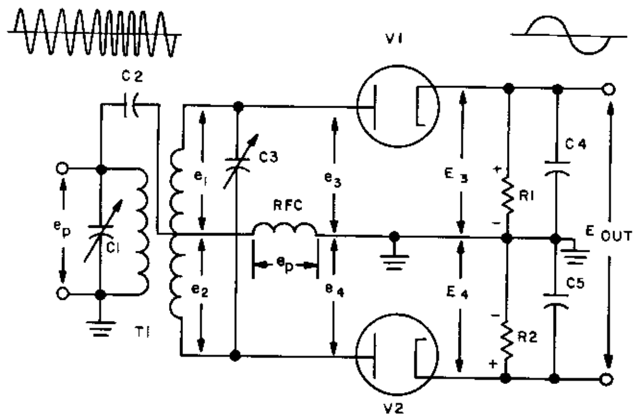
Must be preceded by a limiter since the output is affected by input amplitude variations.

CIRCUIT ANALYSIS.

General. The Foster-Seeley discriminator (also known as the phase-shift discriminator) uses a double-tuned transformer connected in such a way that the instantaneous frequency variations of the input FM signal are converted into instantaneous amplitude variations. The amplitude variations are then rectified and filtered in a manner similar to that employed in AM detectors to provide a d-c output voltage which varies in amplitude and polarity as the input signal varies in frequency. The output voltage is zero when the input frequency is equal to the **center frequency** (unmodulated carrier frequency). When the input frequency rises above the center frequency, the output voltage increases in one direction (for example, become more positive), and when the input frequency drops below the center frequency, the output voltage increases in the other direction (for example, becomes more negative). The specific polarity of output voltage obtained for an increase or a decrease in input frequency is determined by the design of the circuit and may vary in different circuits.

The output of the Foster-Seeley discriminator is dependent not only on the input frequency but also, to a certain extent, on the input amplitude. Since variations in the amplitude of the FM signal are due to unwanted noise or fading, they must be prevented from reaching the discriminator. Therefore, the discriminator is normally preceded by a limiter stage. The limiter produces an output of constant amplitude regardless of variations in the input amplitude, and thus, effectively removes the noise from the received FM signal. (Refer to section 15 of this Handbook for a complete explanation of limiter circuits.)

Circuit Operation. The accompanying circuit schematic illustrates a typical Foster-Seeley discriminator.

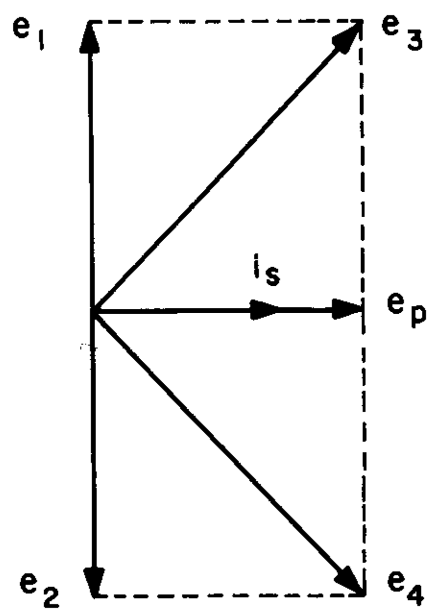


Foster-Seeley Discriminator

The input tank circuit, made up of capacitor C1 and the primary winding of transformer T1, is tuned to the center frequency (f_R) of the received r-f signal. Capacitor C3 and the secondary winding of transformer T1 also form a tank circuit tuned to the center frequency. Capacitor C2 couples the input signal to the center tap on the balanced secondary winding of transformer T1, which is returned to ground through radio-frequency choke RFC to form a dc return path for the diodes. Diodes V1 and V2 rectify the signal from the secondary tank circuit and develop opposing voltage drops across load resistors R1 and R2, respectively. Capacitors C4 and C5 are r-f filter capacitors which remove any remaining r-f signal from the output. The output is taken from across the series combination of the two load resistors (from the cathode of V1 to the cathode of V2).

The operation of the Foster-Seeley discriminator can be best explained with vector diagrams which show the various phase relationships between the voltages and currents in the circuit. The accompanying vector diagram illustrates the circuit phase relationships when the input frequency (f) is equal to the center frequency (f_R).

The input voltage applied to the primary tank circuit is shown as vector e_p on the diagram. Since coupling capacitor C2 has negligible reactance at the input frequency, and r-f choke RFC is effectively connected in parallel with the primary tank circuit, voltage e_p also appears across the choke. When voltage e_p is applied to the primary winding of transformer T1, a voltage is induced into the secondary winding which causes current to flow around the secondary tank circuit. When the input fre-

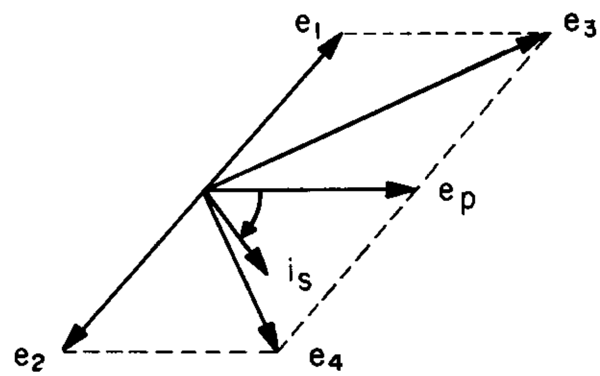


Vector Diagram at Resonance

quency is equal to the center frequency, the tank is at resonance and acts resistive. Therefore, tank current is is in phase with primary voltage e_p, as shown in the vector diagram. The current flowing in the tank causes voltage drops to be produced across each half of the balanced secondary winding of transformer T1, which are of equal magnitude and opposite polarity with respect to the center tap of the winding. Since the winding is predominately inductive, the voltage drop across it is 90° out of phase with the current through it. Because of the grounded center tap arrangement, the voltages to ground at each end of the secondary winding are 180° out of phase, and are shown as e_1 and e_2 on the vector diagram.

The voltage applied to the plate of V1 consists of the vector sum of voltages e_p and e_1 shown as e_3 on the diagram. Likewise, the voltage applied to the plate of V2 consists of the vector sum of voltages e_p and e_2, shown as e_4 on the diagram. Since at resonance there is no phase shift, voltages e_3 and e_4 are equal as shown by the same length vectors. Equal plate voltages on diodes V1 and V2 produce equal plate currents, and with identical load resistors produce equal and opposite voltages (E_3 and E_4) across R1 and R2, respectively. Thus capacitors C4 and C5 are charged to equal voltages, and, since these voltages are of opposite polarity, the output voltage at resonance is zero. Since the opposite ends of the secondary winding are out of phase, only one diode conducts at a time, and conduction occurs as a series of d-c pulses occuring at the center radio frequency. Although the output of the diode is a direct current it contains a ripple component at the center frequency. This r-f component is filtered out by capacitors C4 and C5 since they offer a low reactance path to ground (action is similar to a power supply filter capacitor except for the frequency).

When an input frequency higher than the center frequency is applied to the discriminator circuit a phase shift occurs, and the current and voltage phase relationships change as shown in the accompanying vector diagram.

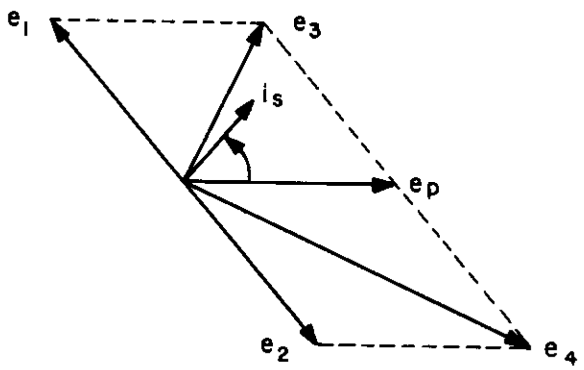


Vector Diagram For Higher Input Frequency

When a tuned circuit operates at a higher frequency than resonance, the inductive reactance of the coil increases, while the capacitive reactance of the tuning capacitor decreases. Therefore, above resonance the tank is predominately inductive and acts like an inductor. Hence, secondary current is **lags** the primary tank voltage e_p. Although secondary voltages e_1 and e_2 are still 180 degrees out of phase, they are also 90 degrees out of phase with the current which produces them (i_s). Thus the change to a lagging secondary current rotates the vector in a clockwise direction. Referring to the vector diagram it is seen that e_1 is brought nearer in phase with e_p, while e_2 is shifted further out of phase with e_p. Thus the vector sum of e_p and e_1 is larger than that of e_p and e_2. Therefore, above the center frequency, diode V1 conducts heavier than diode V2. Consequently, voltage E_3 developed across R1 is greater than E_4 developed across R2, and the voltage on capacitor C4 is likewise greater than on C5. The combined output voltage is therefore, a positive voltage.

When an input frequency lower than the center frequency is applied to the discriminator circuit a phase shift also occurs, and the current and voltage phase relationships change as shown in the accompanying vector diagram.

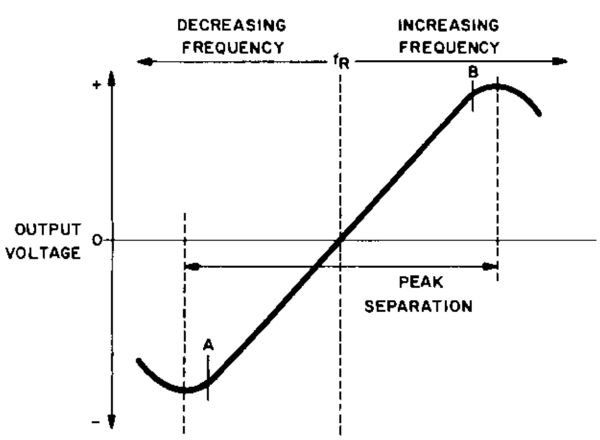
When a tuned circuit operates at a lower frequency than resonance, the capacitive reactance of the tuning capacitor increases, while the inductive reactance of the coil decreases. Therefore, below resonance the tank is predominately capacitive and acts like a capacitor. Hence, secondary current is **leads** the primary tank voltage e_p. Although secondary voltages e_1 and e_2 are still 180 degrees out of phase, they are also 90 degrees out of phase with the current which produces them. Thus the change to a leading secondary current rotates the vector in a counter-



Vector Diagram for Lower Input Frequency

clockwise direction. From the vector diagram it is seen that e_2 is now brought nearer in phase with e_p, while e_1 is shifted further out of phase with e_p. Thus the vector sum of e_p and e_2 is larger than that of e_p and e_1. Therefore, below the center frequency, diode V2 conducts heavier than diode V1. Consequently, voltage drop E4 across R2 is greater than E3 across R1, and the voltage on capacitor C5 is, likewise, greater than on C4; thus the combined output voltage is a negative voltage.

When the input voltage is varied from a lower frequency through the resonance point of the discriminator and is then raised higher in frequency, the typical discriminator response curve shown in the accompanying illustration is obtained. The usable portion of the typical "S" shaped response curve is from point A to point B in the illustration. Between these points, the curve is linear and the instantaneous output voltage is directly proportional to the instantaneous frequency deviation.



Discriminator Response Curve

When weak A-M signals which are too small in amplitude to reach the limiting level pass through the limiter stage, the amplitude variations cause primary voltage e_p to fluctuate with the modulation and induce a similar secondary voltage in T1. Since the diodes are connected as half-wave rectifiers, these small A-M signals are detected as in a diode and appear in the output. This unwanted AM interference is cancelled out in the ratio detector (to be discussed later in this section of the Handbook) and is the main disadvantage of the Foster-Seely circuit in comparison with other FM detectors.

FAILURE ANALYSIS.

No Output. A defect in the primary winding of transformer T1, in the RFC, or in capacitors C1, C2 or C3 may cause a no-output condition. Use an ohmmeter to check the primary winding of transformer T1 and the RFC for continuity; also check both for leakage or shorts to ground. If these checks fail to locate the trouble, use an in-circuit capacitance checker to check capacitors C1, C2 and C3. Note that the failure of either diode will cause distortion rather than a no-output condition; if both diodes fail, however, there will be no output.

Low or Distorted Output. A defect in nearly any component in the discriminator circuit may cause the output to be either low to distorted. Therefore, it is good practice to use an r-f sweep generator and an oscilloscope to isolate the trouble. First, use the oscilloscope to observe the input to the discriminator to be certain that the preceding (limiter) stage is not at fault. If the input signal does not change in amplitude as the input frequency varies, the trouble is most likely in the discriminator circuit. To determine if the discriminator is at fault, ground the grid of the preceding limiter stage, connect the r-f sweep generator to the discriminator input, and connect the oscilloscope to the discriminator output. With the sweep generator set to produce an output which varies above and below the center frequency, the pattern observed on the oscilloscope should be similar to the discriminator response curve illustrated previously. Defects in the circuit will cause either the entire curve, or a portion of it to be distorted or flattened.

If the entire response curve is distorted, the trouble may be caused by either improper alignment or by a defect in transformer T1. First check to be certain that both the primary and secondary tank circuits are properly tuned to the center frequency. If the discriminator is properly aligned, the trouble is most probably caused by a defect in transformer T1.

If only the upper portion of the response curve is distorted, the trouble may be caused by a defect in diode V1, capacitor C4, Resistor R1, or transformer T1. Use a capacitor checker to check capacitor C4 for value and leakage, and use an ohmmeter to check resistor R1 for a change of value. If these checks fail to locate the trouble, transformer T1 is probably defective.

Conversely, if only the lower portion of the response curve is distorted, the trouble may be caused by a defect in diode V2, capacitor C5, resistor R2, or transformer T1. Check capacitor C5 for value and leakage, and use an ohmmeter to check resistor R2 for a change of value. If these checks fail to locate the trouble, transformer T1 is probably defective.

TRAVIS DISCRIMINATOR.

APPLICATION.

The Travis discriminator is used as a detector in FM receivers and for automatic frequency control (AFC) circuits.

CHARACTERISTICS.

Converts instantaneous frequency variations into instantaneous d-c voltage variations.

Employs a triple-tuned transformer.

Has low inherent distortion.

Circuit is difficult to align.

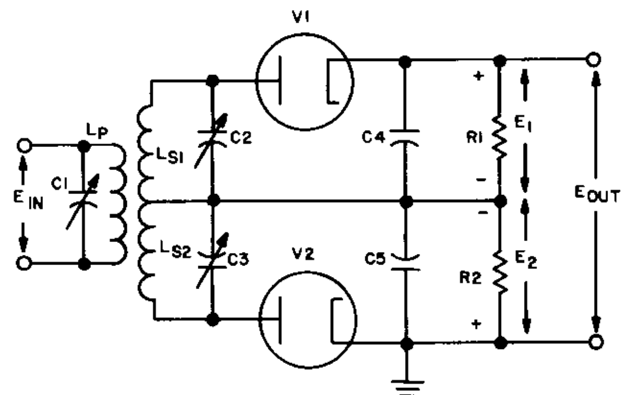
Must be preceded by a limiter since the output is affected by input amplitude variations.

CIRCUIT ANALYSIS.

General. The Travis discriminator uses two secondary tank circuits, with each tank tuned so slightly different resonant frequencies to convert the FM input signal frequency variations into amplitude variations. The r-f amplitude variations are then rectified and filtered to produce a d-c output voltage which varies in accordance with the variations of the input frequency. When the input frequency is equal to the **center frequency** (unmodulated carrier frequency), the discriminator output voltage is zero. As the input frequency rises above the center frequency, the output voltage increases in one direction, for example, increases in the positive direction, and as the input frequency drops below the center frequency, the output voltage increases in the other direction (for example, increases in the negative direction). Thus, the instantaneous discriminator output voltage is dependent on the instantaneous input frequency deviation (shift) from the center frequency. The specific polarity of output voltage obtained for an increase or a decrease in input frequency is determined by the design of the circuit and may vary in different circuits.

The Travis discriminator output is dependent not only on variations in the input frequency, but also to a certain extent, on variations in the input amplitude. Since variations in the amplitude of the FM signal are caused by unwanted noise or fading, they must be prevented from reaching the discriminator or the circuit will reproduce the unwanted noise as well as the desired intelligence. To prevent this, the discriminator is usually preceded by a limiter such as those explained in section 15 of this Handbook. The limiter produces an r-f output signal of constant amplitude regardless of input amplitude variations, and thus effectively eliminates any AM noise from the FM signal.

Circuit Operation. The accompanying schematic diagram illustrates a simple Travis discriminator.



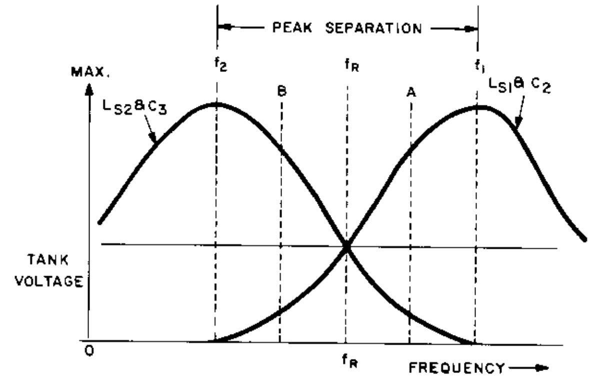
Travis Discriminator

Capacitor C1 and the primary winding (L_P) of transformer T1 form a resonant tank circuit which is tuned to the center frequency. The upper half of the secondary winding (L_{S_1}) of transformer T1 and capacitor C2 form a resonant tank circuit which is tuned above the center frequency by an amount slightly greater than the maximum input frequency deviation. The lower half of the secondary winding (L_{S_2}) of transformer T1 and capacitor C3 form a resonant tank circuit which is tuned below the center frequency by the same amount that the upper tank circuit is tuned above the center frequency. The r-f signals from the two tank circuits are rectified by diodes V1 and V2, and a d-c voltage is developed across load resistors R1 and R2. Capacitors C4 and C5 are filter capacitors which remove the r-f ripple component from the detected signals developed across resistors R1 and R2, and holds these voltages relatively constant. The total output voltage is taken across the **series** combination of resistors R1 and R2 (that is, from the cathode of diode V1 to ground).

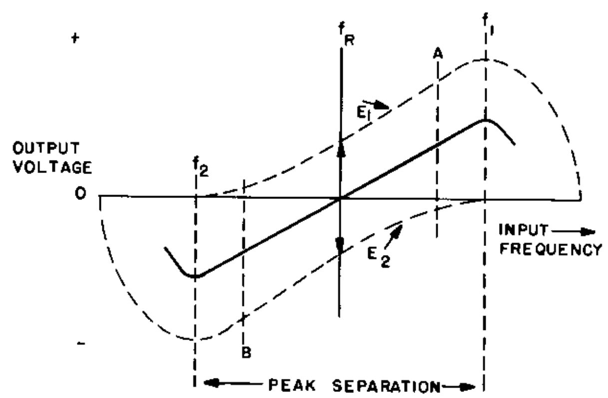
When an input signal with a frequency equal to the center frequency is applied to the primary tank circuit (L_P and C1), a voltage is induced into the secondary winding of transformer T1 which develops r-f voltages of equal amplitudes in secondary tank circuits L_{S_1} and C2, and L_{S_2} and C3, as shown in the accompanying illustration of tank circuit response.

Since the two secondary tank circuits are tuned to resonant frequencies (f1 and f2) equidistant from the center frequency, both tank circuits are tuned off-resonance by equal amounts and equal r-f voltages are produced. On the positive half of the input cycle the anode of V1 is positive and current flows through resistor R1, developing a d-c output voltage with polarity as marked on the schematic. Simultaneously, the anode of diode V2 is also positive and the d-c output voltage produced across R2 by current flow is equal and opposite that of R1. Therefore, the total output voltage taken across the two resistors in series (from cathode of V1 to ground) is zero. This condition is shown at the center frequency (f_r) on the accompanying discriminator response curve illustration.

Voltage E_1 is developed across load resistor R1 (with respect to ground), and voltage E_2 is developed across load resistor R2. As shown in the illustration, voltage E_1 is



Tank Circuit Response Curve



Discriminator Response Curve

equal in magnitude and opposite in polarity to voltage E, at the center frequency. Thus, at the center frequency, the output voltage (E_{out}) is zero.

When an input frequency higher than the center frequency is applied to the primary tank circuit of the discriminator, a voltage is induced into the secondary winding of transformer T1 which is nearer to the resonant frequency of the upper tank, and therefore, a larger voltage is applied to V1 anode. Consequently, V1 conducts heavier and the larger current flow through R1 produces a larger d-c output voltage, E1, charging C4 to a higher value. In a similar manner, the voltage developed across the lower tank circuit as shown by response curve B is further away from the lower-tank resonant frequency and the positive anode voltage on V2 is lower than that of V1. Hence, the small current flow through resistor R2 develops a smaller output voltage, E2, and C5 is charged to a lower value. The net output voltage, E_{out}, across the two resistors is positive when the input frequency is higher than the center frequency, since E1 is always positive and greater than E2. When a still higher frequency is applied the primary tank, the same action occurs except that E1 becomes much larger and E2 becomes much smaller. Likewise, when the input frequency is lower and nearer the lower tank frequency the opposite condition prevails. That is E1 becomes smaller, while E2 becomes larger. Consequently, the net output voltage, E_{out}, across the two resistors is negative when the input frequency is lower than the center frequency, since E2 is always negative and larger than E1.

Thus, the output voltage of the Travis discriminator varies in magnitude and polarity as the input frequency varies above and below the center frequency. As mentioned previously, the discriminator output is dependent not only on the input frequency, but also to a certain extent on the input amplitude. If the input signal amplitude drops below the limiting level of the preceding limiter stage, the signal and any variations in the signal amplitude will appear at the discriminator. Since the discriminator diodes are essentially half-wave rectifiers, they will detect the amplitude variations in much the same manner as an AM detector, producing noise in the discriminator output. Thus, for proper operation, the input signal to the limiter must always remain above the limiting level of the stage. Another disadvantage of the Travis discriminator is that it is difficult to align because each of the three tank circuits must be tuned to a slightly different resonant frequency. Because it is sensitive to amplitude variations, and because it is difficult to align, the Travis discriminator is not often used in modern FM circuits.

FAILURE ANALYSIS.

No Output. Loss of input signal, the failure of capacitor C1, transformer T1, or both diodes can cause a no-output condition. (Note that if only one diode fails, the output will be distorted rather than completely absent.) If the diodes are not at fault, either transformer T1 is defective or capacitor C1 is shorted.

Low or Distorted Output. The failure of nearly any component in the Travis discriminator may cause the output to be low or distorted. Therefore, it is good practice to use an r-f sweep generator and an oscilloscope to locate the specific portion of the circuit that is faulty. First, use the oscilloscope to observe the input to the discriminator to be certain that the trouble is not due to distorted input signal. If the correct discriminator input signal is present, ground the grid of the limiter stage preceding the discriminator, connect the r-f sweep generator to the discriminator input, and connect the oscilloscope to the discriminator output. With the sweep generator adjusted to produce an output signal which varies above and below the center frequency, a characteristic "S" shaped discriminator response curve will be obtained if the circuit is operating properly and aligned correctly. Defects in the circuit or alignment, however, will cause a portion of the response curve to be distorted.

If only the upper (positive) portion of the response curve is distorted, the trouble may be caused by a defect in diode V1, resistor R1, capacitors C2 or C4, transformer

T1 or misalignment of tank C_2, Ls_1. Check resistor R1 for proper value with an ohmmeter, and check capacitor C4 for proper value, leakage, or a short with an in-circuit capacitance tester. If these checks fail to locate the defective component, the transformer assembly (consisting of T1 and C1, C2, and C3) is either misaligned or defective. Check the alignment.

When only the lower (negative) portion of the response curve is distorted, it may be caused by o defect in diode V2, resistor R2, capacitors C3 or C5, transformer T1, or misalignment of tank C3, Ls_2. Check resistor R2 for proper value with an ohmmeter, and check capacitor C5 for proper value, leakage, or a short, with an in-circuit capacitance tester. If these checks fail to locate the defective component, the transformer assembly (T1, C1, C2, and C3) is either misaligned or defective. Check the alignment.

Distortion or flattening of the entire response curve is usually caused by improper alignment of the discriminator, although it may also be caused by low diode emission.

RATIO DETECTOR.

APPLICATION.

The ratio detector is used in FM receivers to demodulate the received r-f signal, and in automatic volume control (AVC) circuits to transform frequency changes into d-c control voltage changes.

CHARACTERISTICS.

Converts instantaneous frequency variations into instantaneous d-c voltage variations.

Employs a double tuned transformer and two diodes.

Has very low inherent distortion.

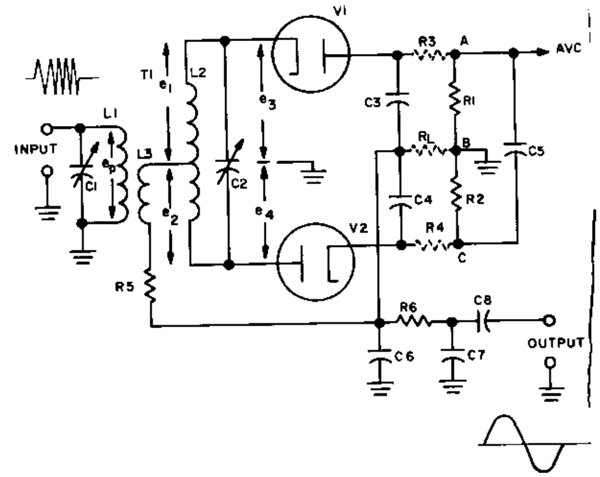
Output not affected by input amplitude variations.

CIRCUIT ANALYSIS.

General. The ratio detector uses a double tuned transformer, connected so that the instantaneous frequency variations of the FM input signal are converted into instantaneous amplitude variations. These amplitude variations are rectified to provide a d-c output voltage which varies in amplitude and polarity as the input signal varies in frequency. The output is zero when the input frequency is equal to the **center frequency** (unmodulated carrier frequency). When the input frequency rises above the center frequency, the output voltage increases in one direction (for example, becomes more positive).

When the input frequency drops below the center frequency, the output voltage increases in the other direction (for example becomes more negative). The specific polarity of the output voltages obtained for an increase or decrease in input frequency is determined by the design of the circuit and may vary in different circuits.

Circuit Operation. The accompanying schematic diagram illustrates a typical ratio detector.

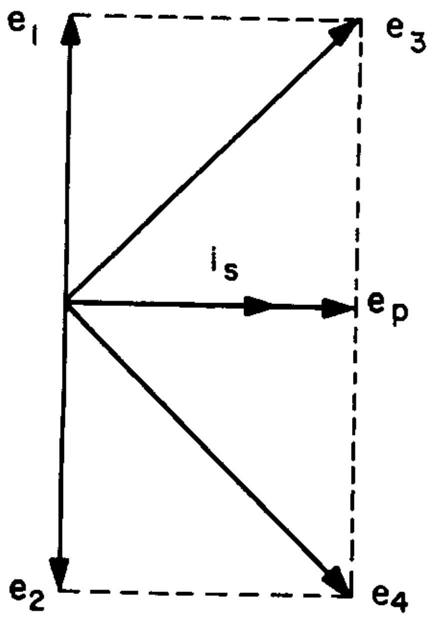


Ratio Detector

The input tank circuit, made up of capacitor C1 and the primary winding of transformer T1, is tuned to the center frequency (f_r) of the received r-f signal. Capacitor C2 and secondary winding L2 of transformer T1 form a tank circuit also tuned to the center frequency. Tertiary winding L3 provides additional inductive coupling which reduces the loading effect of the secondary circuit of the detector on the primary circuit of the detector. Diodes V1 and V2 rectify the signal from the secondary tank circuit. Capacitor C5, in conjunction with resistors R1 and R2, determines the operating level of the detector, while capacitors C3 and C4 determine the amplitude and polarity of the output. Capacitors C6 and C7, together with R6, form a filtering network at the output. Resistor R5 modifies the peak diode currents. Resistors R3 and R4 (shown in dotted lines on the schematic) were used in the original design of the circuit to compensate for the changing reactonce of the diodes for different amplitude input signals. In practical circuits, however, they are combined with R1 and R2, and achieve the same result. The output of the detector is taken from the common connection between C3 and C4 to the common connection between R1 and R2 which is also ground. Resistor R_L represents the load.

Operation can be best explained with vector diagrams which show the various phase relationships between the voltages and currents in the circuits. The accompanying vector diagram illustrates the circuit phase relationships when the input frequency (f) is equal to the center frequency (f_r).

The input voltage applied to the primary tank circuit is shown as vector e_p on the diagram. Since L3 is effectively connected in parallel with the primary tank circuit, voltage e_p appears across it. When voltage e_p is applied to the primary winding of transformer T1, a voltage is induced in the secondary winding which causes current to

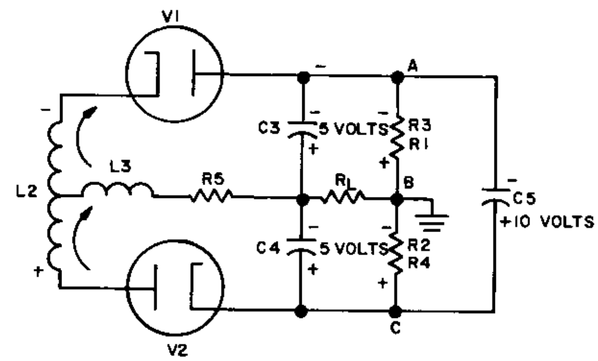


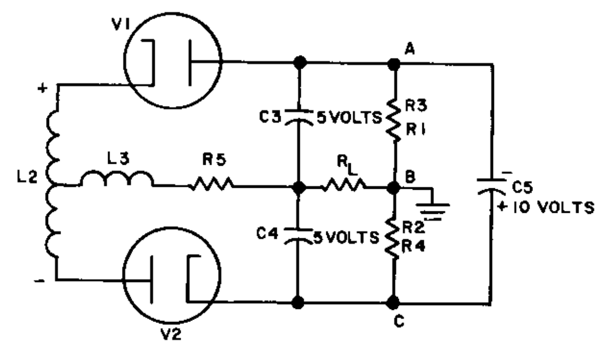
Vector Diagram at Resonance

flow around the secondary tank circuit. When the input frequency is at the center frequency, the tank is at resonance and acts resistive. Therefore, tank current is is in phase with the primary voltage e_p, as shown in the vector diagram. The current flowing in the tank causes voltage drops to be produced across each half of the balanced secondary winding of transformer T1, which are of equal magnitude and opposite polarity with respect to the center tap of the winding. Since the winding is predominately inductive, the voltage drop across it is 90° out of phase with the current through it. Because of the center tap arrangement, the voltages to ground at each end of the secondary are 180° out of phase, and are shown as e_1 and e_2 on the vector diagram.

The voltage applied to the cathode of V1 consists of the vector sum of voltages e_p and e_1 shown as e_3 on the diagram. Likewise, the voltage applied to plate of V2 consists of the vector sum of voltages e_p and e_2, shown as e_4 on the diagram. Since at resonance there is no phase shift, voltages e_3 and e_4 are equal as shown by the same length vectors.

Consider now the manner in which the tubes operate with the discriminator voltages discussed above. When a positive input signal is applied to L1, a voltage of opposite polarity is induced into secondary L2. As shown in the accompanying simplified schematic, the cathode of V1 is negative with respect to its plate, while the plate of V2 is positive with respect to its cathode. Since both voltages are of equal magnitude at resonance, both tubes conduct equally. Hence, current flow through V1 is in one direction, while current flow through V2 is in the opposite direction. This direction of current flow causes a negative polarity at point A and a positive polarity at point B, and through RL applies a positive charge to C3. In a similar manner current flow through V2 produces a negative polarity at point B and a positive polarity at C. Hence, capacitor C4 is charged negatively. Since the polarities are additive, capacitor C5 across the output charges to the series value of twice this voltage. In the example shown it is assumed that equal but opposite voltages of 5 volts exist across C3 and C4. Therefore, the total charge across C5 is 10 volts. Since the voltages across C3 and C4 are equal in amplitude and of opposite polarity the output across load RL is the algebraic sum or zero.

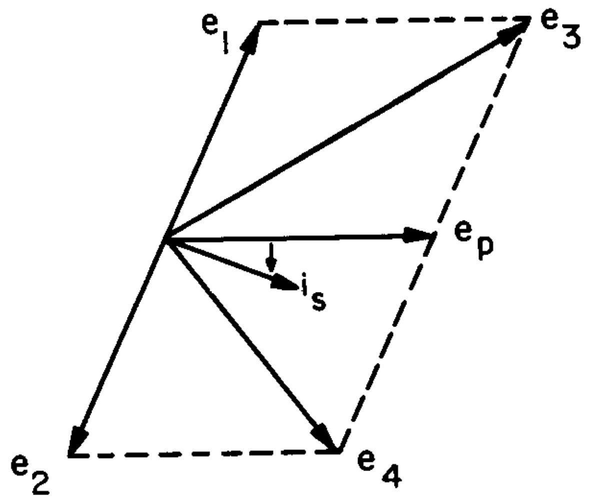




Current Flow and Polarities at Resonance

When the input signal reverses polarity, the secondary voltage across L2 also reverses polarity. The cathode of V1 is now positive with respect to its plate, and the plate of V2 is negative with respect to its cathode. Under these conditions neither tube conducts, and there is no output. Meanwhile, C5 retains most of its charge because of the large time constant supplied by R1 and R2, and discharges very slightly.

When an input frequency higher than the center frequency is applied to the detector circuit, a phase shift occurs and the current and voltage phase relationships change as shown in the accompanying vector diagram.

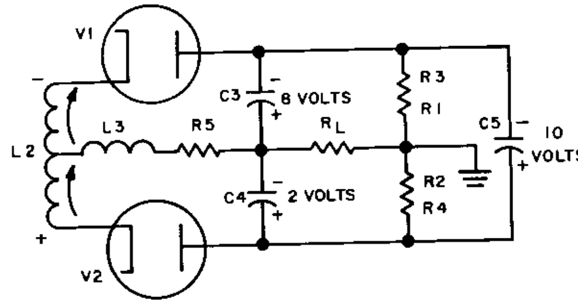


Vector Diagram for Higher Input Frequency

When a tuned circuit operates at a higher frequency than resonance, the inductive reactance of the coil increases, while the capacitive reactance of the tuning capacitor decreases. Therefore, above resonance, the tank is predominately inductive and acts like an inductor. Hence the secondary current is **lags** the primary voltage e_p. Although secondary voltage e_1 and e_2 are still 180 degrees out of phase, they are also 90 degrees out of phase with the current which produces them (i_s). Thus the change to a lagging secondary current rotates the vector in a clockwise direction. Referring to the vector diagram it can be seen that e_1 is brought nearer in phase with e_p, while e_2 is shifted further out of phase with e_p. Thus the vector sum of e_p and e_1 is larger than that of e_p and e_2. Therefore, above the center frequency, e_3, which is applied to the cathode of V1 becomes greater than e_4, the voltage applied to the plate of V2.

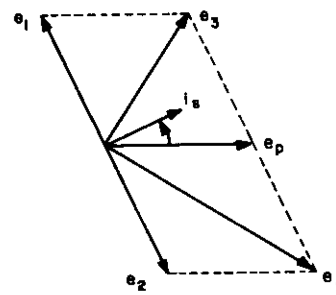
Let us now examine the manner in which the tubes operate with the discriminator voltages developed above resonance as discussed above. When a positive input signal is applied to L1, the same polarity as in the previous example discussed above exists, namely, V1 cathode is negative and V2 plate is positive and both tubes conduct. However, e_3 is now greater than e_4. Therefore, diode V1 conducts more than diode V2, and C3 charges to a higher voltage than at resonance, as shown in the accompanying simplified illustration.

Thus we assume in the figure an 8 volt charge on C3 and only a two volt charge on C4. Since C3 is positive with respect to C4, the output is a 6 volt positive signal. Meanwhile, capacitor C5 still remains charged to the sum of these voltages, or 10 volts, as originally stated. When the input signal reverses polarity, the polarity of the secondary also reverses, biasing both diodes in the opposite direction and preventing conduction. During the nonconducting period, C5 discharges very little because of its long time constant.



Current Flow and Polarities Above Resonance

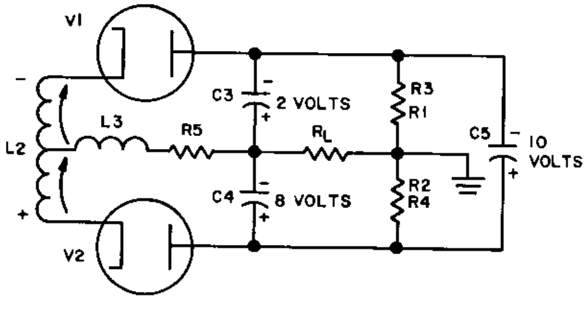
When an input frequency lower than the center frequency is applied to the detector circuit, a phase shift also occurs, and the current and voltage phase relationships change as shown in the accompanying vector diagram.



Vector Diagram for Lower Input Frequency

When a tuned circuit operates at a lower frequency than resonance, the capacitive reactance of the tuning capacitor increases, while the inductive reactance of the coil decreases. Therefore, below resonance, the tank is predominately capacitive and acts like a capacitor. Hence, secondary current is **leads** the primary voltage e_p. Although secondary voltages e_1 and e_2 are still 180 degrees out of phase, they are also 90 degrees out of phase with the current which produces them. Thus the change to a leading secondary current rotates the vector in a counterclockwise direction. From the vector diagram it can be seen that e_2 is now brought nearer in phase with e_p, while e_1 is shifted further out of phase with e_p. Thus the vector sum of e_p and e_2 is larger than that of e_p and e_1. Therefore, below center frequency, e_4, which is applied to the plate of V2, becomes greater than e_3, the voltage applied to V1.

The following simplified schematic shows the polarities and voltages developed for the lower than resonance condition. Once again V1 and V2 are conducting, but this time V2 is conducting more than V1, and hence, capacitor C4 is charged to the larger voltage 8 volts while C3 is only charged to 2 volts. The output voltage across the load in this case is a negative 6 volts because C4 is negatively charged with respect to C3. Again the charge across capacitor C5 consists of the sum of the voltages across C3 and C4, or 10 volts as originally developed.



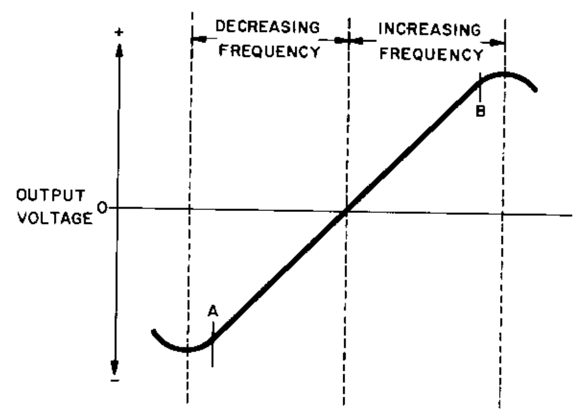
Current Flow and Polarities Below Resonance

When the input signal reverses its polarity, the signal across the secondary also reverses its polarity. The cathode of V1 is now positive with respect to its plate, and the plate of V2 is negative with respect to its cathode. Under these conditions, neither tube conducts, but the time constant of C3 and C4 maintains the current through the load in a negative direction until the next cycle of input.

When the input signal is varied from a lower than center frequency, through center frequency, and is raised to a frequency higher than the center frequency, the typical "S" shaped discriminator response curve shown in the accompanying illustration is obtained. The usable portion of the typical "S" shaped response curve is from point A to point B in the illustration. Between these points, the curve is linear and the instantaneous output voltage is directly proportional to the instantaneous frequency deviation.

The output of the ratio detector adjusts itself automatically to the average r-f amplitude of the input signal. Through the action of resistors R1 and R2, together with capacitor C5, audio output variations which would occur due to r-f amplitude variations in the input (such as noise) are eliminated. As previously mentioned, C5 charges to the sum of e_3 and e_4. The average sum of e_3 and e_4 depends upon the average r-f amplitude of e_p. Any amplitude variations at the input of the detector tends to change the voltages across R1 and R2, but because of the long time constant of C5, across the resistors, these voltages are held constant. Before the capacitor can charge or discharge to the higher or lower amplitude variation the impulse disappears, and the difference in charge on C5 is so slight that it is not discernable in the output. Because the voltage across C5 remains relatively stable and changes only with the amplitude of the center frequency, and since it is negative with respect to ground it is usually used for automatic volume control (AVC) applications.

Capacitors C6 and C7 together with resistor R6 form a low pass filter which attenuates the high audio frequencies and passes the lower frequencies. This is known as a



Ratio Detector Response Curve

de-emphasis network, which compensates for the pre-emphasis with which the high frequencies are transmitted and returns the audio frequency balance to normal. When pre-emphasis is not employed these parts are not needed.

FAILURE ANALYSIS.

No Output. A defective discriminator transformer, T1, shorted tuning capacitor C1 or C2, an open output resistor R6, an open coupling capacitor C8, or shorted filter capacitors (C6 or C7) will produce a no output condition. Check the continuity of the windings of T1 with an ohmmeter. Check capacitors C1, C2, C6 and C7 for shorts, and capacitor C8 for an open with an ohmmeter, and measure the resistance of R6. If above checks fail to restore the output, check all capacitors with an in-circuit capacitor checker. Note that one defective diode will produce a partial loss of output, and that both diodes must fail to cause a complete loss of output.

Low or Distorted Output. A defect in nearly any component in the detector circuit may cause the output to be either low or distorted. Therefore, it is good practice to use an r-f sweep generator and an oscilloscope to isolate the trouble. Ground the grid of the last I-F tube, connect the r-f sweep generator to the detector input, and connect the oscilloscope to the detector output. With the sweep generator set to produce an output which varies above and below the center frequency, the pattern observed on the oscilloscope should be similar to the discriminator response curve illustrated previously. Defects in the circuit will cause either the entire curve, or a portion of it to be distorted or flattened.

If the entire response curve is distorted, the trouble may be caused by either improper alignment or by a defect in the transformer T1. First check to be certain that both primary and secondary tank circuits are properly tuned to the center frequency. If the detector is properly aligned, check capacitors C1 and C2 with an in-circuit capacitor checker. Check R1 and R2 with an ohmmeter for their proper values, and capacitor C5 for value and leakage with an in-circuit capacitor checker. If the trouble is still not located, the trouble is most likely caused by a defect in transformer T1.

If only the upper portion of the response curve is distorted, the trouble may be caused by a defect in diode V1, capacitor C3, or transformer T1. If the diode V1 checks good, use an in-circuit capacitor checker to check C3 for value and leakage. If these checks fail to locate the trouble, transformer T1 is probably defective.

Conversely, if only the lower portion of the response curve is distorted, the trouble may be caused by a defect in diode V2, capacitor C4, or transformer T1. Use an in-circuit capacitor checker to check C4 for value and leakage. If these checks fail to locate the trouble, transformer T1 is probably defective.

GATED-BEAM DETECTOR.

APPLICATION.

The gated-beam detector is used in FM receivers to demodulate the received r-f signal.

CHARACTERISTICS.

Converts instantaneous frequency variations into instantaneous d-c voltage variations.

Employs three tuned tank circuits and a special beam-power tube.

Has low inherent distortion.

Output is independent of input amplitude variations.

Provides both limiting and discriminator action in a single tube.

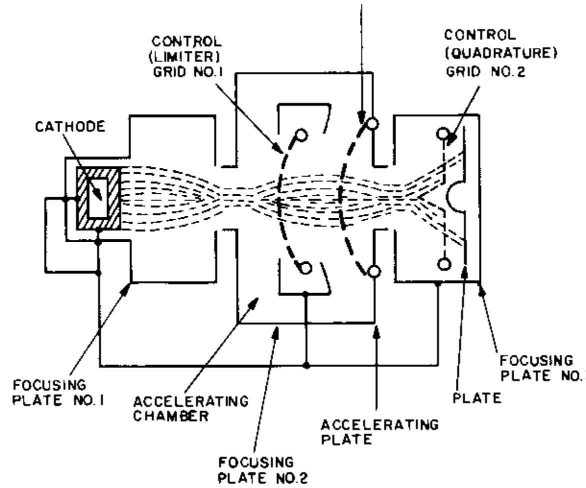
CIRCUIT ANALYSIS.

General. The gated-beam detector uses a gated-beam tube to limit, detect, and amplify the received f-m r-f signal. The output is a d-c voltage which varies in amplitude and polarity as the input varies in frequency. This output voltage is zero when the input frequency is equal to the center frequency (unmodulated carrier frequency). When the input frequency rises above the center frequency, the output voltage increases in a positive direction, and when the input frequency drops below the center frequency, the output increases in a negative direction.

Circuit Operation. Before attempting to explain the circuit operation of the gated beam detector, a brief review of the tube used in the circuit is essential. The accompanying illustration shows a cross-sectional diagram of a typical gated-beam tube.

There are two major differences between the gated-beam tube and an ordinary pentode. First, the flow of electrons from the cathode to the plate is maintained in a concentrated beam formed by the elements of the tube, and secondly, cathode current flows at all times, even during the period of time during which no plate current flows.

The shield around the cathode, known as focusing plate No. 1, is internally connected to the cathode, and as the electrons leave the cathode they pass through a narrow

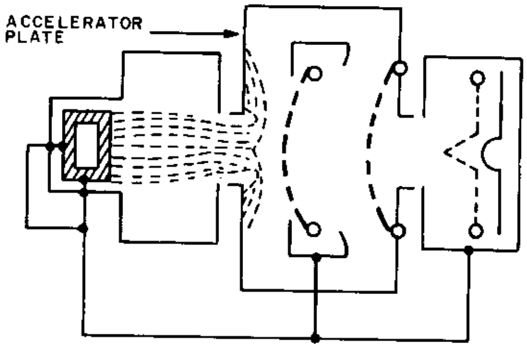


Gated-Beam Tube Cross-Section

opening in the shield, which is at cathode potential and repels electrons. Thus a narrow stream of electrons is formed.

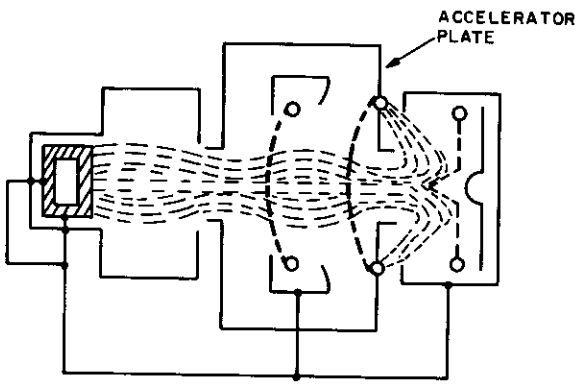
As the electron stream enters the accelerating chamber, which is at a high positive potential, it tends to spread, due to the attraction of the positive field. Ordinarily, the stream would continue to spread, but as it approaches the No. 1 control grid, it is prevented from spreading further by the repelling action of a second focusing plate, also connected to the cathode. Once the electrons pass through the first control grid, they are attracted towards the accelerator grid, which is at the same potential as the accelerator plate, and again the electron stream tends to spread. However, before the spreading becomes excessive, the stream enters the field of focusing plate No. 3 which is also at cathode potential, and further spreading is checked. The focusing plate is provided with a narrow opening, which concentrates the beam into a narrow stream again as it passes through this orifice. The electron stream then passes through a second control grid (referred to as the quadrature grid) and is attracted to the potential positive plate.

If a signal is applied to the first control grid, and it is sufficiently negative to prevent the electron stream from passing through it, the electrons approaching this grid rapidly build up a dense space charge in front of the grid. Because electrons repel each other, the accumulated space charge aids the control grid in quickly cutting off plate current flow, and accounts for the sharp cut-off tube characteristic. (This control grid is also referred to as the limiter grid for this reason.) The electrons cannot return to the cathode because of the narrow opening in the focusing plate, and they are attracted to the wall of the accelerator chamber instead, thus maintaining cathode current flow, as illustrated below.



First Control (Limiter) Grid at Cut-off

In a similar manner, when a signal of sufficient strength and of proper polarity to repel the electron stream is applied to the quadrature grid (No. 2 control grid), with the limiter grid above cut-off, plate current will not flow. Cathode current flow continues, however, because the electron stream is attracted to the accelerator wall instead, as illustrated below.

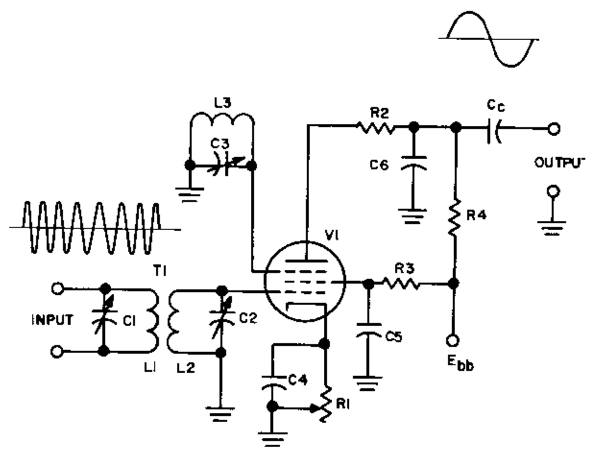


Second Control (Quadrature) Grid at Cut—off

To summarize tube operation, both the limiter grid and the quadrature grid must be sufficiently positive at the same time to permit passage of the electron stream to the plate.

The accompanying circuit schematic illustrates the gated beam tube connected as a typical gated-beam detector.

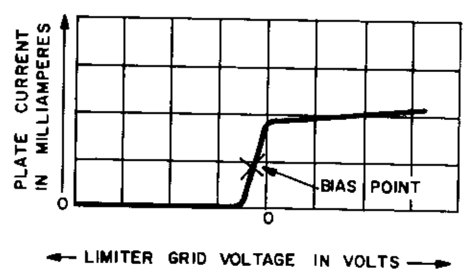
The input tank circuit, consisting of L 1, the primary of i-f transformer T 1, and capacitor C 1, is tuned to the center frequency of the incoming f-m signal. L2, the secondary of the transformer T1, and capacitor C2, also comprise another tank circuit, which is also tuned to the center frequency. The first grid of the tube and the cathode, perform the function of a limiter stage, with resistor R1 and capacitor C4 in the cathode circuit to provide a method



Typical Gated-Beam Detector

of adjusting the limiter bias. The accelerator grid is connected to voltage-dropping resistor R3 which establishes the proper voltage on the accelerator grid, and C5 bypasses it to ground. Capacitor C3, together with L3, form another tank circuit also tuned to the center frequency, and is connected to the second control grid. Resistor R2, (usually of a small value) is placed in the plate lead to increase output linearity. Resistor R4 is the plate load, and together with capacitor C6 forms an integrating network which produces the sine-wave output. The output is taken from across C6, and applied to the audio stages through coupling capacitor Cc.

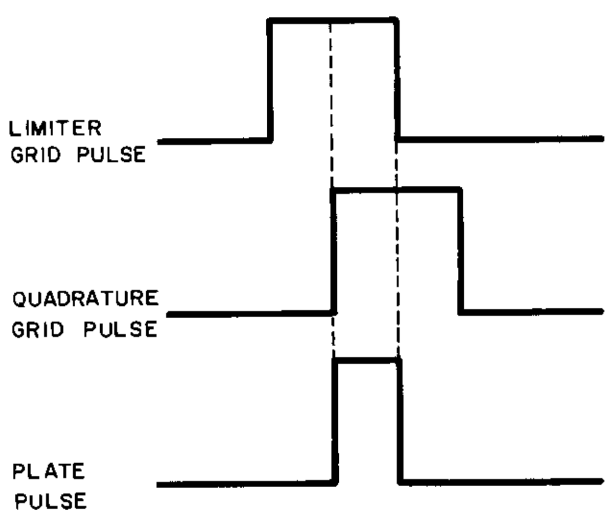
The limiting capabilities of the gated beam detector are much better than that of a conventional pentode, because of the sharp control characteristic, as shown in the graph below.



Limiter Grid Tube Control Curve

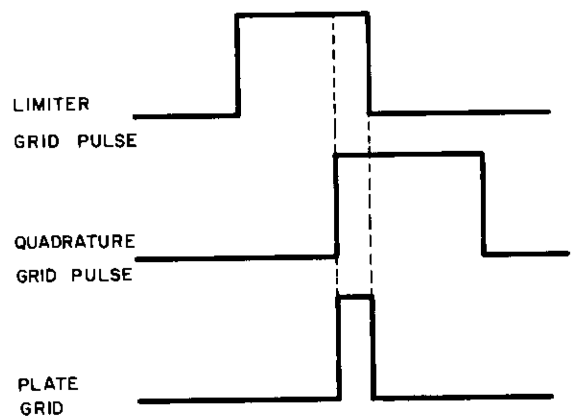
Cathode resistor R1 is adjusted to bias the limiter at the center of the steepest part of the control-characteristic curve. With no signal applied to the limiter grid, the tube conducts. When the electron stream arrives at the quadrature grid, some electrons are absorbed by this grid, and the resulting current flow charges C3 of the quadrature tank circuit. When C3 is charged sufficiently negative, the grid current stops and this negative charge momentarily maintains the quadrature grid at cut-off. Tank inductor L3, however, tries to keep the current moving in the same direction, but when its field collapses it causes a reverse flow of current which discharges C3. When C3 discharges sufficiently, the grid again becomes positive and begins drawing grid current, and the cycle repeats. Since the tank is tuned to the center frequency of the received signal, it oscillates at the tuned frequency. The voltage across C3 lags the current which produces it, and the result is a series of pulses appearing on the quadrature grid at the center frequency, but lagging the limiter grid voltage by 90 degrees. Because the quadrature grid has the same control characteristics as the limiter grid, these pulses place the tube alternately at cut-off and at saturation on alternate half cycles of oscillation.

When a signal appears on the limiter grid at the center frequency and increases slightly in a positive direction, the tube is effectively driven into saturation. That is, as the electron stream passes through the limiter and accelerator grids, and arrives at the quadrature grid, the quadrature grid is out-of-phase and is at cut-off, and the electron stream is attracted to the accelerator wall. However, some 90 degrees later, the quadrature grid shifts in a positive direction because of the favorable oscillation of the quadrature tank, and this time the electron stream is permitted to pass through the quadrature grid to the plate. Before the quadrature grid phase changes, the signal applied to the limiter grid drives the tube quickly into cut-off, and plate current again ceases. The resulting signal appearing on the plate, therefore, is a square shaped pulse, which starts with the delayed opening of the quadrature grid, and ends with the closing of the limiter grid, as illustrated below.



Relationship of Pulses at Center Frequency

If the signal on the limiter grid shifts to a frequency higher than the center frequency, the pulse appears on the limiter grid at an earlier time than at the center frequency, and therefore, also arrives at the quadrature grid at an earlier time. Since the pulses on the quadrature grid are still occurring at the center frequency (because of tank circuit oscillation), and the limiter pulse arrives earlier, the resulting pulse relationships are as shown in the second waveform illustration.



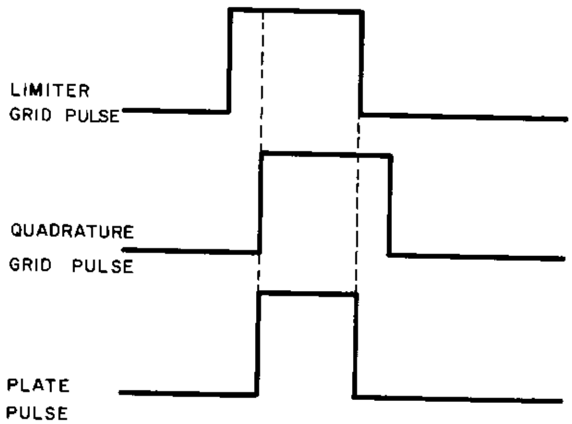
Relationship of Pulses above Center Frequency

Since plate current starts with the delayed opening of of the quadrature grid, and ends with the closing of the limiter grid, the plate pulse is now narrower than it was at the center frequency.

Conversely, if the signal on the limiter grid shifts to a frequency below the center frequency, the pulse arrives on the limiter grid at a later time, and thus arrives at the quadrature grid at a later time. It is therefore nearer in phase with the pulses on the quadrature grid, since these quadrature pulses are still occurring at the center frequency, and the resulting pulse relationships are as shown in the third waveform illustration.

Under the three circumstances discussed above, the peak amplitude of the plate current remains the same (it is effectively at saturation and limited), while the variations in the frequency of the input pulses are represented at the plate only by the length of time for which plate current flows. A higher input frequency produces a shorter duration of plate current, and a lower input frequency produces a longer duration of plate current.

These plate pulses, however, are occurring at an r-f rate, and therefore will not be reproduced by the following audio stages. However, since the width of the plate pulses constantly vary in accordance with the f-m modulation, the plate pulses also vary at an audio rate. Therefore, the average plate current varies at audio frequencies, and a useable audio output is obtained by an integrating network consisting of C6 and R4. Since the charge on C6



Relationship of Pulses below Center Frequency

varies at the same rate as the average plate current, taking the output from capacitor C6, provides an audio output, and at the same time, it changes the squared pulse into a useable sine-wave to minimize distortion.

The advantage of the Gated Beam Detector lies in its extreme simplicity. It employs only one tube, yet provides a very effective limiter with a linear detector. It requires relatively few components, and is very easily adjusted. Operation, however, is limited to the frequencies below 30 Mc. Since at the higher frequencies, the shunting effect of the interelectrode capacitance between the limiter and quadrature grids is sufficient to produce an out-of-phase voltage across the quadrature grid, which subtracts from the quadrature voltage and reduces the output. This effect is minimized in some circuits by the addition of a screen grid, to the tube or by careful shielding, but neither method completely eliminates the out-of-phase effect, and for this reason, the gated-beam circuit is usually used only in low frequency applications.

FAILURE ANALYSIS.

No Output. A defect in nearly any component in the circuit could cause a no-output condition to exist. Check the plate supply voltage at the tube socket, if plate voltage is not present, check resistors R2 and R4 and capacitor C6. If plate and grid voltages are normal, the tube is probably defective.

Check for a signal on the limiter grid with an oscilloscope. If no signal is present, check for a signal on the primary of the transformer. If still no signal appears, the trouble is somewhere in the preceding stages, and the detector is probably not faulty. If there is a signal on the primary of the transformer, check the tuning capacitors with an in-circuit capacitor checker. If they are found to be good, the trouble is probably a defective transformer. Check cathode resistor R1 for proper value and adjustment, and capacitor C4 also, using an in-circuit capacitor checker. With the oscilloscope, check for a signal on the quadrature grid. If a signal is present, make sure it is at the center frequency. If no signal is present, check C3 with an in-circuit capacitor checker, and L3 with an ohmmeter. Check R3 for proper value, and C5 for a short to ground.

Low or Distorted Output. It is unlikely that a low output condition will exist, but if it does, R2, R4, or C6 is most likely at fault. Check R2 and R4 for proper value, and C6 with an in-circuit capacitor checker.

If the output is distorted, make the checks just mentioned above for a low output condition, and if the distortion still occurs, make certain that the three tanks are aligned properly, and contain no defective components. Also check R1 for proper value and adjustment, using a voltohmmeter and also check capacitor C4 with an in-circuit capacitor checker.

VIDEO DETECTORS

A video detector is very similar to the standard AM detector, with the exception of the requirement for handling a broader range of frequencies. Since it is located between the IF and the video amplifier stages, it must be able to handle the same wide range of frequencies as the IF and video amplifier stages without distortion. The IF frequencies used in radar applications vary from about 30 Hz to 8 MHz, and in television, from about 20 MHz to 4.5 Hz. This requirement necessitates the use of high-frequency compensating circuits in the detector output, which consist of both series and shunt peaking circuits. (See paragraph 2.5.2 in section 2 of this Handbook for an explanation of RL peaking circuits). Another precaution, though less critical, is the selection of a diode with a low plate to cathode capacitance. Operation of the video detector is the same as that of a typical AM diode detector, except for the frequency response changes caused by use of the compensating circuits.

BASIC VIDEO DETECTOR

APPLICATION.

The video detector is used to change the received amplitude modulated video signal into a d-c voltage.

CHARACTERISTICS.

Employs a basic AM diode detector.

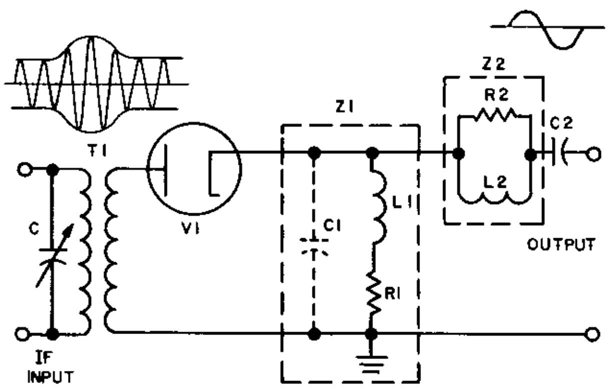
Has a wider bandwidth than the conventional AM detector.

Employs compensating networks for frequency compensation and to improve linearity.

CIRCUIT ANALYSIS.

General. The operation of the basic video detector is identical to the operation of the AM diode detector previously discussed in this section of the Handbook. The only difference lies in the addition of compensating circuits for the added frequency response requirements. Discussion of the operation of the detector in stripping off the modulation from the carrier is covered completely in the previous discussion of the diode detector. The reader should refer to the discussion of the Diode Detector in this section of the Handbook for proper background before proceeding with the discussion of the video detector.

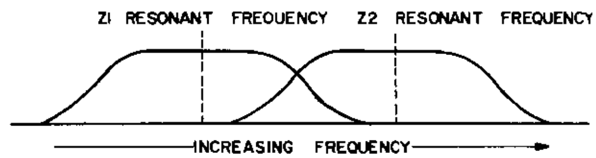
Circuit Operation. The schematic diagram of a typical video detector employing series and shunt peaking is shown in the accompanying illustration.



Basic Video Detector

The anode of diode V1 is connected to the untuned secondary of IF transformer, T1, with the primary tuned by capacitor C. Inductance L1, in series with resistor R1, together with capacitor C1, forms a shunt peaking circuit, referred to as impedance network Z1. Inductance L2, together with R2, forms a series peaking circuit, referred to as impedance network Z2. Capacitor C2 is the output coupling capacitor. Resistor R1 broadens the bandwidth of Z1, and R2 broadens the bandwidth of Z2.

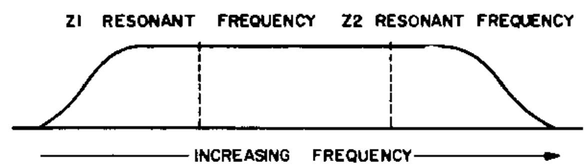
Peaking circuits Z1 and Z2 are utilized to improve the output linearity, and provide a wide band-pass characteristic. The circuit operates in the following manner. A frequency increase causes the capacitive reactance of the stray capacitance to decrease, and since this stray capacitance (represented by C1) shunts the output, the output voltage tends to decrease at high video frequencies. Z1 is a parallel-tuned circuit resonated to the high frequency at which the output first tends to decrease, by the stray and distributed wiring and circuit capacitance represented by C1. Since the impedance of the parallel tuned (shunt peaked) circuit is maximum at resonance, the output remains linear beyond the high frequency drop-off point (without compensation). The bandwidth of this tuned (shunt peaked) circuit is widened because the Q of the circuit is decreased by the presence of series resistor R1. As the output frequency is increased still further, it passes beyond the resonant peak of Z1, and as the impedance of Z1 now decreases, the output again tends to decrease. Z2, however, forms another broadly-tuned circuit, and is series-resonated at a point above the resonant frequency of Z1. These circuits are so tuned that some overlap of the tuned circuit response curves occurs, as shown in the following illustration.



Combined Response Curve of Z1 and Z2

Since the impedance of a series tuned circuit is minimum at resonance, and because Z2 is in series with the load, the output once again is extended. Actually L2 is series peaked using the stray capacitance to ground, and is also broadened by shunt resistor R2.

The resultant overall response curve for the video detector is as shown below.



Overall Response Curve for Video Detector

FAILURE ANALYSIS.

No Output. A defect in transformer T1, a defective tube, or an open C2 will cause a no-output condition. Check the continuity of the windings of T1 with an ohmmeter. Check C2 for an open with an ohmmeter. If a no-output condition still exists, check the value of the capacitor with an in-circuit capacitor checker.

Low or Distorted Output. A defective diode is about the only component in the circuit that would cause a low output condition to exist. While a low output is also possible because the values of L1 or L2 may change and change the response curve, this possibility is rather remote. Do not neglect the possibility of either R1 or R2 changing value sufficiently to affect the response.

If the output is distorted only at the lower frequencies, the defect is probably in one of the components of Z1. Check the value of L1. Check L1 for continuity and R1 for proper value with an ohmmeter.

If the output is distorted only at the higher frequencies, series peaking circuit Z2 is probably defective. Check C2 with an in-circuit capacitor checker. Check L2 for continuity and R2 for proper value.

PART B. SEMICONDUCTOR CIRCUITS

AM DETECTORS.

Detector circuits are used to remove the modulation from the received modulated r-f signal and transfer it back to its original form, so that it may be used for listening, viewing, communication, or other purposes. There are many forms of detector circuits and many variations of these circuits. The circuits used in the semiconductor field are similar to those used in the electron-tube field. The diode AM detector is a particularly good example of this parallelism, since the semiconductor diode merely replaces the diode tube. Only AM detectors will be discussed in the following paragraphs; other types of detectors will be discussed later.

The semiconductor diode evolved from the original "**crystal detector**" of the early radio era, which was basically a point-contact galena diode. Today's grown PN (or NP) junction diode is more stable and physically more rugged than the early galena detector. It is usually designed to handle fairly high voltage and current, since it acts as a large-signal detector after a number of r-f or i-f amplifiers. Because of its small size, good power-handling capabilities, lack of power consumption, and small cost, the design trend is to replace the electron tube diode with the semiconductor diode.

Generally speaking, the semiconductor diode detector for AM is used in one of two types of circuits: the **voltage-output** circuit and the **current-output** circuit. (In other texts these circuits may be called "series diode detector and shunt diode detector".) Although semiconductors operate basically by virtue of a changing **current**, when current is passed through a resistor a **voltage drop** is produced across the resistor. Therefore both types of circuits are applicable to either tubes or semiconductors, and the functioning is similar regardless of whether tubes or semiconductors are used. The voltage output circuit is usually preferred for electron-tube applications.

Because of the lack of gain in the diode detector, transistors are also used for detection. The transistor detector provides amplification of the detected signal. With the proper circuit connections and bias it can be made the semiconductor equivalent of the grid, plate, or infinite-impedance electron-tube detector. By suitable arrangement of biasing potentials and proper selection of the transistor, either square-law or linear detection can be achieved.

While the semiconductor diode detector is used universally in electron-tube equipment, the transistor triode detector is generally used only in all-transistor equipments. When used, the transistor detector is limited to the common-base and common-emitter configurations because of the less-than-unity gain provided by the common-collector circuit.

VOLTAGE OUTPUT DIODE DETECTOR.

APPLICATION.

The semiconductor diode detector with a voltage output is usually used as the second detector in superheterodyne receivers, or as a linear detector where large input signals are supplied. It is also used in test equipment where linear response is desired, as in VTVM's and field strength indicators.

CHARACTERISTICS.

Operates linearly over a large range of voltage.

Does not amplify the input signal.

Has an average efficiency of approximately 90 percent.

Normal large-signal distortion is on the order of 1 to 2 percent.

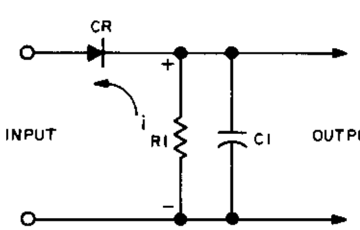
Is not restricted to any particular frequency range, but is operable on the entire electronic spectrum.

CIRCUIT ANALYSIS.

General. Since the electron tube diode detector is practically identical with the voltage-output semiconductor diode, read the discussion on Diode Detectors in Part A of this section, before continuing; refer also to the discussion on Junction Diode Theory, in paragraph 3.2.1 of Section 3, for a review of the basic operation of the diode. It should now be evident that the principal difference between a tube diode and a semiconductor diode is the reverse-leakage current of the semiconductor, plus a difference in current and voltage ratings. As far as the diode detector is concerned, the reverse-leakage current is usually negligible. Although it does produce a slightly increased loading effect on the input circuit, this increased loading is of interest only when the diode is operated as a small-signal detector. In this instance operation is not linear, but observes a square-law response (output varies as the square of the input voltage). It is this weak-signal square-law response which creates the inherent distortion in the diode detector. As normally operated, the diode voltage-output detector is employed after a number of stages of amplification. Thus, the input signal to the detector is relatively large in amplitude, the response is relatively linear, and the basic fidelity of the diode detector is achieved.

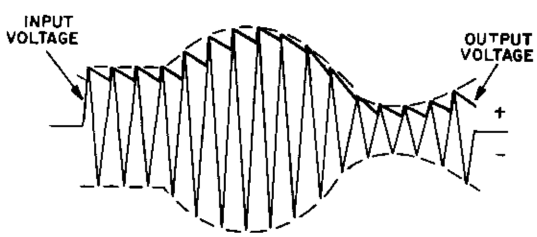
Circuit Operation. A simplified schematic of the voltage-output diode detector is shown in the accompanying figure.

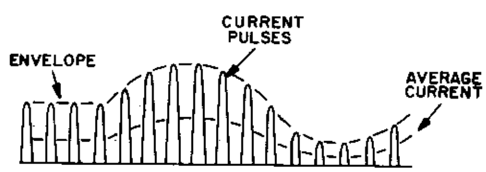
From this figure it can be seen that diode CR is in series with the input voltage; it acts as a simple rectifier, with R1 as the load and C1 as the filter. The diode conducts only during the positive half-cycle of the input signal. During the negative half-cycle it remains inoperative, since it is then reverse-biased. When the diode conducts, current flows through R1 and produces a voltage drop across



Voltage-Output Diode Detector

the resistor. The voltage developed across R1 is equal to the peak value minus the drop across the diode (which is very small and much less than in an electron tube diode). Since capacitor C1 is connected in parallel with R1 it charges to the same voltage. Since the diode response is considered linear, the larger the input voltage the greater the current through R1 and the larger the charge on C1. As the positive half-cycle ceases, the diode ceases conducting and capacitor C1 discharges through R1 for the duration of the negative half-cycle. The capacitor discharge is controlled by the time constant of R1 and C1, and is not quite completed before the positive half-cycle again begins. The diode again conducts, and capacitor C1 is again charged for the duration of the positive half-cycle. Since these alternations are at radio-frequency rates and the RC time constant is on the order of seconds, the voltage to which C1 is charged never has time enough to reach the full peak value of the input voltage, and the voltage to which C1 is discharged never has time enough to reach zero value. The voltage is, however, proportional to the envelope of the modulation, rising as the input signal amplitude increases, and falling as the input signal amplitude decreases, as shown in the following illustration. Thus, the voltage across C1 is a nearly linear replica of the original modulation.





DETECTOR WAVEFORMS

When the time constant of R1 and C1 is too short (capacitor, resistor, or both are too small), the capacitor voltage cannot follow the envelope (it reaches full charge before the signal reaches its peak), part of the signal is lost, and the detected modulation is distorted. When the time constant is too long, the capacitor tends to smooth out variations in the modulation (it cannot respond to very fast voltage variations—only slow variations), and distortion occurs. With the proper time constant, the capacitor is never fully charged or fully discharged, but rather follows the peak excursions of the envelope in accordance with the audio modulation.

FAILURE ANALYSIS.

No Output. A no-output condition can occur from failure of the diode to conduct, from an open or shorted load resistor, or from a defective capacitor. A resistance and continuity check will determine whether the resistor is satisfactory, whether the diode front-to-back resistance is normal, and whether the capacitor is short-circuited. With the resistor and diode checked out, it is a simple matter to connect a capacitor in parallel with the suspected capacitor to determine whether it is open (an output will appear if the capacitor is open). If an oscilloscope is available, it may be used to observe the waveform across the load resistor.

Low Output. Low output can occur from a change in the time constant of the circuit, or from a lack of sufficient input to the detector to produce the desired output amplitude. Poorly soldered connections, a leaky capacitor, or a defective diode can cause this condition. Under normal operation, the amplitude of the signal across the detector should be from 80 to 90 percent of the input amplitude. Less than this value indicates lack of efficiency due to increased resistance in the diode or leakage in the capacitor.

Distorted Output. This can result from a change in capacitor value. Either too large or too small a capacitor will cause distortion. A change in a resistor or capacitor value, producing too short or too long a time constant, will also cause distortion. The parts should be within 10 to 15 percent of their rated values. If the values are normal, the trouble must be in the diode. A high-resistance condition caused by a poorly soldered joint is always a possibility.

CURRENT OUTPUT, DIODE DETECTOR.

APPLICATION.

The current output diode detector is used to detect the audio modulation in semiconductor receivers, where the voltage output is small and does not vary sufficiently to produce full output from the audio amplifier stages.

CHARACTERISTICS.

Is usually self-biased.

Linear current swings produce linear output voltage swings.

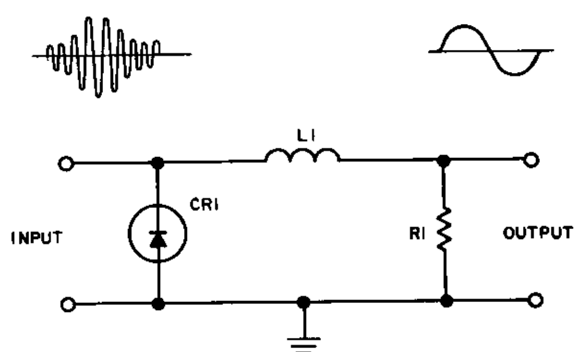
Impedance at the output is low, and usually direct coupling is employed.

Is inherently a small signal detector.

CIRCUIT ANALYSIS.

General. The current form of diode detector operates similarly to the voltage form of diode detector. Except that the output variations are in the form of current pulses rather than voltage pulses. However, by passing this current through a shunt resistor, a voltage output is developed across the resistor. The voltage output is, however, much reduced so that a current amplifier is required to build up the signal to a respectable output level. Thus, while the voltage detector will supply an output which can drive the following audio stage, the current detector usually utilizes direct coupling and an additional transistor stage to control another transistor stage in the output. Because of the direct coupling, response is somewhat better. On the other hand, the higher frequency signals are slightly attenuated by the coil reactance of the series inductor, which operates similar to the power supply low pass filter. This has the effect of eliminating any high frequency ripple and distortion in the output, so that practically the response is identical to the voltage diode but of lesser magnitude. Actually the current detector operates as a square law detector and is usually used in circuits other than the superheterodyne (which uses the voltage form of detector). Therefore, the shunt diode (current) detector is used mainly in regenerative receivers of the pocket variety and is usually combined with reflex audio circuits to provide a loud but distorted output.

Circuit Operation. The circuit of a typical current diode detector is shown in the accompanying illustration.



Current Diode (Shunt) Detector

As shown, the diode is connected in shunt with the input circuit, and L1 is connected in series, with load resistor R1 also connected in shunt to ground. The LR combination of L1 and R1 have a combined time constant which is satisfactory for detection.

When the input signal is applied across CR1 the output is shunted to ground for the negative half cycle of the r-f input signal because CR1 conducts and no output occurs. During the positive half-cycle the signal is applied to L1 and current flows through R1 to ground and produces an output current which follows the r-f envelope. This action occurs because of the integrating effect of the LR circuit. During the current flow through L1 and R1 to ground a field is built up around L1 which tends to keep current flowing in the same direction when conduction ceases, and during the time that the detector diode is shunting the signal to ground, the field discharges through R1. Thus an integratin action occurs similar to that which would be produced if R1 were shunted by a capacitor, and the output current follows the peak waveform closely. Because of the reactance offered to high frequencies by L1, there is always a loss of voltage which makes the output smaller than the applied signal. Since a conducting path to ground is offered on the positive half-cycle of input signal, the rectification efficiency is lower than for a series connected diode (voltage detector) hence this circuit is not often used. In addition the low shunting effect during conduction and the low overall impedance to ground during the nonconducting period provide a heavy load on the source, and creates distortion when sufficient driving power is not available. Thus, the shunt detector is usually less preferred than the higher impedance, voltage-output form.

FAILURE ANALYSIS.

No Output. If the diode is shorted, or if either L1 or R1 are open there will be no output. Because of the few components involved a resistance check with an ohmmeter will usually locate the defective part.

Low Output. A defective diode CR1, high resistance soldered joints, or large changes in L1 or R1 can reduce the output. Check the values of L1 and R1 with an ohmmeter.

Distorted Output. If the output is continuously distorted, check the diode. If the distortion still persists, use an oscilloscope to observe the input and output signals, since the distortion is probably located in an earlier r-f stage or a later audio stage.

COMMON-EMITTER DETECTOR.

APPLICATION.

The common-emitter transistor detector is usually used in semiconductor superheterodyne receivers to supply a detected and amplified output.

CHARACTERISTICS.

Uses self-bias.

Offers a high input impedance.

Is equivalent to the diode detector in quality, with more gain available.

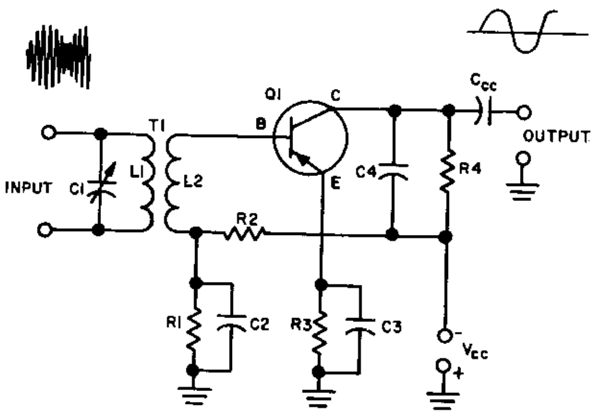
May be operated as either a small-signal, or a large-signal detector, depending upon bias voltage.

CIRCUIT ANALYSIS.

General. This detector is equivalent to the grid detector used in electron tubes. The base-emitter junction acts as a diode rectifier for large-signal linear detection when biased sufficiently, or as a square-law, small-signal detector when operating with low bias. When used in a receiver with only a few transistors it operates as a small signal detector, when used in superheterodynes it is used as a large signal detector. The operation is similar to that of the electron tube counterparts (grid and plate detectors) described earlier in Part A of this section.

Diode detection occurs in the base-emitter junction and amplification occurs using the emitter-collector junction. The combination can be considered the same as that of a diode and a transistor used separately.

Circuit Operation. The schematic of a typical transistor common-emitter detector is shown in the accompanying illustration.



Common-Emitter Detector

Tuned input transformer, T1, has a primary and secondary winding. The primary winding, L1 is tuned by capacitor C1 to the operating frequency (in superheterodyne receivers it is tuned to the IF), while secondary L2 remains untuned and inductively coupled. Resistors R1 and R2 are fixed-bias voltage dividers connected from the supply to the base and ground. Resistor R1 is bypassed by C2 for radio frequency and this RC combination also acts as the load resistor and bypass capacitor as used in a diode detector. The audio is detected in the base-emitter circuit and is applied as a d-c bias varying at audio frequencies to control collector current. The output is developed across collector load resistor R4, which is bypassed for r-f but not for audio frequencies. The emitter is connected to ground through a conventional swamping resistance (R3) for temperature stabilization, and is bypassed by C3 for both RF and audio.

In the absence of an input signal, transistor Q1 rests in a Class A-biased condition, drawing a moderate but steady collector current, and no output is obtained. When an input signal appears on the base of Q1 it is rectified by the base-emitter junction (operating as a diode) and appears as a d-c bias voltage with a varying audio frequency component across R1. This a-f component is developed across R1 as in the conventional diode detector previously discussed earlier in this section. Variations in base current flow caused by the input signal develop a voltage across R1 which follows the modulation envelope of the signal, any degenerative bias which tends to develop across emitter resistor R3 is eliminated by bypass capacitor C3. The output is developed by collector current flow from the supply through R4 which varies under control of the bias voltage across R1. Any radio frequency ripple in the output is bypassed across the collector load resistor by capacitor C4. The audio frequency variations, however, are not bypassed, and as the base is forward-biased by the negative half-cycle of input, it increases collector current flow, and a positive output voltage is developed across load R4. Likewise, when the base current is made to decrease on positive portion of the input signal (which reverse-biases the junction) collector current flow is reduced, and the collector output voltage rises towards the supply (becomes more negative). Thus since the output rises and falls in accordance with the modulation envelope, an amplified output of similar waveform is obtained and passed through coupling capacitor Ccc to drive the base of the following audio stage.

When a small fixed-bias is applied Q1, operation is on the lower (curved) portion of the base-emitter transfer curve and square law detection is obtained, with an increase of distortion. When biased higher (on the straight portion of the curve) the transistor operates as a linear diode detector with the additional amplification supplied by the collector circuit. The type of operation is determined during design by selecting the proper values of R1 and R2 to provide the desired bias for square law detection, and by choosing the proper value of emitter resistor R3 and bypass capacitor C3 for linear detection. The output in both instances is equivalent to that from a separate diode, amplified by a separate transistor operating at the same bias voltages. Usually when operating as a high-level (large signal) detector it is capable of driving an audio output stage directly. In this respect, it is the transistor equivalent of the electron tube power-detector.

FAILURE ANALYSIS.

No Output. Loss of an input signal, lack of bias, a defective transistor, loss of supply voltage, an open load resistor, or an open output capacitor can produce a no-output condition. Check the bias, supply, and collector voltages with a high resistance ohmmeter. If normal base bias is obtained, L2 and bias divider R1, and R2 are satisfactory, and C2 is not shorted. Likewise, with normal collector voltage R4 is okay and C4 is not shorted. An emitter voltage slightly larger than the bias applied and still no signal indicates that R3 and C3 are operating satisfactorily and that either L1 is open or C1 is shorted. Check the input circuit for continuity and shorts with an ohmmeter. The possibility exists that coupling capacitor Ccc may be open. In this instance, use of an oscilloscope would immediately show an output on the transistor side of Ccc, but nothing on the output side. When an oscilloscope is available, follow the signal through the circuit and note where it disappears or changes in shape or amplitude to locate the trouble.

Low Output. Improper bias, low collector voltage, or a defective transistor are the most likely causes of low output. Check for proper bias and collector voltage, and also check the supply to be certain that a blown fuse or the supply itself is not the cause. With normal voltages, the transistor must be defective.

Distortion. Normally the output is distorted to a certain extent, however, the modulation should be intelligible. When it is so distorted that it is garbled, check the output circuit to make certain the trouble is not in the following audio stage. When the distortion appears in the output stage but not in the detector, the trouble is in the output stage. Improper bias is usually the foremost cause of excessive distortion, and should be checked first with a voltmeter. If the bias voltages are normal, use an oscilloscope and follow the signal through the circuit until the pattern changes and shows the part at fault. It is important to remember to use an r-f probe when checking with the oscilloscope, since distortion in the r-f portion of the circuit will not show unless it is first detected by an r-f probe.

COMMON-BASE DETECTOR.

APPLICATION.

The common-base detector is usually used in small portable semiconductor receivers to provide detection with some amplification, and where extreme fidelity is not required.

CHARACTERISTICS.

Employs grid-leak bias.

Is equivalent in output to a diode and a separate amplifier stage.

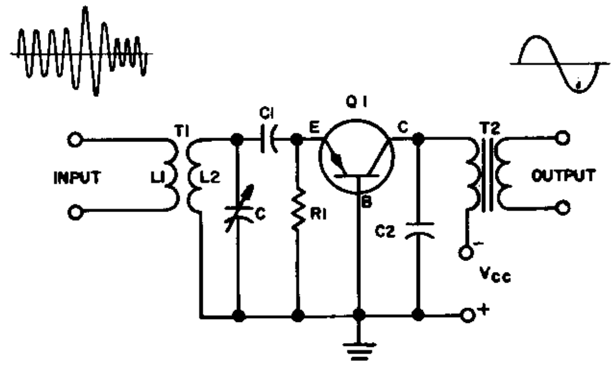
Produces more distortion than the common-emitter detector, or a diode detector.

Operates as a small signal detector which can easily be overloaded.

CIRCUIT ANALYSIS.

General. The common-base detector is the transistor equivalent of the electron tube grid-leak detector. Detection occurs in the base-emitter junction and amplification occurs through use of the collector junction. The output is the equivalent of a diode detector followed by a stage of audio amplification, but with more inherent distortion. Where less distortion and better quality are required a separate diode and transistor audio stage are used.

Circuit Operation. The schematic of a typical common-base detector is shown in the accompanying illustration.



Common-Base Detector

Transformer T1 is an r-f transformer when used in simple two or three stage receivers, or an i-f transformer when used in superheterodynes. It is tuned to either the i-f frequency or the operating frequency, as applicable. In the drawing T1 is single tuned in the secondary, but may also be tuned in the primary. Resistor R1 and capacitor C1 form a grid-leak bias network which sets the operating point of the emitter junction. The audio output is taken from the collector circuit through audio output transformer T2, however, RC coupling may be used to help improve fidelity if a smaller output is satisfactory. The primary of T2 forms the detector output load and is bypassed for r-f ripple by capacitor C2.

The input signal is applied to either the tuned or untuned primary and inductively coupled to the L2 secondary. When tuning capacitor C is tuned to the proper frequency, the input signal is coupled through C1 to the emitter. In the absence of a signal, contact bias exists as determined by resistor R1. The small flow of reverse current develops small bias voltage across R1 which is near zero and only the small normal reverse current flows. When the positive portion of the input signal occurs, current flows through the emitter-base junction driving the emitter positive (forward bias) and capacitor C1 is charged negatively, establishing the operating point. On the negative excursion of the input signal capacitor C1 is discharged through R1 creating a negative, reverse-bias which reduces conduction in the emitter junction. The bias developed follows the wave envelope of the modulated signal and produces a d-c emitter bias which varies at audio frequencies. Variation of the emitter bias causes the collector current to flow in accordance with the audio frequency variations of the modulation, and the output voltage is developed by collector current flow through the primary of audio transformer T2. Capacitor C2 effectively acts as a low pass filter, and filters out any r-f or i-f component (ripple) existing in the collector circuit. Thus only the audio variations induce a voltage in the primary of T2, and the field around the secondary of T2 varies in accordance with collector current changes, inducing an output voltage in the secondary. Strong signals may develop too much bias on the emitter, cut off collector current flow, and cause blocking. Since the bias ordinarily is small, the transistor operates on the lower portion of the emitter-base transfer characteristic curve and is a square law detector. Thus, at 100% modulation, distortion up to a maximum of 25 percent can exist. Such high values of distortion render this type of detector unsuitable for music or high fidelity broadcast use, except in cheap receivers in which the distortion can be tolerated for the sake of simplicity, economy, and portability.

FAILURE ANALYSIS.

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

No Output. Lack of collector voltage, an open input or output circuit caused by a defective transformer (T1 or T2), or a defective transistor can cause a no-output condition. Measure the collector voltage with a VTVM. Normal collector voltage on Q1 indicates that T2 and the output circuit are satisfactory. If no collector voltage exists, either T2 is open or C2 is shorted. Use a volt-ohmmeter and a capacitance checker to check these two parts. When collector voltage exists but there is no output, check T1 primary and secondary for continuity with an ohmmeter and tuning capacitor C for a short circuit. There is also the possibility of C1 being open. Use an ohmmeter and capacitance checker to check continuity and the capacitor for proper value. If T1 is satisfactory the transistor must be at fault.

Low Output. Lack of collector voltage or an open output circuit, as well as a defective transistor can cause a reduced output. Measure the collector voltage, if it is normal, either output transformer T2 is open or shorted, or Q1 is defective. Check the transformer for continuity or short circuit with an ohmmeter, and check C2 with a capacitance checker.

Distorted Output. The output will normally be distorted, but should be intelligible. If the distortion is so bad that the modulation is garbled, check the input and output waveform with an oscilloscope. If the waveform is undistorted in the base circuit but appears distorted in the collector circuit, check the values of C1 and R1. Since these parts set the bias point, a change in the value of either one can cause clipping or peak distortion effects. If these parts values are proper and within the tolerance indicated in the instruction book on the equipment, the transistor is most likely at fault.

FM DETECTORS.

The f-m detectors discussed in the following paragraphs are used to demodulate a frequency modulated r-f signal. Because of the similarity between a frequency modulated (FM) signal and a phase modulated (PM) signal f-m detectors may also be used with minor changes to demodulate a phase-modulated signal. While the circuits used in FM transmission and reception are more complex than those used for AM, FM provides more advantages which outweigh the additional complex circuitry. One of the most important advantages is in noise reduction of both man-made and natural static. Since most of these noise variations occur as amplitude variations, and the FM receiver is designed so that it does not respond to amplitude variations, noise is automatically eliminated in FM reception.

Semiconductor FM detectors can be divided into roughly three groups of circuits, namely, discriminators, ratio detectors, or slope detectors. These detectors are very similar in circuitry to that of their electron tube counterparts in that crystal diodes are merely substituted for the vacuum-tube diodes. Although these diodes do not have the practically infinite back resistance of the electron tube, otherwise, their performance is similar. And, they do have the advantage of not requiring filament power. For precise frequency response or frequency control, discriminator circuits are usually employed. Whereas, the reduced response of the ratio detector is reserved for receivers where economy and simplicity are desired. Each of these circuits is discussed in detail in the following paragraphs.

FOSTER-SEELEY DISCRIMINATOR.

APPLICATION.

The Foster-Seeley discriminator is used in semiconductor communications receivers and particularly where automatic frequency control or high fidelity is required.

CHARACTERISTICS.

Must be preceded by limiter stages to eliminate any AM response.

Uses a double-tuned transformer.

Uses two separate diodes.

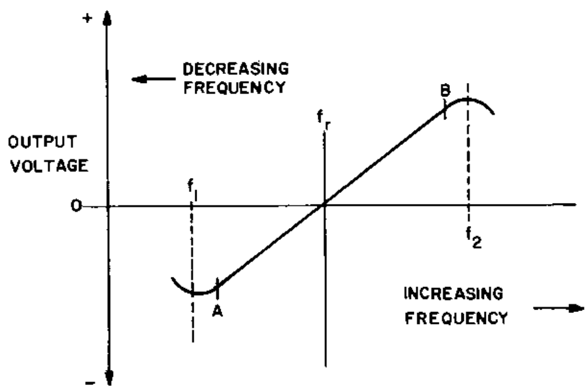
Has low inherent distortion.

Converts instantaneous frequency variations into instantaneous d-c voltage variations.

CIRCUIT ANALYSIS.

The Foster-Seeley discriminator (also known as the phase-shift discriminator) uses a double-tuned r-f transformer to convert the instantaneous frequency variations of the received f-m signal into instantaneous amplitude variations. The amplitude variations are then rectified and filtered to provide a d-c output voltage which varies in amplitude and polarity as the input signal varies in frequency. The output voltage is zero when the input frequency is equal to the **center frequency** (unmodulated carrier frequency). When the input frequency rises above the center frequency the output increases in one direction (for example, becomes more positive), and when the input frequency drops below the center frequency, the output increases in the other direction (for example, becomes more negative).

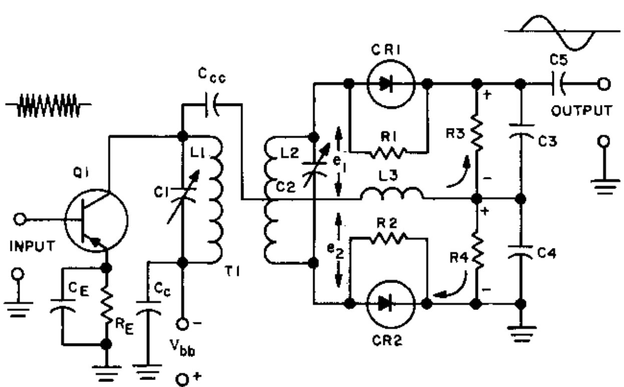
Since the output of the Foster-Seeley discriminator is dependent not only on the input frequency, but also to a certain extent upon the input amplitude, it is necessary to use one or two limiter stages before detection. When properly limited, and the input frequency is varied from a lower frequency through the resonance point of the discriminator, and is then raised higher in frequency, the typical discriminator response curve shown in the accompanying illustration is obtained.



Discriminator Response Curve

The usable portion of the typicol "S" shaped response curve is from point A to point B in the illustration. Between these points, the curve is linear and the instantaneous output voltage is directly proportional to the instantaneous frequency deviation.

Circuit Operation. The accompanying circuit schematic illustrates a typical Foster-Seeley semiconductor discriminator.



Foster-Seeley Discriminator Circuit (including limiter stage)

The collector portion of the preceding i-f (limiter) amplifier Q1 is shown on the schematic with conventional emitter resistor RE and bypass capacitor CE. The collector circuit tank consisting of C1 and L1 is the primary tank of i-f input transformer T1, while L2 and C2 form the secondary tank circuit; both tanks are tuned to the center frequency. Choke L3 forms the d-c return for diode rectifiers CR1 and CR2. While CR1 and CR2 are shown bypassed by equalizing resistors R1 and R2, they are not always used (they are usuolly used when the diode back resistances are different). Resistors R3 and R4 are the load resistors bypassed by C3 and C4, respectively, for r-f, capacitor C5 is the output coupling capacitor.

The center tap on coil L2 is capacitively coupled through coupling capacitor Ccc to the primary. And the full voltage exists across choke L3. At resonance (the center frequency) equal voltages e_1 and e_2 are produced across both halves of L2, thus equal voltages are applied to the anodes of CR1 and CR2. Assuming these voltages are positive, conduction occurs and current flow through diode load resistors R3 and R4 produce equal and opposing voltages across filter capacitors C3 and C4. Since the output is taken from C5 to ground, the equal and oppositely polarized signals cancel and produce no output at the center frequency. However, as the frequency is raised above the center frequency, the phase relationships in the halves of the tank circuit cause a voltage change so that e_1 becomes larger than e_2. Since it is larger than the voltage across R4, the voltage of R3 predominates, creating a positive output voltage.

Conversely, when the input signal frequency drops below the center frequency and is lower, voltage e_2 is larger than e_1 and the voltage across R4 predominates, creating a negative output. As long as the input frequency variations remain within the limits of peak separation marked A and B on the discriminator curve, a linear frequency versus amplitude relationship is maintained. That is the higher the frequency the larger the positive output voltage becomes, and the lower the frequency the larger the negative output becomes. (If desired, the discriminator transformer can be wound and connected to produce opposite polarities from that described above.) In any event, the output voltage is always developed across both R3 and R4, and it is always the algebraic sum of these. Capacitors C3 and C4 are used to store the instantaneous voltages and develop an average output which varies at audio frequencies. This output, in turn, is coupled to the audio amplifying stages by coupling capacitor C5 (any coupling method may be used). Thus, while the input consists of a constantly varying f-m signal of steady amplitude, the output is an audio frequency which varies linearly both in frequency and amplitude in accordance with the frequency swing of the input signal.

FAILURE ANALYSIS.

No Output. A defect in the primary or secondary windings of T1, in the RFC, or in tank tuning capacitors C1, C2, or C3, as well as defective diodes can cause a no-outpu condition. It is also possible for coupling capacitors Ccc or C5 to be open, or for bypass capacitors Cc, as well as

C3 or C4 to be shorted and bypass the signal to ground. Use an ohmmeter to check the primary and secondary of T1 and the RFC for continuity, and for shorts to ground. If these checks fail to locate the trouble, use an in-circuit capacitance checker to measure the values of C1, Cc, Ccc, C3, and C4. Note also, that both diodes must fail to cause no-output, since if only one fails there still will be an output. When possible, use an oscilloscope to observe the waveform at the input and follow the signal through the circuit noting where the signal disappears to locate the source of the trouble.

Low or Distorted Output. A defect in nearly any component in the discriminator circuit may cause the output to be low or distorted. Use an R-F Sweep Generator and an oscilloscope to isolate the trouble. Connect the sweep generator to the input and check the output with the scope on Q1 and at the anode of diode CR1 or CR2. Lack of signal at Q1 indicates defective transistor or part in the transistor stage of Q1. A signal on Q1 but not at the diode anodes indicates Ccc is either open or shorted to ground. If the input signal does not change in amplitude as the input frequency varies, the trouble is most likely in the discriminator circuit. To determine if the discriminator is at fault, ground the base of limiter stage Q1 and connect the r-f sweep input to the discriminator input, with the oscilloscope connected to the discriminator output. Adjust the sweep generator to produce an output which varies both below and above the discriminator center frequency and observe if the pattern on the oscilloscope is that of the typical "S" curve shown in the first illustration of this discussion. Defects in the circuit will cause either the entire curve or a portion of it to be distorted, or flattened.

If the entire response curve is distorted the trouble may be caused by either improper alignment or by a defect in transformer T1. First check to be certain that both the primary and secondary tank circuits are tuned to the proper center frequency. If the discriminator is aligned properly, the trouble is most likely in the transformer.

If only the upper portion of the response curve is distorted, the trouble may be caused by a defect in diode CR1, capacitor C3, resistor R3 or transformer T1. Use an in-circuit capacitance checker to check capacitor C3 for value and leakage, and use an ohmmeter to check resistor R3 for a change of value.

Conversely, if only the bottom portion of the discriminator response curve is distorted, the trouble may be caused by diode CR2, capacitor C4, resistor R4, or transformer T1. If the trouble persists use an in-circuit capacitance checker to check C4 for value and leakage, and use an ohmmeter to check resistor R4 for a change of value. If these checks fail to restore the output to normal, transformer T1 is most likely defective.

RATIO DETECTOR.

APPLICATION.

The semiconductor ratio detector is used in semiconductor type FM receivers to demodulate the received r-f, f-m signal, and in afc control circuits to transform frequency changes into d-c control voltages.

CHARACTERISTICS.

Employs a double tuned transformer and two solid state diodes.

Converts instantaneous frequency variations of the f-m signal into instantaneous d-c voltages.

Distortion is inherently low.

Output is not affected by input amplitude variations when preceded by a limiter stage.

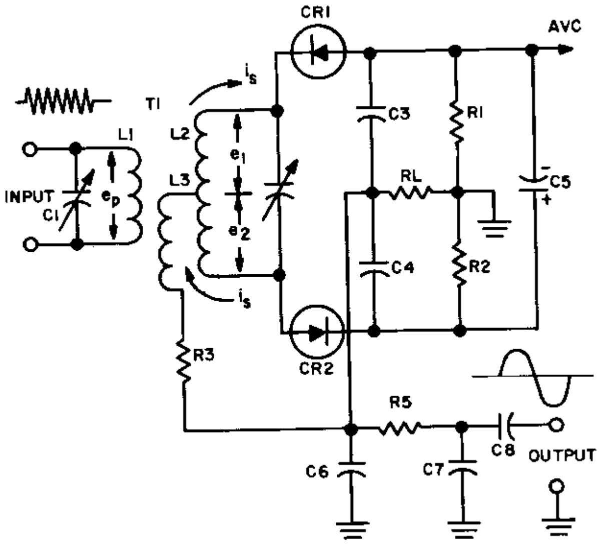
CIRCUIT ANALYSIS.

General. The semiconductor ratio detector, like the electron tube ratio detector previously discussed in Part A of this Handbook, uses a double tuned transformer (discriminator) connected so that the instantaneous frequency variations of the FM input signal are converted into instantaneous amplitude variations. These amplitude variations are rectified by the diodes to provide a d-c output voltage which varies in amplitude and polarity as the input signal varies in frequency. The output is zero when the input is equal to the **center frequency** (unmodulated carrier frequency). When the input frequency rises above the center frequency, the output voltage increases in one direction (for example, becomes more negative). The specific polarity of the output voltages obtained for an increase or decrease in input frequency is determined by the design of the circuits and may vary from circuit to circuit.

Circuit Operation. The accompanying schematic diagram illustrates a typical semiconductor ratio detector.

The input tank circuit comprised of C1 and primary winding L1 of T1 is tuned to the center frequency of the received f-m signal. Secondary winding L2 and capacitor C2 also form a tank circuit tuned to the center frequency. Tertiary winding L3 provides additional inductive coupling which reduces the loading effect of the secondary on the primary circuit of the detector. Solid state diodes CR1 and CR2 rectify the signal from the secondary tank. Capacitor C5, in conjunction with resistors R1 and R2 determines the operating level of the detector, while capacitors C3 and C4 determine the amplitude and polarity of the output. Resistor R3 modifies the peak diode current and furnishes a d-c return path to ground. The output of the detector is taken from the common connection between C3 and C4 to ground, which is also the common connection of R1 and R2. Resistor RL is the load resistor. A low-pass filter is formed by R5 together with C6 and C7 to provide high frequency deemphasis. Capacitor C8 is the output coupling capacitor.

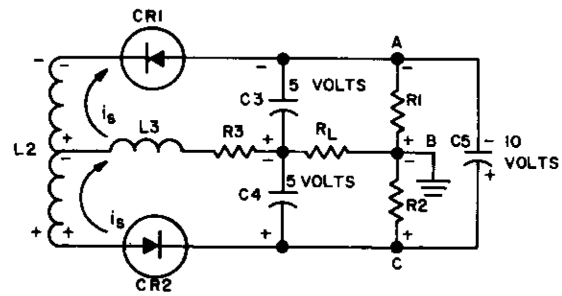
When input voltage e_p is applied to the primary, it also appears across L3 since it is effectively connected in



Ratio Detector

parallel with the primary tank circuit by inductive coupling. When voltage ep is applied to the primary winding of transformer T1, a voltage is also induced in the secondary winding and causes current to flow around the secondary tank circuit. When the input frequency is at the center frequency, the tank is at resonance, is resistive, and acts like a resistor. Therefore, tank current is in phase with primary voltage ep. The current flowing in the tank circuit causes equal voltage drops to be produced across each half of the balanced secondary winding of T1, which are of equal magnitude and of opposite polarity with respect to the center tap of the winding. Since the winding is predominately inductive, the voltage drop across it is 90 degrees out of phase with the current through it. At the same time, because of the center tap arrangement, the voltages to ground at each end of the secondary are 180 degrees out of phase and are shown as e_1 and e_2 on the schematic.

The voltage applied to the cathode of CR1 consists of the vector sum of e_1 and ep. Likewise, the voltage applied to the anode of CR2 consists of the vector sum of voltages e_2 and ep. Since at resonance there is no phase shift, both voltages are equal. Consider now the manner in which the diodes operate with the discriminator voltage discussed above. When a positive input signal is applied to L1, a voltage of opposite polarity is induced into secondary L2. As shown in the accompanying simplified schematic, the cathode of CR1 is negative with respect to its anode and is forward biased, while the anode of CR2 is positive with respect to its cathode and is likewise, forward biased. Since both voltages are of equal magnitude at resonance, both diodes conduct equally. Hence current flow through CR1 is in one direction, while the current flow through CR2 is in the opposite direction. This direction of current flow causes a negative polarity at point A and a positive polarity at point B. Through RL a positive charge is applied to C3. In a similar manner current flow through CR2 produces a negative polarity at point B and a positive polarity at C. Hence capacitor C4 is charged negatively. Since the polarities are additive, capacitor C5 across the output charges to the series value of twice this voltage.



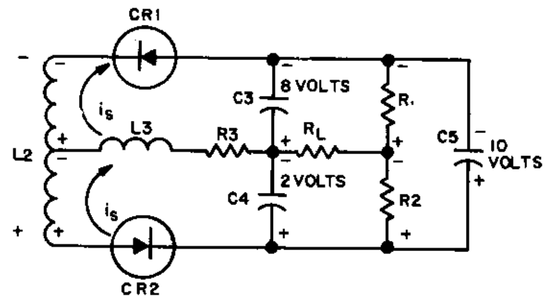
Simplified Schematic

In the example shown, it is assumed that equal but opposite voltages of 5 volts exist across C3 and C4. Therefore, the total charge across C5 is 10 volts. Since the voltage across C3 and C4 are equal in amplitude (5 volts) and of opposite polarity, the output across load resistor RL is the algebraic sum or zero.

When the input signal reverses polarity, the secondary voltage across L2 also reverses polarity. The cathode of CR1 is now positive with respect to its anode, and the anode of CR2 is negative with respect to its cathode. Under these reverse-bias conditions neither diode conducts, and there is also no output. Meanwhile C5 retains most of its charge because of the long time constant offered by R1 and R2 and discharges very slightly.

When a tuned circuit operates at a higher frequency than resonance, the inductive reactance of the coil increases, while the capacitive reactance of the tuning capacitor decreases. Therefore, above resonance the tank is predominately inductive and acts like an inductor. Hence the secondary current (is) lags the primary voltage ep. Therefore, when an input frequency higher than the center frequency is applied to the detector circuit, a phase shift occurs. Although secondary voltages e_1 and e_2 are still 180 degrees out of phase, they are also 90 degrees out of phase with the current (is) which produces them. Thus the change to a lagging secondary current rotates the vector in a clockwise direction and e_1 is brought nearer in phase with primary voltage ep, while e_2 is shifted further out of phase with ep. Thus the vector sum of ep and e_1 is now larger than that of ep and e_2. Therefore, above the center frequency the voltage applied to the cathode of CR1 becomes greater than the voltage applied to the anode of CR2.

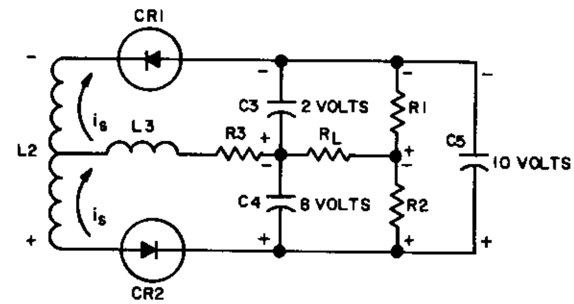
Consider now the manner in which the diodes operate with the discriminator voltages developed above resonance, as discussed above. When a positive input is applied to L1 the same polarity as in the previous example discussed above exists, namely CR1 cathode is negative and CR2 anode is positive, and both diodes conduct. However, e_1 is now greater than e_2. Therefore, diode CR1 conducts more than diode CR2, and C3 charges to a higher voltage than at resonance, as shown in the accompanying simplified illustration.



Current Flow and Polarities Above Resonance

Thus, we assume in the figure an 8-volt charge on C3 and only a 2-volt charge on C4. Since C3 is positive with respect to C4, the output is a 6-volt positive signal. Meanwhile, capacitor C5 still remains charged to the sum of these voltages or 10-volts, as originally stated. When the input signal reverses polarity, the polarity of the secondary also reverses, biasing both diodes in the opposite direction, and preventing conduction. During the non-conducting period, C5 discharges very little because of the long time constant.

When a tuned circuit operates at a lower frequency than resonance, the capacitive reactance of the tuning capacitor increases, while the inductive reactance of the tank coil decreases. Therefore, below resonance, the tank is predominately capacitive and acts like a capacitor. When an input frequency lower than the center frequency is applied to the detector circuit, a phase shift also occurs and secondary current is leads the primary voltage e_p. Although secondary voltages e_1 and e_2 are still 180 degrees out of phase they are also 90 degrees out of phase with the current which produces them. Thus the change to a leading secondary current rotates the vector in a counterclockwise direction, and e_2 is now brought nearer in phase with e_p, while e_1 is shifted further out of phase with e_p. Thus the vector sum of e_p and e_2 is now larger than that of e_p and e_1. Therefore, below the center frequency the voltage applied to the anode of CR2 becomes greater than the voltage applied to the cathode of CR1 as shown in the accompanying simplified schematic.



Current Flow and Polarities Below Resonance

Once again CR1 and CR2 are conducting, but this time CR2 is conducting more than CR1, hence, capacitor C4 is charged to the larger voltage of 8-volts, while C3 is only charged to 2-volts. The output voltage across the load in this case is a negative 6-volts because C4 is charged negatively with respect to C3. Again the charge across capacitor C5 consists of the sum of the voltages across C3 and C4, or 10-volts as originally developed.

When the input signal reverses its polarity, the signal across the secondary also reverses its polarity. The cathode of CR1 is now positive with respect to its anode and the anode of CR2 is negative with respect to its cathode. Under these conditions, neither diode conducts, but the time constant of C5 together with R1 and R2 maintains the current through the load in a negative direction until the next cycle of input, and C5 discharges but slightly.

The output of the ratio detector adjusts itself automatically to the average amplitude of the input signal. Through the action of resistors R1 and R2 together with capacitor C5, audio output variations which would occur due to r-f amplitude variations in the input (such as noise) are eliminated. Since C5 charges to the sum of the voltages developed across R1 and R2, any amplitude variations at the input of the detector tends to change the voltages across R1 and R2, but because of the long time constant of C5 across these resistors, these voltages are held to a minimum. Before C5 can charge or discharge to the higher or lower amplitude variation the impulse disappears, and the difference in charge across C5 is so slight that it is not discernible in the output. Because the voltage across C5 remains relatively stable and changes only with the amplitude of the center frequency, and since it is negative with respect to ground, it is usually used for automatic volume control (AVC) applications.

Capacitors C6 and C7 together with resistor R5 form a low pass filter which attenuates the high audio frequencies and passes the lower frequencies. This is known as a de-emphasis network, which compensates for the pre-emphasis with which the high frequencies are transmitted, and returns the audio frequency balance to normal. When pre-emphasis is not employed these parts are not needed.

FAILURE ANALYSIS.

No Output. A defective discriminator transformer, T1, shorted tuning capacitor C1 or C2, an open output resistor R5, an open coupling capacitor C8, or shorted filter capacitors (C6 or C7) will produce a no-output condition. Check the continuity of the windings of T1 with an ohmmeter. Check capacitors C1, C2, C6 and C7 for shorts and capacitor C8 for an open with an ohmmeter, and measure the resistance of R5. If any of these checks fail to restore the output check all capacitors for value with an in-circuit capacitance checker. Note that while one defective diode will produce a partial loss of output, both diodes must fail to cause a complete loss of output.

Low or Distorted Output. A defect in nearly any component of the detector will cause the output to be either low or distorted. Therefore, it is good practice to use an r-f sweep generator and an oscilloscope to locate the trouble. Ground the grid of the last I-F stage and connect the r-f sweep generator to the detector input, and connect the oscilloscope to the detector output. With the sweep generator set to produce an output which varies above and below the center frequency, the pattern observed on the oscilloscope should be similar to the discriminator response curve illustrated previously. Defects in the response curve will cause either the entire curve or a portion of it to be distorted or flattened.

If the entire curve is distorted, the trouble may be caused by improper alignment or by a defect in transformer T1. First check to be certain that both primary and secondary circuits are tuned properly to the center frequency. If the detector is properly aligned, check capacitors C1 and C2 with an in-circuit capacitance checker. Check R1 and R2 for their proper value with an ohmmeter, and capacitor C5 for value and leakage with an in-circuit capacitance checker. If the trouble is still not located, it is most likely caused by a defect in transformer T1.

If only the upper portion of the response curve is distorted, the trouble may be caused by a defect in diode CR1, capacitor C3, or transformer T1.

Conversely, if only the lower portion of the response curve is distorted, the trouble may be caused by a defect in diode CR2, capacitor C4, or transformer T1.

VIDEO DETECTORS.

The semiconductor video detector is very similar to the vacuum tube video detector. Generally speaking, the video detector must handle a larger range of frequencies than the standard detector. Thus we usually find either shunt or series peaking, or both systems, used to compensate for loss of the higher frequencies. Actually, whether or not there is excessive loss of high frequencies is sometimes doubtful. For example, using the standard diode detector provides a broad response and it is the relative amount of loss of output voltage in response to frequency that is important. Thus in the case where the high frequency output tapers off gradually it is questionable if peaking is necessary. On the other hand, where the cutoff is rather sharp, then boosting circuits are in order.

The simplest circuit, of course is that of the diode video detector, however, this provides little or no gain since inherently the diode has no amplification. On the other hand by using a transistor type of detector, the emitter-base junction can provide the detection while amplification is obtained from the collector-base junction. Thus, in one stage both detection and amplification are obtained and fewer driver circuits are needed to boost the output amplitude sufficient to drive an indicator.

If the diode is used it is necessary to keep the input impedance level on the high side to maintain the rectification efficiency of the diode at a high level. On the other hand, a transistor can serve efficiently as a video detector into a relatively low value of impedance. The high base impedance provides the necessary high impedance input, while the output at medium or moderately low impedance matches the following video amplifier stage. Hence the general trend is to use triode video detectors, rather than diodes followed by extra stages of video amplification which do require adequate equalizing and peaking.

BASIC VIDEO DETECTOR.

APPLICATION.

The basic video detector is used in semiconductor receivers of the superheterodyne type to provide a high gain video output.

CHARACTERISTICS.

Uses either fixed or self-bias.

Is equivalent of a diode and one stage of transistor amplification.

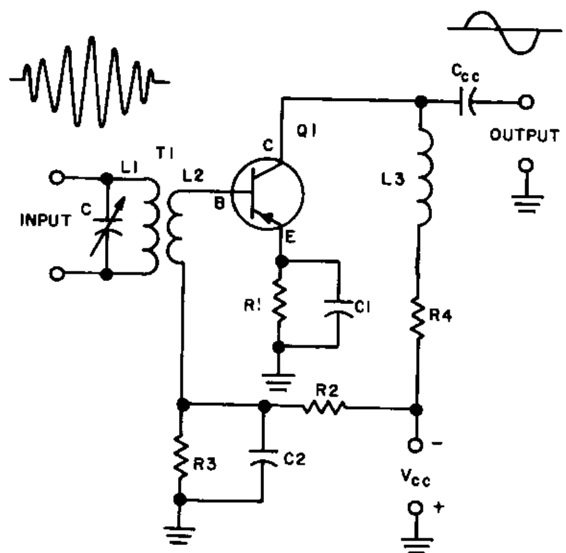
Uses video peaking circuits to provide good high frequency responses.

CIRCUIT ANALYSIS.

General. The operation of the basic video detector is identical to the operation of the AM diode detector previously discussed in Part A of this Handbook. The only difference lies in the use of the base-emitter junction of the transistor as a diode in place of a separate diode. Compensating circuits are added in the collector circuit to ensure better high frequency response. The reader should refer to the discussion of the Diode Detector, in Part A of this section of the Handbook, for proper background before proceding with the discussion of the semiconductor basic video detector.

Circuit Operation. The schematic of a typical transistor video detector using shunt peaking is shown in the accompanying illustration.

The base of transistor Q1 is connected to the untuned secondary of i-f transformer T1, with the primary tuned by capacitor C. Resistors R2 and R3 from a base bias voltage divider from the negative supply to ground, with the voltage drop across R3 supplying the base bias to Q1 through the



Basic Video Detector

secondary winding L2 of T1. R3 is bypassed by C2 to prevent a degenerative voltage from being developed across R3 with the instantaneous bias swings, thus allowing voltage divider R2 and R3 to provide a steady forward bias to the base of Q1. Resistor R1 is a conventional emitter swamping resistor used to stablize the transistor against thermal changes and, likewise, is bypassed by C1 to prevent degeneration in the emitter circuit and negative feedback effects. Inductor L3 is a shunt peaking inductance with R4 supplying resistance to widen the response. L3 also acts as the detector output load resistor across which the output voltage is developed and applied through coupling capacitor Ccc to the following stage, or direct to the CRT if sufficient drive exists.

When an input signal is applied to T1, the i-f frequency is selected by tuned circuit L1 and C, and this i-f together with any modulation component is inductively coupled through secondary L2 which is left untuned for a broad response, and the signal is applied to the base of Q1. The emitter-base junction of Q1 acts as a rectifier and instantaneously changes the bias in accordance with the low frequency variations of the modulation envelope. Any remaining i-f is bypassed through capacitors C1 and C2 to ground and has no effect on circuit operation. As the audio envelope of the received signal changes the bias on Q1, the collector current is varied likewise, and the collector current fluctuates in accordance with the modulation. The audio frequency variations are bypassed across emitter resistor R1 by capacitor C1 so that only the long time temperature variations can produce a voltage change across R1. However, the flow of collector current through L3 and R4 produces a change of collector voltage on the collector side of the choke. A positive modulation swing causes a decrease of forward conduction and raises the instantaneous collector voltage. Likewise, a negative audio excursion causes an increased forward bias and conduction, and the collector voltage of Q1 reduces. Since only a small change in base current causes a large change in collector current, amplification of the detected signal is obtained in the collector circuit of Q1 and appears as a larger output voltage across L3 and R4. By resonating L3 with the stray capacitance in the circuit, the normal drop off in amplitude at higher frequencies is compensated for and the high frequency range is extended. Resistor R4 keeps L3 loaded down so that the overall frequency response of the detector is broadened. As the output voltage is developed across L3 it also is applied through Ccc to the output. Where the output voltage is sufficient the CRT may be driven directly. Where the voltage is not sufficient, an additional voltage amplification driving amplifier stage is added to increase the overall drive, as required.

FAILURE ANALYSIS.

No Output. An open input transformer, an open base circuit, emitter circuit, or collector circuit, as well as a defective transistor or open coupling capacitor can cause a no-output condition. Check the collector, base, and emitter bias with a high resistance voltmeter. Voltage at the collector indicates that L3 and R4 are not open, while emitter voltage indicates that R1 is not open or shorted. Likewise, base bias indicates that voltage divider R2 and R3 is operating, and that secondary L2 of T1 has continuity. With these voltages obtained and no output, either winding L1 of T1 is open or shorted, or Ccc is open. Check C and Ccc with an in-circuit capacitance checker, and also check the continuity of T1 primary L1 with an ohmmeter. If base bias is zero R3 is shorted, also check C2 for capacity with an in-circuit capcaitance checker. If the emitter voltage is also zero R1 is shorted by C1, however, the transistor will still function and produce an output which will vary with temperature. If there is no collector voltage, check the supply voltage to make certain it is not at fault, check the value of R4 with an ohmmeter and check L3 for continuity.

Low Output. High base bias, low collector voltage, or a defective transistor can cause a no-output condition. If bias voltage divider resistor R3 changes to a higher value of resistance, or if R2 becomes lower in value, the net effect is to make the total base bias higher, check these resistors with an ohmmeter. If R4 becomes higher in resistance, the collector voltage will also drop and reduce the output. Check R4 with an ohmmeter. If a high bias is measured across emitter resistor R1, capacitor C1 is open, check C1 for value with an in-circuit capacitance checker. Do not neglect the possibility that the input tank controlled by capacitor C may be detuned from the desired i-f input frequency. If not shorted, tuning C will peak the response. If the response does not peak as C is tuned around the input frequency, check capacitor C for a short or open on a capacitance meter.

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

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.

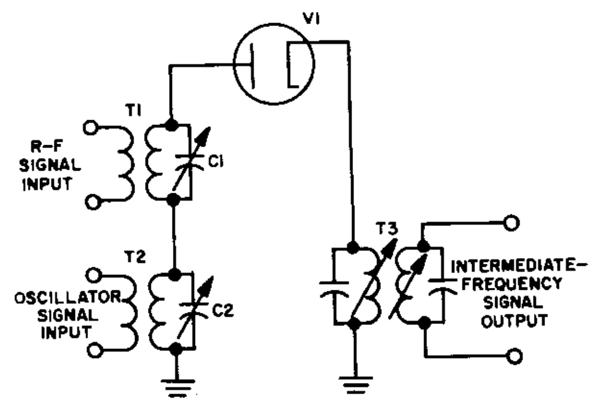
General. The diode mixer is one of the simplest types of mixer circuits employed as a frequency converter. In this application, voltages of the two input frequencies to be heterodyned are applied in series to the diode, and the mixer-output voltage is obtained from a tuned transformer or impedance-coupling 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.

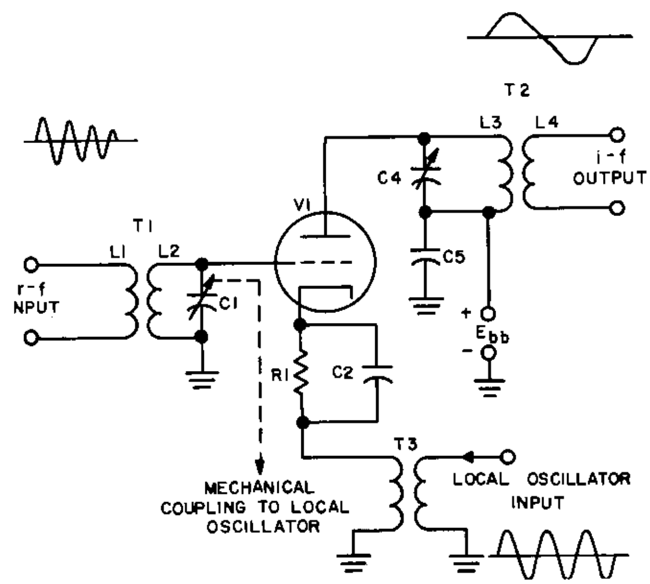
General. The purpose of the mixer stage is to convert the incoming r-f frequency, usually into a lower frequency, which contains the same characteristics (modulation) as the original r-f frequency. This lower output frequency, called the intermediate or i-f frequency, remains the same, regardless of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

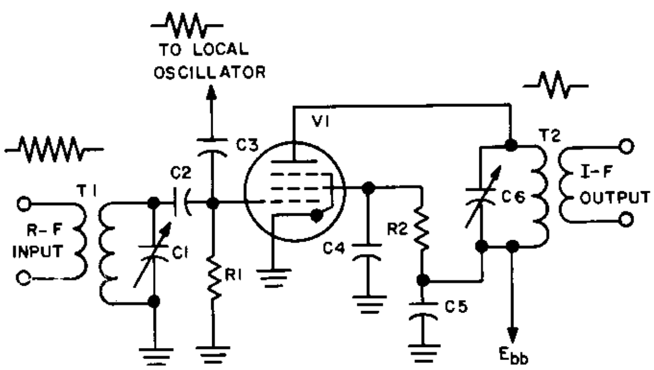
CIRCUIT ANALYSIS.

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 C1, 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).

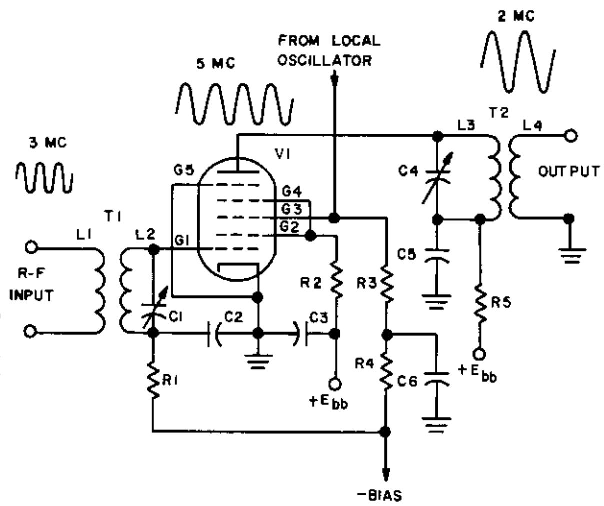
The space charge greatly limits the plate voltage swing, so a negative grid (G5) is placed between screen and plate, and its negative charge diverts electrons back to the plate.

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 nonlinearly, 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 resistance. 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.

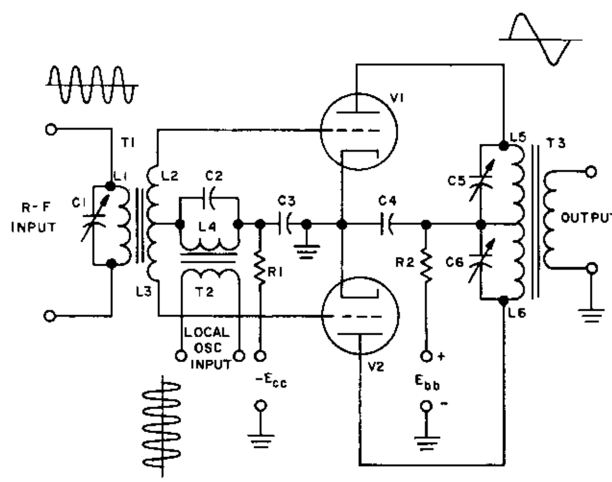
General. The purpose of the mixer stage is to convert the incoming r-f frequency, usually into a lower frequency, which contains the same characteristics (modulation) as the original r-f frequency. This lower output frequency, called the intermediate, or i-f frequency, remains the same, regardless of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

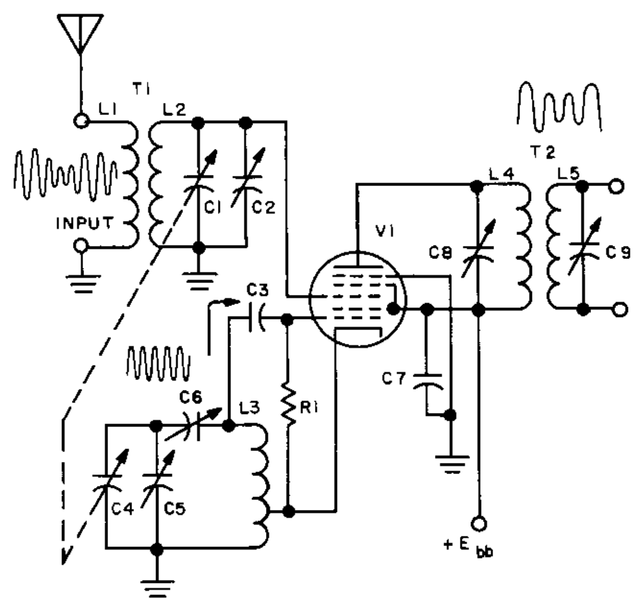
Basically, the pentagrid converter can be divided into two separate circuits; an electron-coupled oscillator (formed by the cathode, inner control grid, and screen grid) and a conventional pentagrid mixer with separate grid injection.

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

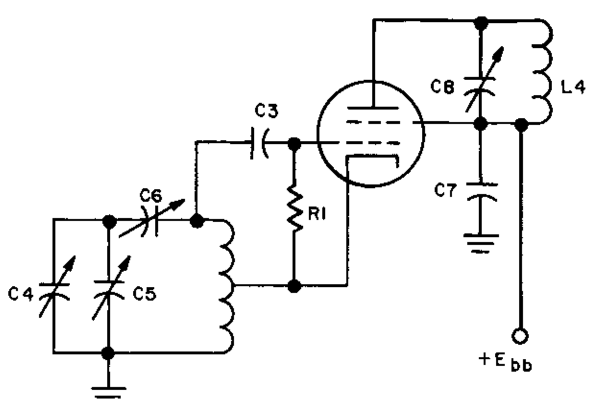
R-f signals arriving at the antenna are impressed across L1 and coupled across transformer T1 to the secondary tuned tank formed by inductor L2 and capacitor C1. C2 is a trimmer capacitor used to track the high frequency end of C1 during alignment. The selected r-f frequency is inserted into the converter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

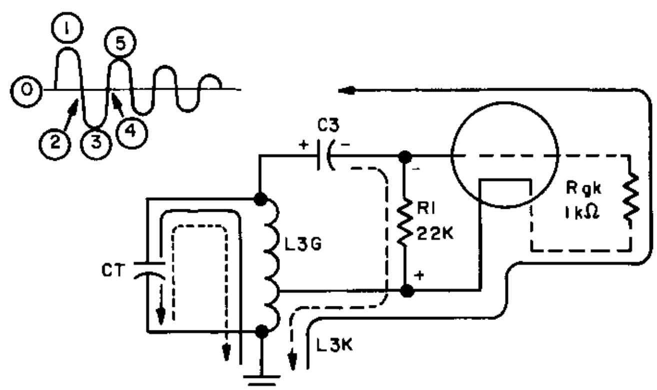


Oscillator Section

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 (discharge 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 regenera ive (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 originol 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 intermittant 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.

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.

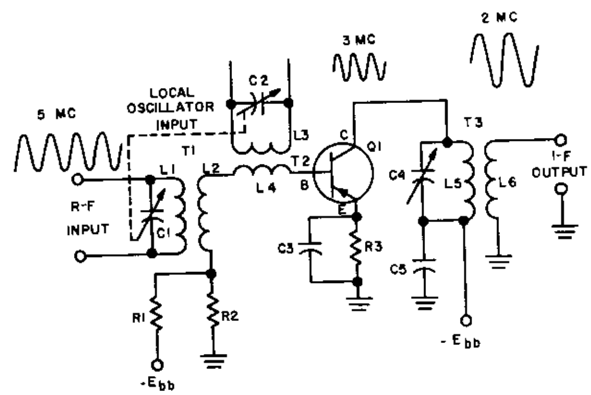
CIRCUIT ANALYSIS.

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