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

FAILURE ANALYSIS.

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

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

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

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

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

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

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

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

MICROWAVE DIODE MIXER.

APPLICATION.

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

CHARACTERISTICS.

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

Transit time effects are minimized.

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

Requires a separate local oscillator to supply the heterodyning voltage.

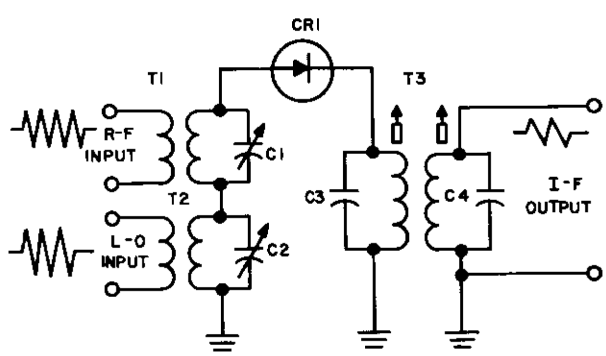
Output circuit is tuned to the i-f frequency.

Conversion gain is less than unity.

CIRCUIT ANALYSIS.

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

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



Microwave Diode Mixer Equivalent Circuit

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

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

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

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

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

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

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

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

FAILURE ANALYSIS.

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

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

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

AUTODYNE CONVERTER.

APPLICATION.

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

CHARACTERISTICS.

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

Acts as a local oscillator.

Acts as an i-f amplifier.

Acts as a self-contained mixer.

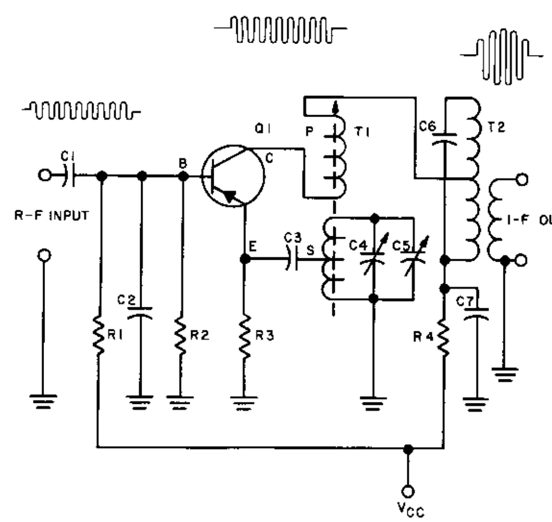
Has lower conversion gain than circuit using a separate oscillator.

CIRCUIT ANALYSIS.

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

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

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



Typical Autodyne Converter Circuit

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

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

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

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

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

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

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

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

FAILURE ANALYSIS.

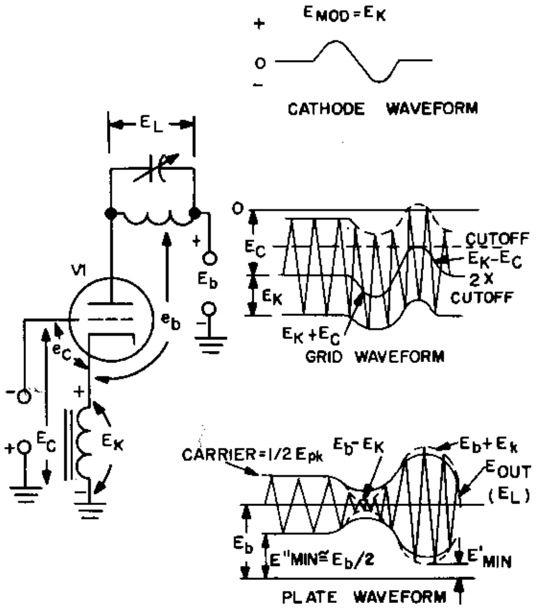
General. When making voltage checks use a vacuum tube voltmeter to avoid the low values of shunting resistance employed on the lower ranges of conventional voltmeters. Be careful also to observe the proper polarity when checking continuity with an ohmmeter, since a forward bias through any of the transistor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

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

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

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

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



Operating Polarities and Waveforms

and only the carrier is produced. While this plate current is about 20 percent higher than it would be in the grid modulator, and represents about 70 percent of the plate modulation rating of the tube, it is the normal value which is doubled at the modulation peak. Therefore, additional power is required when the modulation drives it above the carrier level. The increase of carrier power above that of the grid modulator is obtained from the transmitter power supply by a change in plate efficiency.

As the modulation cycle progresses sinusoidally below zero toward the negative peak, the cathode bias is further reduced by the negative-going cathode voltage. Since the cathode voltage is now in a direction to add to the effective plate supply, the instantaneous plate voltage is increased. With a reduced bias and an increased plate voltage, the plate current is increased. At the peak of the cycle the instantaneous plate current is twice the normal (carrier) value. At this time the drop across the load is the greatest, and the actual plate voltage reaches its minimum value, near zero. The minimum value of plate voltage (for triodes) is kept above the maximum positive grid swing at this point to prevent excessive grid dissipation. (If it were zero, the grid would act as the plate during this interval.) Once the negative modulation peak is reached, the modulation signal again goes in a positive direction toward the zero or carrier level. The cathode voltage is now going in the opposite direction (increasing positive), and once again opposes the plate voltage, increases the total effective grid bias, and reduces the plate current. Thus we can say that the modulation signal effectively drives the tube to twice the normal plate voltage and current on the peaks of modulation, and to almost zero on the troughs of modulation (the negative peaks).

FAILURE ANALYSIS.

No Output. Lack of output should first be isolated to failure of the r-f amplifier stage or the modulator and speech circuits. Even though the modulator is operative, an open rfc or tank circuit, a shorted or gassy electron tube, or lack of grid excitation to the r-f amplifier will produce a no-carrier indication. An open modulator primary will permit a carrier to appear, but no modulation will occur, while an open secondary will produce neither a carrier nor any modulation. Observation of the amplifier r-f plate current meter will determine whether the circuit has continuity, while tuning for a maximum indication with a resonant dip will determine whether sufficient drive and load and the proper bias are present for operation without modulation. Grid-drive-meter indications will also show whether there is proper r-f drive. When the tank can be resonated for a minimum dip and then loaded to maximum plate current with a normal grid-current indication, the trouble is in the modulator or speech circuits.

Lack of grid drive places the trouble in the exciter stages of the transmitter or in the coupling network to the final stage. Lack of plate current indicates possible power-supply trouble, an open-circuited r-f stage, or a defective modulation transformer; if screen grid tubes are used, lack of plate current can also be due to an open screen-voltage dropping resistor or a short-circuited screen bypass capacitor.

High transmitter plate current usually indicates short-circuited components, a lack of bias, or improper tuning; low transmitter plate current indicates excessive bias, high-resistance joints, low tube emission, lack of sufficient r-f drive, a possible lack of sufficient coupling to the load, or possible antenna or transmission -line trouble. A simple resistance analysis made with the power off and the **high-voltage supply** grounded for safety usually will quickly determine the defective components, using the meter indications as a guide to the most probable location of the trouble.

Low Output. Determine first whether the low output is due to lack of sufficient audio drive or to an actual reduction in the percentage of modulation. Low modulation is usually caused by lack of sufficient audio output, and may be the result of a reduced setting of the audio gain control or from trouble in the speech amplifier stages. An oscilloscope should be used to view the waveform to determine whether 100 percent modulation is being obtained. For quick, simple tests of modulation percentage, the trapezoidal waveform check is useful. The envelope or waveform check, however, will show the percentage of modulation and also waveform distortion at the same time, so that it is usually more useful. Too high a grid bias will cause a reduction of output and an inability to obtain 100 percent modulation with the same r-f drive. The grid bias can be easily checked with a voltmeter (use an rfc in series with the test prod). A reduced screen voltage is most likely of all to produce a low output, usually with overmodulation or distortion, since the plate and screen swings will be excessive. Such a condition may be caused by too heavy a screen current, causing a large drop in the screen-voltage dropping resistor, by a defective screen voltage dropping resistor, or by a partially shorted screen bypass capacitor. Where a separate screen supply is used, the latter trouble is the most likely.

Lack of proper tuning can also cause a low output. Too light a loading or too high an excitation will cause a flattening of the upward peaks of modulation, as in grid modulation. The antenna loading must be such that a further increase in loading causes a slight drop in antenna current. For optimum performance, the grid excitation should also be adjusted for minimum plate dissipation with maximum power in the antenno. The cathode current will be practically constant with or without modulation when the proper operating conditions have been established.

Improper load matching by the modulation transformer will produce a lack of sufficient audio power, as well as distortion. Where taps are provided, the proper tap may be selected. Where no taps are provided and the load appears to be mismatched when checked with an oscilloscope, the tube or the transformer may be defective. Substitution of a known good tube or transformer will eliminate these components from suspicion. Lack of sufficient filament emission in the final amplifier tube can cause peak flattening, inability to obtain 100 percent modulation, and distortion.

Distorted Output. Distortion can occur from a number of causes, and is easy to detect when monitoring the audio modulation. Overmodulation will cause a chopping off of the carrier (carrier shift), producing severe interference to stations operating near the transmitter frequency, as well as distortion.

In stages operating on the same input and output frequencies, there is always the possibility of sufficient internal plate-to-grid feedback to cause self-oscillations accompanied by severe distortion, particularly on the peaks of modulation. When this occurs with triodes, it indicates the necessity for readjustment and a check of the neutralization. With pentodes and tetrodes it can occur at the high frequencies, particularly if the lead dress is changed after a repair. Self-oscillation can usually be recognized on an oscilloscope by the characteristic fuzzy appearance of the display. Plate current meter indications will usually be excessive and erratic when this condition is present.

Lack of sufficient capacitance to supply the peak power requirements can occur through loss of filter capacitance, and can cause peak flattening with consequent distortion. Usually, however, such a condition will be indicated by a hum on the carrier, or in the modulation, before the distortion is excessive enough to notice unless an oscilloscope is used to monitor the transmissions.

A similar condition caused by lack of sufficient filament emission in the r-f amplifier stage will also cause peak flattening and resulting distortion. Sometimes this condition can be observed by noting the inability of the r-f output meter to respond to heavy modulation peaks, accompanied by a gradual reduction in plate current readings over a long period of time. Under normal conditions, the r-f ammeter will indicate approximately a 22 percent increase in output current at 100 percent modulation.

Improper bias and drive conditions will also cause distortion, and usually are accompanied by a reduction in output or an inability to attain 100 percent modulation.

SERIES MODULATOR.

APPLICATION.

The series modulator is used to amplitude modulate a carrier (r-f) signal with an audio (or video) intelligence with a minimum of circuitry.

CHARACTERISTICS.

Uses two triodes connected in series.

Has a wide bandpass.

Is critical to adjust.

Used as either a high-level or low-level modulator.

Inefficient in comparison to other methods of producing AM.

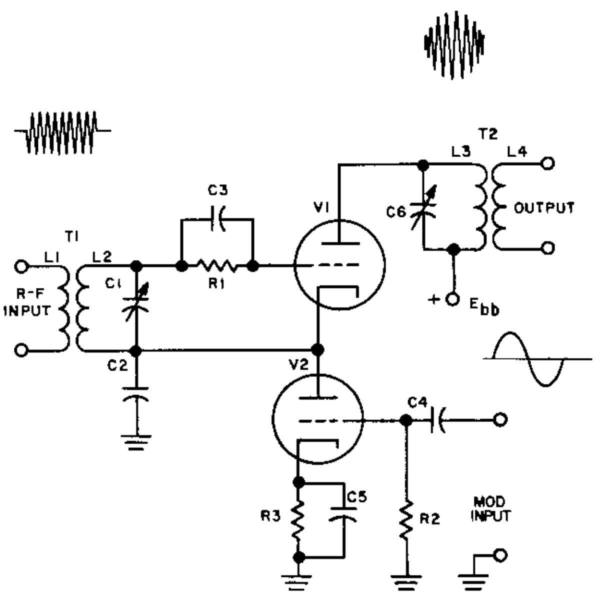
CIRCUIT ANALYSIS.

General. The series plate modulator is used in a-m transmitters where it is desired that the modulator stage pass a wide band of frequencies. Because of its inherent wideband characteristics and relatively good quality, the series modulator is employed primarily in television applications; however, because adjustments are critical, the series modulator has not been widely accepted for common usage. Basically, the circuit consists of a triode modulator and a Class C r-f amplifier connected in series using a common dc plate supply. The modulator triode may be connected in either the plate or cathode circuit of the r-f amplifier with operation remaining basically the same, regardless of which method is employed. Only the cathode connected circuit is discussed in detail.

Circuit Operation. A cathode connected series modulator is illustrated in the accompanying schematic diagram.

Modulator tube V2 is biased Class A by cathode resistor R3. Capacitor C5 by passes the cathode resistor to prevent degeneration and helps to maintain a constant bias voltage. Resistor R2 is the grid return resistor with C4 acting as a coupling and dc blocking capacitor.

R-f amplifier V1 is biased Class C by the series grid leak circuit comprised of R1 and C3. Transformer T1 couples the r-f signal into the tuned grid tank formed by secondary winding L2 and capacitor C1. Capacitor C2 is the cathode bypass capacitor and prevents degeneration in the cathode and r-f from entering the audio circuits. C6 and L3 form a tuned plate tank (load) for V1, and L4 inductively couples the signal into the following stage.



Series Modulator

When power is initially applied to the circuit no bias exists on either of the series connected triode tubes. As a result, plate current readily flows through the tubes to voltage source, Ebb. As the current flows through R3 and V2 voltage is developed across each component. The voltage dropped across R3 biases the modulator Class A so that any signal arriving on the grid will be faithfully reproduced in the plate circuit. The voltage dropped across the modulator tube, V2, protects the r-f amplifier in the event r-f drive is lost because of failure in the oscillator or multipliers. It will be helpful to remember that placing a positive potentiol on the cathode has the same effect as placing an equally negative potential on the grid. For the following discussion assume that no audio modulation voltage is applied to the grid of V2 and plate voltage remains relatively stable.

R-f signals arriving from the oscillator (or multiplier) stage are impressed across L1, the primary winding of T1. The signals are transformer coupled into the secondary tuned tank formed by inductor L2 and capacitor C1. The grid tank is tuned to the desired r-f frequency by C1 which is variable over a short range.

On the positive excursions of the r-f signal the grid is driven positive. Grid current flows and C3 charges quickly. As the signal swings negative, grid current ceases to flow and C3 begins discharging through R1 developing a negative voltage which is applied to the grid. Discharge time is much slower than charge time because of the large grid leak and consequently, the charge on C3 is not completely dissipated before the next positive excursion of the r-f signal. The cycle repeats itself and eventually, after a few more cycles, the voltage applied to the control grid stabilizes. Thus, the tube is now biased by the grid leak (signal) bias on the control grid in addition to the bias voltage applied to the cathode. The sum of the voltage applied to the cathode and control grid of V1 biases the tube Class C (below cutoff) so that only the positive peaks of the r-f input signal results in plate current flow; therefore, plate current is broken into pulses at the signal frequency. Capacitor C2 by-posses any r-f plate current variation in the cathode to ground and prevents degeneration effects. The parallel resonant tank formed by C6 and L3 oscillates (flywheel effect) every time a pulse of current flows in the plate circuit. Hence, even though plate current flows in pulses, tank current flows for the entire cycle and a linear sine wave at the resonant frequency is transformer coupled into L4.

The preceding discussion describes the operotion of the r-f amplifier with no modulation signal applied, and if operation was limited to this condition no intelligence could be transmitted. The following discussion concerns operation when modulating signals are applied.

A modulating signal from the final speech (or video) amplifier is r-c coupled through coupling capacitor C4 onto the grid of V2. R2 is the grid return resistor and provides a low impedance path for dc return current. As the positive half-cycle of the modulating signal is applied to the grid, V2 bias is decreased and the cathode current through V2 increases. Consequently, V2 plate voltage decreases. Decreasing the plate voltage of V2 is the same as decreasing the plate voltage of V1 (since both tubes are in series) and, in effect, reduces the cathode bias from V1 to ground so that conduction in V1 is increased; this results in developing an increased output across the plate load (resonant tank). Conversely, when the modulating signal swings negative the opposite effect takes place, and the output across the plate load decreases.

Hence, in this application, the plate voltage decreases to nearly zero (with respect to the cathode) at maximum output, and increases to nearly the supply value, Ebb, at minimum output. Unlike other modulators, no voltage doubling takes place due to the absence of a reactive element (inductor) in the plate circuit. Instead, the circuit is initially adjusted so that full carrier output is obtained with half the supply voltage applied, so that swinging it from zero to the full supply value is the same as doubling the voltage in other types of modulators.

If the modulating signal is of sufficient amplitude to overdrive V1 into saturation, a loss of intelligence (clipping) results for the period of time the tube is in saturation. Hence, transmitters are usually equipped with a modulator gain control to insure that the modulating signal does not exceed design limitations. From basic theory it is known that when two signals are injected simultaneously into a non-linear device, new frequencies appear in the output. When the r-f and modulator signals are injected into V1, which is operated as a Class C (non-linear) r-f amplifier, (whose output varies as the square of the applies plate voltage) two additional frequencies appear in the output; namely, the sum and difference frequencies. In transmitters these "new" frequencies are referred to as upper and lower sidebands and represent approximately 1/6 of the total power, per sideband with 2/3 of the power in the carrier. The sidebands contain the same modulation as the carrier and in some transmitters, such as single-sideband (ssb) and double sideband (dsb), the sidebands are transmitted in preference to the carrier. However, in this instance the carrier and two sideband frequencies are selected by the tuned tank and coupled into the output circuits by the transformer action of T2.

FAILURE ANALYSIS.

No Output. A loss of r-f or audio signal will result in either a no output or unmodulated carrier condition. Use an oscilloscope equipped with a high impedance probe to check the r-f (across L1) and audio (across input terminals) signals. If either signal is absent the modulator will not function properly, and the absent signal must be secured before further troubleshooting is accomplished. Next, check each tube element on the base of the tube socket for correct operating voltages. Check the bias voltages carefully as an abnormal bias voltage may cause erroneous readings on the plate elements. If voltage are abnormal, use an ohmmeter to measure the dc resistance of R3, R1 and inductors L1, L2, and L3 also, use an in-circuit capacitor checker to check C1, C2, C3 and C5 for a shorted or leaky condition.

Weak or Distorted Output. A weak or distorted output will be caused by: weak or distorted input signals; improper bias; improper power supply voltages; defective tubes; or improper tuning or loading of the grid or plate tank.

DOUBLE SIDEBAND MODULATOR.

APPLICATION.

Double sideband modulation is used in double sideband communication systems where upper and lower sideband are transmitted and the carrier frequency used to generate these sidebands is eliminated.

CHARACTERISTICS.

Generates upper and lower sidebands at high power levels while suppressing the r-f carrier.

Utilizes two push-pull connected triodes operated class C.

Uses low level grid modulation.

Modulating signal is applied to the control grids in push-pull, while the r-f carrier is applied to the control grids in parallel.

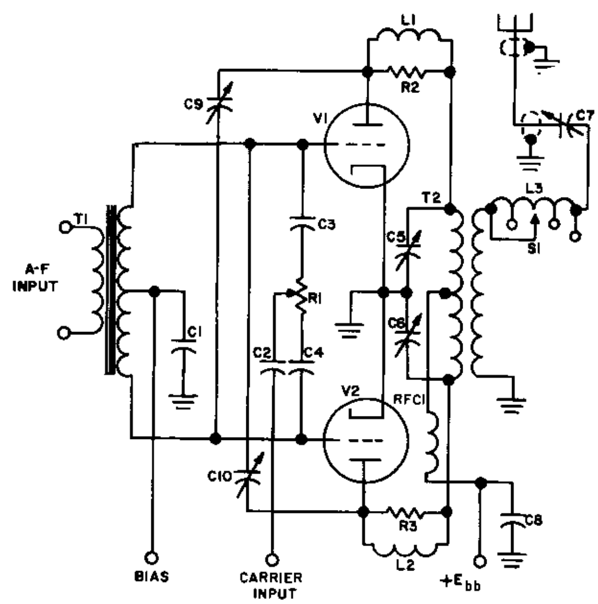
Utilizes nonlinear characteristics of electron tubes to generate sidebands.

Even-order harmonics are cancelled through push-pull action.

CIRCUIT ANALYSIS.

General. Double sideband communications systems differ from conventional a-m systems and from single sideband systems in that both sidebands and no carrier is transmitted. It should be noted that carrier elimination is achieved in a specially designed power amplifier. The modulator is a conventional AM modulator. This discussion will pertain to the power amplifier, since the power amplifier is the only unit in the DSB transmitter which is significantly different from units in the conventional full carrier AM transmitter. Single sideband systems achieve the same result by transmitting only one sideband. Both DSB and SSB provide the advantage of eliminating "whistles" or beats caused by the beating of the carrier with other carriers and sidebands in the receiver, since both DSB and SSB do not transmit a carrier. At first glance it may appear that a single sideband system makes more effective use of the available transmitter power, since the SSB transmitter concentrates all of the available transmitter power into one sideband while the DSB transmitter transmits two identical sidebands. However, this apparent gain of SSB over DSB is not realized at the receiver output, since double sideband signal voltages combine vectorially in the receiver detector and produce audio frequency voltage proportional to twice that produced by one sideband. For example, a double sideband r-f envelope containing 100 watts (50 watts in each sideband) produces the same receiver audio output as a 100 watt SSB r-f envelope (all 100 watts in the sideband). It has been reasoned that a double sideband system can provide results equal to or greater than that produced by a SSB system. In a conventional full carrier AM system the r-f carrier transmitted with the sidebands heterodynes with the sidebands in the receiver detector circuit and audio frequency voltages are produced. In the DSB system and in the SSB system no carrier is transmitted and an artificial carrier, generated in the receiver must be combined with the sideband, or sidebands in the case of DSB, to properly demodulate the signal. This artificial carrier frequency must be very stable and must be as close as possible to the frequency of the carrier used to generate the sidebands in the transmitter in order to keep distortion of intelligence to a minimum. One of the arguments in favor of DSB over SSB is the distortion caused by the phase shift inherent in SSB due to the loss of the opposing phase shift of the other sideband. This shift can be minimized by maintaining a sufficiently high level of carrier insertion at the receiver. This phase shift has little effect on voice transmissions but pulse and data transmissions may be seriously affected. In a DSB system the effects of this phase shift are greatly minimized since the phase shift of one sideband tends to oppose the phase shift of the other sideband. The DSB system, however, requires that the locally inserted carrier be of the same phase relationship as the original modulation at the transmitter. This is accomplished by the use of a phase-locked oscillator to generate the carrier to be reinserted in the receiver. Another advantage seen in DSB transmission over SSB is the possibility of greater reliability of reception under varying conditions of fading. Under such conditions one sideband may be phased out by multi-path fading while the other sideband may not be excessively attenuated. By definition, selective fading results when the various frequency components of a transmission are not received exactly as transmitted with respect to power levels and phase relationships. The adverse effects of this condition on full carrier AM is distortion of received intelligence, and decreased receiver output. It can then be said that SSB is not subject to selective fading since only one sideband is transmitted. However, if propagation conditions are such that the frequency of the sideband being transmitted is excessively attenuated the receiver output is likewise decreased, whereas a DSB system operating at the same frequency will probably maintain satisfactory communications since the other sideband will probably be unaffected. Another advantage of DSB over SSB is the simplicity of the DSB transmitter. To convert a conventional full carrier AM transmitter to a DSB suppressed carrier transmitter only the power amplifier must be modified. The modified DSB power amplifier closely resembles the balanced modulators used in SSB transmitters. The DSB power amplifier discussed here consists of two push-pull connected triodes operating class C with r-f carrier applied to the control grids of both tubes in parallel (in-phase), and the audio modulating signal applied to the control grids in push-pull (180° out-of-phase). In push-pull amplifier circuits a push-pull input is required to produce an output and an in-phase input cancels in the output. The r-f carrier and the audio modulation present simultaneously on the control grids of the tubes beat together, and four basic frequencies are present in the plate circuit of the modulator tubes. These frequencies are the original r-f carrier, the original audio modulation and sum-difference frequencies generated as a result of heterodyning. Heterodyning results when two or more frequencies are applied to any element of a nonlinear resistance such as an electron tube or a transistor. If the reader desires detailed information on heterodyning he may find it in the introduction to chapter 13 of this Handbook. The r-f carrier frequency present in the plate circuit is canceled out by push-pull action in the output transformer (the r-f carrier is applied to the push-pull amplifier in parallel) and the output transformer presents a very low impedance to audio frequencies. Therefore, the original audio modulating signal is not developed in the output. The generated sidebands, which are a product of the in-phase r-f carrier input and the out-of-phase audio modulation input are therefore, out-of-phase at the plates of the tubes and add in the output transformer, rather than cancel as in-phase signals do, and they are inductively coupled to the antenna circuit through the output transformer. The power amplifier described here uses two power triodes, however, the use of power tetrodes may be encountered.

Circuit Operation. The following schematic diagram illustrates a final power amplifier designed to suppress or eliminate the r-f carrier and produce a double sideband output.



Double Sideband Generator

Transformer T1 couples the audio modulation from the modulator to the grids of the power amplifier. Capacitor C1 places the centertap of T1 at a-f ground potential so that 180° out-of-phase audio voltages are developed across the top and bottom halves of the secondary of T1, and are felt on the grids of power amplifier tubes V1 and V2. Coupling capacitor C2 couples the r-f carrier from the preceding stages to the slider of carrier balance potentiometer R1, which provides a means of varying the amplitude of the r-f carrier coupled to the grids of V1 and V2 with respect to each other. Capacitors C3 and C4 couple the r-f carrier from carrier balance potentiometer R1 to the grids of V1 and V2, respectively. Power triodes V1 and V2 are the nonlinear devices used to generate upper and lower sidebands at high power levels. Resistor R2 which is shunted by inductor L1, and resistor R3 which is shunted by inductor L2 form parasitic suppressor networks intended to decrease the tendency for parasitic r-f oscillations to develop. Center-tapped transformer T2 serves as the push-pull output transformer for the power amplifier and capacitors C5 and C6 form a split-stator type of tank capacitor used to resonate T2 to the output frequency. Radio frequency choke RFC1 together with bypass capacitor C8 prevent r-f energy from entering the power supply. Tapped inductor L3, whose inductance can be varied by switch S1, together with variable capacitor C7 couple the transmitter output to a coaxial transmission line which transmits the sideband r-f energy to the antenna. Since triodes are used the circuit must be neutralized or the relatively high value of grid to plate capacitance of the triodes would provide a feedback path and the amplifier would break into self oscillations. Capacitor C9 and C10 couple r-f energy from the plate of one tube to the grid of the other and cancel or "neutralize" the effects of grid to plate capacitance and thus prevent self oscillations.

To more easily examine the operation of the DSB power amplifier assume first that only the r-f carrier is applied.

The r-f carrier is coupled from the preceding driver stage through coupling capacitor C2 to the slider of carrier balance potentiometer R1. The r-f carrier appears at both ends of R1 and is coupled in-phase through capacitors C3 and C4 to the grids of V1 and V2. The amplitude of the r-f carrier at the grid of each tube is controlled by the adjustment of half cycle, both plates draw an increasing amount of plate current (the input is in phase) and the voltage drop across each half of the tapped primary of the output transformer T2 is negative going, so that opposing voltages are developed in the transformer primary which cancel, and no output is produced. If the circuit is properly balanced by the adjustment of R1, these opposing signals are equal in amplitude and the carrier is effectively suppressed. Since the amplifier is operated with class C bias (approximately twice cut-off) only the peaks of the positive half cycle of the r-f input have an effect on conduction. Neither tube conducts during the negative half cycle of r-f carrier input and again no output is produced. Therefore, an output is not produced by the DSB power amplifier when only the r-f carrier is applied. When audio modulation is applied in addition to the r-f carrier, upper and lower sidebands are generated and are coupled through the output circuit to the antenna.

Audio modulation is applied to the primary of T1 and since the center tap of the secondary of T1 is placed at a-f ground potential by capacitor C1, audio modulation signal voltages are developed across each half of the winding, which are 180° out-of-phase with each other. This modulation signal is applied directly to the grids of V1 and V2. Capacitors C3 and C4 are of such a value that they present a high impedance to audio frequencies and, thus, prevent the out-of-phase audio modulation from crossing over from one grid to the other and canceling each other out. During the period when both tubes are driven into conduction by the positive half cycle of r-f carrier input, the audio modulation and the r-f carrier beat together, and sum and difference frequencies (sidebands) are generated as the result of heterodyning. Actually there are four basic frequencies present in the plate circuit of V1 and V2. There are the original r-f carrier, the original audio modulating signal, and the upper and the lower sideband. Other higher order harmonics are also present but are of little consequence. Of the frequencies present only the sidebands are developed in the output circuit since the r-f carrier cancels in the push-pull output transformer, as explained previously. The audio modulating frequency is not developed because of the low value of impedance offered by the r-f output transformer. The sideband frequencies, being a product of the out-of-phase modulating signal, are developed across the primary, of the output transformer and are inductively coupled through the secondary of T2 to the output circuit. The even order harmonics present in the plate circuit are cancelled through push-pull action and the odd order harmonics are shunted around the primary of T2 to ground by capacitors C5 and C6. The sidebands are coupled through inductor L3, whose inductance can be varied by switch S1, and variable capacitor C7 to the coaxial transmission line. L3, S1, and C7 match the impedance of the power amplifier output to the impedance of the coaxial line so that maximum power is transferred to the antenna and minimum power is reflected.

FAILURE ANALYSIS.

No Output. Dangerous high voltages are present in the power amplifier and all applicable safety precautions should be taken when working with the power amplifier. Since each branch of the power amplifier performs essentially the same function, failure of one branch is not likely to cause a no-output condition to exist. Failure of the power supplies or failure of the input or output circuits are likely causes of output. If the power amplifier is at fault, make resistance checks with the equipment denergized, and pay particular attention to the resistances measured from the plates to ground; since components having high voltages applied to them are more likely to breakdown and short than components having lower voltages applied to them. Capacitors C5, C6 and C8 would short the high voltage to ground if they broke down, and capacitors C9 and C10 would short the high voltage supply to the bias supply if either capacitor broke down. Capacitor C1 would short the bias supply to ground if it failed. Transformer T2, inductors L1 or L2 or RFC1 could become shorted to ground. This would also short the HV power supply to ground as well as a possible shorted tube. Insulation breakdown on any of the wires carrying high voltage could also be the cause of a shorted power supply.

If the no-output condition does not manifest itself in the form of blown H.V. fuses, lack of high voltage at the plates of V1 and V2 could be the trouble. Observing all applicable safety precautions, measure the plate voltage of the power amplifiers with the transmitter keyed. If there is no plate voltage on either tube, the power supply is defective or RFC1 is open. If proper plate voltage is applied but there is no output, failure of either the r-f carrier, or modulation, to reach the grids of V1 and V2 could be the cause of no output, since the DSB power amplifier, like the SSB balanced modulator, produces an output only when both inputs are present simultaneously at the grids. Presense of these signals can easily be determined by observing, with an oscilloscope, the waveform present at the grids of V1 and V2. If either input signal is missing, signal trace from the grids of V1 and V2 to the preceding stage to determine the defective component. Failure of T1 is a likely cause for no modulation drive to V1 and V2. Resistance checks of transformer windings and leakage checks to ground should reveal any defects that may exist in T1. Failure of R1, or an open C2, could prevent the r-f carrier from reaching the grids of V1 and V2, hence, no output would result. Failure of output transformer T2 could also result in a no-output condition. Resistance checks of transformer windings and checks for leakage to ground, and leakage between windings should reveal any defects existing in T2.

Low Output. A low output condition can be caused by defective tubes, improper power supply voltages, low amplitude inputs, or improper tuning of the output circuit. Observe all applicable safety precautions and check the high voltage applied to the plates of the power amplifier. Also check the bias voltage applied to the grids V1 and V2. If the tubes are good and the power supply voltages are correct, low output could be caused by insufficient r-f carrier, or modulation drive applied to the power amplifier. This condition can be checked by observing with an oscilloscope, the amplitude of the r-f carrier and the modulating signal on the grids of V1 and V2. If either input signal is weak on the grids of V1 and V2, check the amplitude of that signal at the point where it enters the power amplifier, in order to determine whether the defect exists in the power amplifier, or in the preceding stages. A defect in T1 such as a partially shorted winding or excessive leakage to ground could result in a decreased amplitude modulating signal on the grids of V1 and V2, and a partial failure of C2 or R1 could result in decreased amplitude r-f carrier on the grids of V1 and V2. Both situations could result in a low output. Likewise, if one of the input signals is unable to reach the grid of either V1 or V2 that branch of the power amplifier would be inoperative, since both modulating signal and r-f carrier must be present at the grid simultaneously to produce an output, and low output would result. If C3 or C4 opened, or R1 opened, the r-f carrier would not be coupled to the grid of either V1 and V2. Likewise, a similar situation would arise if either the top or bottom half of the tapped secondary of T1 become shorted. In this case the audio modulation signal would not be coupled to the grid of one of the tubes and low output could, again, result. Another possible cause of low output is a defect in the parasitic suppressors networks L1-R2 and L2-R3. If the resistor in either network opened, a decreased output could result since much of the sideband voltage would be dropped across the inductor shunting the open resistor.

Distorted Output. A distorted output condition may be caused by defective tubes, improper power supply voltages, excessive input drive, or a distorted input. Check the power supply voltages taking care to observe all safety precautions, and make any required adjustments, if necessary. If the output is still distorted it would be wise at this point to observe, with an oscilloscope, the amplitude and waveshape of the input signals. It should be noted that if the input signals are excessive or distorted the fault lies in the stages preceding the power amplifier.

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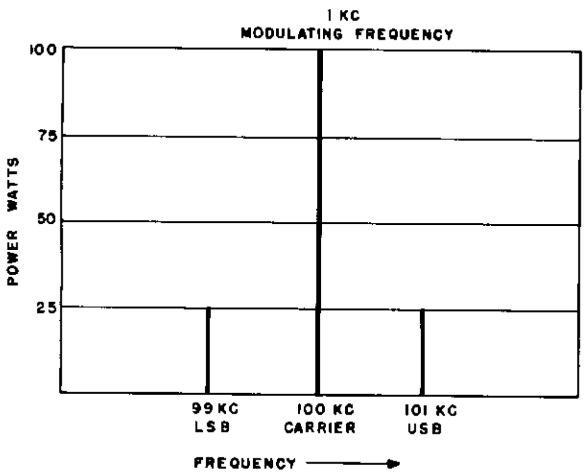
SINGLE SIDEBAND MODULATORS (SSB)

An amplitude modulated r-f signal can be separated into three different frequencies. They are, the carrier frequency, the upper sideband frequency (USB) and the lower sideband frequency (LSB). A 100-percent modulated A-M signal utilizes two thirds of its total power in the carrier. The following diagram illustrates the frequency verses power relationships of a fully modulated AM envelope.

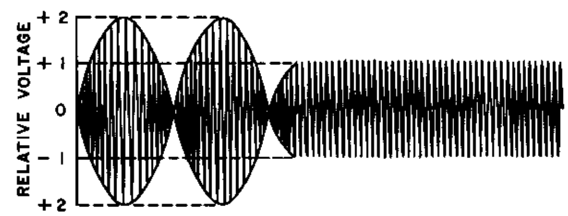


100% Modulated A-M Signal (100 Watt Carrier Power)

An understanding of the principles of Amplitude Modulation is essential to the understanding of SSB modulation, since SSB is basically a form of AM. A brief review of the principles of amplitude modulation as discussed in Section 14 of this Handbook will greatly facilitate the understanding of SSB modulation for the reader who is not throughly familiar with A-M.

Since only the AM sidebands carry all of the intelligence (modulation) the carrier can be eliminated, and the available transmitter power utilized to a much greater advantage. Both upper and lower sidebands are identical in waveform except for a difference in frequency. Therefore if one of the sidebands along with the carrier is suppressed or eliminated leaving only a single sideband, an even greater efficiency may be obtained.

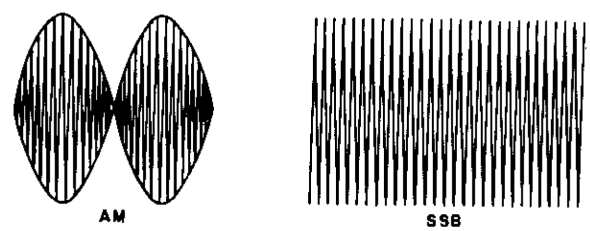
Normally, an effective 6 db power gain can be obtained from a r-f power amplifier, capable of dissipating say 400 watts of peak power, by using SSB instead of conventional DSB AM. For comparison purposes we shall use a 100 watt rated carrier power AM signal and a 400 watt peak envelope power (abbreviated PEP) SSB signal. Note that the 100 watt rated carrier A-M signal also dissipates 400 watts on audio peaks when fully modulated as illustrated below.



100% Modulated AM Envelope

As can be seen from the illustration, the peak to peak voltage of a fully modulated A-M envelope is twice that of the unmodulated carrier. Peak power is four times carrier power, since $P = E^2/R$.

The following illustration compares a fully modulated 100 watt rated carrier power envelope to a 400 watt PEP single sideband envelope for a single sustained tone.

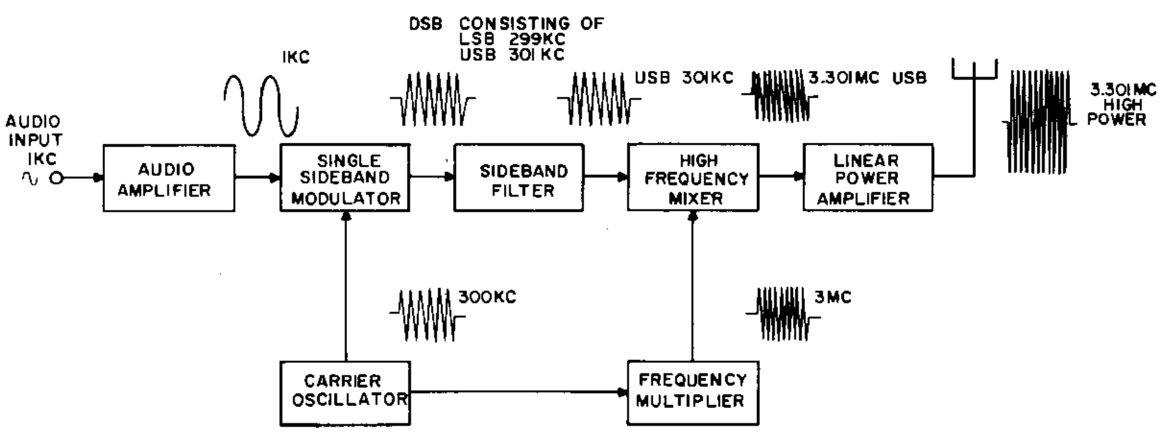


Comparison of A-M and SSB Modulation Envelopes

Note that while the peak power ratings of both signals are identical, the conventional AM modulated signal only reaches full peak power at the instant of 100 percent modulation. On the other hand, the single-sideband signal operates constantly at full peak power. Assuming that the AM envelope consists of a 100 kc carrier modulated by a 1 kc audio tone, an upper sideband at 101 kc and a lower sideband at 99 kc are produced, along with the 100 kc basic carrier in the r-f envelope. Thus, the average sideband power is only 50 watts (25 watts in each sideband). On the other hand the 400 watt single sideband r-f envelope is either the upper sideband or the lower sideband (depending upon which sideband is selected to be transmitted), and there is no carrier frequency present. Hence all 400 watts of PEP is usable power. Consequently, there is an apparent 8-fold (9 db) increase in usable power of SSB over conventional DSB AM. Actually this only amounts to a 6 db gain is useful power, since a conventional DSB AM signal containing 50 watts of total sideband power produces twice the receiver output that a 50 watt PEP SSB signal produces. This is because the upper and lower sidebands of the DSB AM signal combine in the receiver detector circuit, and produce an audio voltage which is proportional to double the amplitude of each sideband. The loss of one sideband reduces the apparent 9 DB gain of the SSB transmission over conventional AM to an actual 6 db advantage.

Up to this point we have only discussed the power advantages gained through the use of single sideband in the transmitting system. Another important advantage realized through the use of SSB is that of frequency spectrum conservation. For good intelligibility modulating frequencies up to 3 kc are required for voice transmissions. A conventional DSB AM contains the carrier frequency and sideband frequencies deviating 3 kc on both sides of the carrier frequency, when the carrier frequency is modulated by a 3 kc tone. Thus the total bandwidth of this signal is 6 kc. With the same modulating frequency the bandwidth of the SSB system is only 3 kc, since only one sideband is transmitted. It is apparent that a SSB system will provide twice the number of channels of a comparable conventional DSB A-M system. Still another advantage of SSB operation is reduced receiver noise, since the required bandwidth of the receiver is halved due to the reduced bandwidth of the transmitted signal. Since noise power is directly proportional to bandwidth, a 3 db gain in signal-to-noise ratio results because of the increased selectivity. From the above discussion, it can be seen that the SSB system provides an effective 9 db overall improvement (6 db in the transmitter, and 3 db in the receiver) over the conventional DSB AM system. The power comparison between SSB and AM stated previously is also based on ideal propagation conditions. Over long distance transmission paths, AM is subject to selective fading, which causes severe distortion and sometimes a weaker received signal. Only the A-M transmission is subject to this type of deterioration under poor propagation conditions, because the upper sideband, the lower sideband, and the carrier must both be received exactly as transmitted to realize full fidelity, and the full theoretical power from the signal. If one, or both, of the transmitted sidebands is attenuated more than the carrier, a loss of received signal results. The most serious and most common result is selective fading which occurs when the carrier is attenuated more than the sidebands. The effect of this type of selective fading is severe distortion of the received intelligence. Selective fading can also cause a phase shift between the relative phase positions of the carrier and sidebands. This condition also results in distortion of intelligence. On the other hand, a SSB signal is not subject to selective fading, which varies the amplitude or phase relationship between the sidebands and the carrier, since only one sideband and no carrier is transmitted.

The following block diagram illustrates a simple SSB transmitter arrangement.



Single Conversion SSB Transmitter

The audio amplifier stage increases the speech input voltage to a level sufficient to drive the SSB modulator. An extremely stable r-f signal is provided for use in generating the desired r-f sidebands by the carrier oscillator. The SSB modulator generates both upper and lower sidebands when both audio modulation and r-f carrier are applied simultaneously. The sideband filter stage passes the selected sideband and rejects the undesired sideband. The frequency multiplier stage multiplies the r-f carrier generated in the carrier oscillator to a higher frequency for use in the high frequency mixer stage, where this multiplied frequency heterodynes with the sideband frequency from the sideband filter, and produces the desired transmitter output frequency. The linear power amplifier stage is used to amplify the signal from the HF mixer stage to a power level suitable for transmission. Since very stable oscillators and very sharp filters are much easier to produce for low frequency applications, SSB generation is made to occur at relatively low radio frequencies. The generated sideband frequency is brought to the desired high r-f output frequency by frequency conversion. Although the simple single sideband transmitter discussed above uses single conversion for ease of understanding, it is normal practice to use double conversion to obtain the desired high frequency output.

The single sideband modulator is used to generate amplitude modulated upper and lower sidebands, meanwhile suppressing or cancelling the r-f carrier which was used to generate the sidebands. By beating the audio modulation against the unused carrier frequency, sum and difference frequencies are produced to provide the actual sideband frequencies. It is also important to note that the carrier frequency does not appear in the output of the modulator because circuit elements are arranged to produce this effect. All types of single sideband modulators such as the balanced modulator, the balanced-bridge rectifier-type modulator, and the product modulator produce the same end result. They differ, however, in the manner in which they achieve carrier suppression and generate sidebands. Each of these circuits is discussed in detail in the following paragraphs.

BALANCED (PUSH-PULL CARRIER INPUT) MODULATOR.

APPLICATION.

The balanced (push-pull carrier input) modulator is used to produce amplitude modulated upper and lower sidebands for use in single sideband transmitters.

CHARACTERISTICS.

Operates class C with push-push output.

Both r-f carrier and audio modulation are applied to the modulator in push-pull.

Generates upper and lower sidebands while suppressing the r-f carrier.

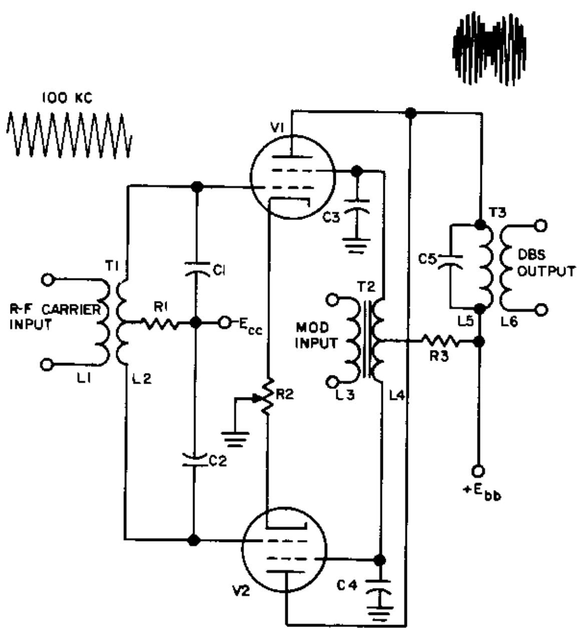
Utilizes two tetrodes with their plates connected in parallel.

CIRCUIT ANALYSIS.

General. While all modulators have the characteristic of producing sidebands the balanced modulator is unique in that it produces only upper and lower sidebands and suppresses, or cancels the r-f carrier in the output. Different types of balanced modulators differ in the manner in which they achieve carrier suppression. This discussion concerns the manner in which the balanced (push-pull carrier input) modulator achieves carrier suppression. The balanced modulator discussed here utilizes two tetrodes with their plates connected in parallel, and operated class C. The r-f carrier is applied to the modulator control grids in push-pull (out of phase) while the modulating signal is applied to the screen grids in push-pull, also out of phase. The r-f carrier signal is cancelled in the output tank circuit and upper and lower sidebands are generated. It is important to consider that carrier suppression occurs in the output tank circuit and not in the plate circuit. The parallel-plate connected modulator tubes are operated with Class C bias, and conduct only on positive-going input signals. Since the r-f carrier input is applied to the modulator control grids push pull, the modulator tubes conduct and produce an r-f output on alternate half cycles of the r-f input. Since only one tube is conducting at a given instant, the r-f pulses appearing in the plate circuit of each tube are not affected by the other tube. In the tank circuit, however, the r-f pulses occur at a rate which tends to cancel rather than reinforce tank circuit oscillations. The generated sidebands do not cancel in the output, since the output tank is resonant to only the carrier frequency. The audio modulation signal is not developed in the output due to the low impedance presented to audio frequencies by the r-f output transformer. This discussion concerns the use of tetrodes in the push-pull carrier input balanced modulator. Triodes or pentodes may be used in place of tetrodes, the need being determined by system requirements.

Circuit Operation. The following schematic diagram illustrates a typical balanced (push-pull carrier input) modulator.

Transformer T1 couples the r-f carrier signal from the carrier oscillator to the control grids of balanced modulators V1 and V2. Secondary L2 of T1 is effectively centertapped by R1 and capacitors C1 and C2. Resistor R1 also permits fixed bias insertion for V1 and V2, and serves as a bias decoupling resistor. Potentiometer R2 provides a means for electrically balancing the circuit by varying the cathode resistance of V1 and V2. V1 and V2 are the nonlinear devices used to generate the upper and lower sidebands. Transformer T2 couples the audio modulation to the screen grids of V1 and V2. The secondary of T2 is center-tapped to form a push-pull screen circuit so that the induced audio frequency voltages will be 180 degrees out of phase at the screen grids of the modulator tubes. The audio frequencies do not appear in the output since the output transformer, T3, presents a low impedance to audio frequencies. Capacitors C3 and C4 are screen grid r-f bypass capacitors preventing r-f from entering the screen supply. Resistor R3 is a screen voltage dropping resistor intended to keep screen voltage



Push-Pull Carrier Input Balanced Modulator

always lower than the plate voltage, so that the negative resistance effects inherent in the tetrode are not encountered. Transformer T3 serves as the tuned output transformer. The primary L5 of T3 together with capacitor C5 form a parallel resonant tank circuit which is sharply tuned to the carrier frequency.

To more easily understand the operation of the balanced (push-pull carrier input) modulator assume first that only the r-f carrier is applied. Assume that the first half cycle of r-f carrier drives the grid of V1 positive and the grid of V2 negative. Since V2 is cutoff due to class C bias, the negative signal on the grid of V2 has no effect on V2. On V1, however, the positive half cycle of r-f drives the tube into conduction and a negative going r-f signal appears in the plate circuit. Capacitor C5 charges during the period of increasing plate current. When plate current starts to decrease C5 discharges building a magnetic field around L5. When plate current ceases the magnetic field around L5 would normally collapse and charge C5 in the opposite direction. This is normal tank circuit oscillation sometimes called, "flywheel action".

At this time, however, the next half cycle of r-f input drives V2 into conduction and a negative going r-f pulse appears in the plate circuit. Capacitor C5 charges and prevents the magnetic field around L5 from collapsing. When plate current starts to decrease C5 discharges and maintains constant current through L5. With constant current through L5 the magnetic field around L5 remain unchanged, and an output is not inductively coupled to the following stages. In effect, the r-f output pulse from V2 cancels the r-f output pulse from V1. The amplitude of these pulses should be approximately equal, considering the losses in the tank circuit, for the r-f carrier signal to be effectively canceled. The relative amplitude of the r-f carrier pulses can be varied by the adjustment of potentiometer R2.

Under actual operating conditions with both the r-f carrier and the audio modulation applied, upper and lower sidebands are produced through the beating of the r-f carrier and the audio modulating signal in the non-linearly operated modulator tubes. It is important to note that the sideband frequencies, unlike the carrier frequency, are not canceled in the output tank circuit. This is because the output tank circuit is sharply tuned to the carrier frequency and the sideband frequencies will deviate sufficiently from the carrier frequency for the output tank circuit to appear non-resonant to these frequencies. Hence no sideband energy will be stored in the tank circuit from one half cycle of r-f input to the next and cancellation of the sidebands will not occur.

FAILURE ANALYSIS.

No Output. Failure of one of the modulator tubes is not likely to cause a no-output condition to exist. Failure of the power supply or a circuit component common to both branches of the balanced modulator is a much more likely cause of no output. Voltage checks of V1 and V2 with a voltmeter would reveal a defective component that could be the cause of no output. Power supply voltages should be checked and adjusted if necessary. Any discrepancies found during voltage checks can be followed up, with the equipment deenergized, with resistance checks of associated circuit components to reveal the component at fault. Since both r-f carrier and modulation inputs are required to produce a sideband output, lack of either signal could be a cause of no output. Presence of these input signals can be readily determined with an oscilloscope. The r-f carrier should be present on the control grids of both tubes and should have sufficient amplitude to drive the tubes above cutoff. If the r-f carrier is not present on the grids of the modulator tubes, check for presence of the r-f carrier on the primary of T1. If no signal is present on the primary of T1 the fault likely lies in the stage, or stages, preceding the balanced modulator. If a signal is present on the primary of T1 but absent on the control grids of V1 and V2 the fault likely lies in transformer T1. If the audio modulating signal is not present on the screen grids of the modulating tubes, check for presence of the modulation signal on the primary of T2. If modulation is present on the primary of T2 but absent on the screen grids of V1 and V2, transformer T2 is defective. If the modulation signal is absent at the primary of T2 the fault likely lies in the preceding stages.

Low Output. A common cause of low output is decreased emission of the modulator tubes. The power supply voltages should be checked and corrected if necessary. Voltage checks of V1 and V2 would reveal if a defective circuit component is the cause of low output. Should a discrepancy be found during voltage checks a resistive analysis of cicuit components would reveal the component at fault. Another possible cause of low output could be decreased amplitude r-f carrier input or decreased amplitude modulation input. The existance of this condition can be determined by observing with an oscilloscope the amplitude of the r-f carrier signal on the control grids, and the amplitude of the modulating signal on the screen grids of V1 and V2.

Distorted Output. Distortion of intelligence in SSB systems will occur if the transmitter and receiver are not exactly on frequency. Distortion in SSB transmitter is usually caused by improper operation of the linear power amplifier or by operating any stage in the transmitter beyond its capabilities. If the balanced modulator is determined to be the cause of distortion a possible cause could be defective tubes. Check the power supply voltages with a voltmeter. If the tubes are good and the power supply voltages are correct, a resistive analysis of circuit components with the equipment deenergized would reveal a component failure that could be a cause of distorted output. Do not overlook the possibility that the audio modulation is distorted before it reaches the balanced modulator. The existance of this condition can be determined by observing, with an oscilloscope, the quality of the modulation signal on the screen grids of V1 and V2 with an audio tone from an audio signal generator applied to the transmitter.

BALANCED (PARALLEL CARRIER INPUT) MODULATOR.

APPLICATION

The parallel carrier input balanced modulator is used to produce amplitude modulated upper and lower sideband frequencies for use in suppressed-carrier, single sideband transmitters, commonly abbreviated as SSSC.

CHARACTERISTICS.

Utilizes nonlinear characteristics of electron tubes to produce sidebands.

Produces amplitude modulated upper and lower sidebands while suppressing the r-f carrier.

No output is produced unless both r-f carrier and modulation are present.

Modulation is accomplished at low power levels, therefore, no large modulator power supply and transformers are needed.

Uses push-pull output and parallel input to cancel out the carrier.

Can provide conversion gain i.e. Sideband output greater than modulation input.

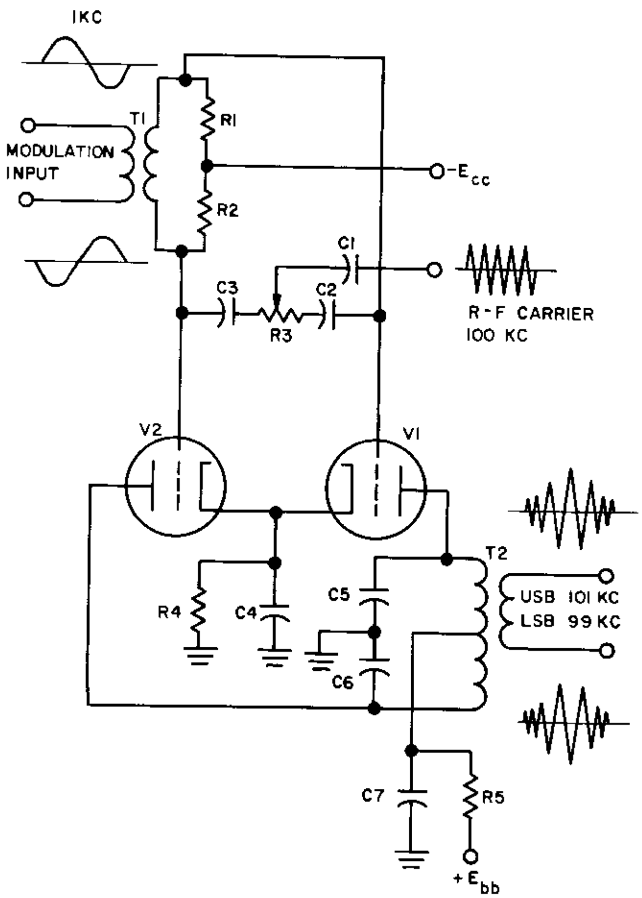
CIRCUIT ANALYSIS.

General. The parallel carrier-input balanced modulator produces amplitude modulated sidebands and suppresses the r-f carrier. This is achieved by coupling the r-f carrier, in-phase, to the grids of two tubes whose output is connected in push pull (out-of-phase). The r-f carrier signal voltage is kept 8 to 10 times as large as the modulating voltage to keep distortion to a minimum. In push pull amplifiers an input signal inserted in-phase on the grids (in parallel) will cancel in the output. The modulating signal is applied in series to the grids of the balanced modulator through a transformer. This transformer is effectively centertapped by a resistance network connected across the secondary winding for bias insertion. The center tap arrangement produces a 180 degree phase different between the audio modulation signal voltages on the grids of the modulating tubes. When both r-f carrier and modulating audio signal are applied to the grids of the balanced modulators, sum and difference frequencies (sideband) are produced by the modulating frequencies beating against the carrier, since any amplitude modulation process is essentially the same as heterodyning. As in a frequency converter, any modulation which exists on one of the mixing frequencies is linearly transposed to the resultant sum and difference frequencies. The plate circuit contains the upper and lower sidebands, which are the sum and difference frequencies, respectively, the r-f carrier, and the audio modulation. The carrier is cancelled out by push-pull action in the output transformer and the output transformer also presents a low impedance to the audio modulating signal. Therefore, the original modulating signal is not developed in the output. The generated sidebands are out-of-phase with each other at the plates of the tubes, since the modulating signal is out-of-phase at the grids. These out of phase signals add in the output rather than cancel as in-phase signals do, and they are inductively coupled to the following stages through the output transformer. Tetrodes and pentodes may be used with equal or greater effectiveness, their use being determined by system requirements.

Circuit Operation. The accompanying diagram illustrates a typical parallel carrier-input balanced modulator.

Transformer T1 couples the audio modulation to the grids of balanced modulator tubes V1 and V2. Resistors R1 and R2 provide grid bias and an effective centertap for T1. Capacitor C1 couples the r-f carrier from the carrier oscillator to carrier balance potentiometer R3. Carrier balance potentiometer R3 is adjusted to vary the relative amplitude of the carrier signal on the grids of V1 and V2, so that the circuit may be completely balanced and the carrier suppressed in the output. Capacitors C2 and C3 couple the r-f carrier from balance potentiometer R3 to the grids of V1 and V2. Modulator tubes V1 and V2 are the nonlinear devices used for developing the modulation. Resistor R4, which is bypassed by C4, provides cathode bias for both tubes. Center-tapped plate transformer T2 provides a push-pull plate load for the modulators. Capacitors C5 and C6 bypass any higher order harmonics that might be generated in the plate circuit to ground. Resistor R5 is a plate voltage dropping resistor, while C7 bypasses any unwanted signals to ground, and places the center tap of T2 at ground potential.

The operation of the parallel carrier-input balanced modulator can be more easily examined by first applying only the r-f carrier. The r-f carrier generated in the carrier oscillator is coupled through C1 to the slider of variable resistor R3. Thus the carrier signal appears at both ends of R3 and is coupled through C2 and C3 to the grids of V1 and V2. The carrier signal voltage is inserted in-phase on the grids of V1 and V2, and the amplitude, at each tube is controlled by adjusting R3. Assuming that the r-f input is



Parallel Carrier Input Balanced Modulator

operating on the positive half-cycle, both plates draw an increasing plate current (the grid input is in-phase), and the voltage drop across each half of the transformer winding is negative going, so that equal and opposing voltages are developed in the transformer primary which cancel, and no output is obtained from the secondary. Likewise, on the negative half-cycle less plate current is drawn and the drop across the transformer is positive going, and equal and opposing voltages are developed in the primary and also cancel out, so no carrier again is produced. If the circuit is properly balanced by the adjustment of R3, these opposing signals are equal in amplitude and the carrier is effectively suppressed.

The amount of carrier suppression obtained depends upon the degree of balance between the two legs of the balanced modulator circuit. When two tubes of the same type are used in a balanced modulator circuit (without any balancing adjustment) carrier suppression of 10 to 15 DB generally results. Since carrier suppression of at least 35 DB is usually required in suppressed-carrier, single-sideband systems it can be seen that some type of fine balancing adjustment is required. In this circuit R3 is used for carrier balancing, but other methods (such as varying the bias or plate voltage on the modulator tubes) may be encountered in other circuits.

When audio modulation also is applied, a different situation arises. The audio modulation is applied through transformer T1. Since the secondary of T1 is effectively center tapped by resistors R1 and R2 modulation signal voltages will be developed across each half of the winding which are out of phase with each other. This modulating signal is applied directly to the grids of V1 and V2. Capacitors C2 and C3 are of such a value that they present a high impedance to audio frequencies and prevent any audio modulation from crossing over, from one grid to the other, and canceling each other out. The audio modulating signal modulates the r-f carrier and produces upper and lower sidebands in the plate circuit of the modulator tubes. These sidebands are produced by mixing the r-f carrier frequency and the modulation signal across a nonlinear device. To illustrate the operation of the parallel carrier-input balanced modulator with both r-f carrier and modulating signal applied assume that the first half cycle of the modulating voltage applied to the grid of V1 is positive and the first half cycle of the modulating signal applied to the grid of V2 is negative. It can readily be seen that conduction of V1 will increase with negative going sideband frequencies being generated across the top half of the output transformer. At the same time, the negative half cycle of audio modulation applied to the grid of V2 decreases conduction of V2, causing positive going sideband frequencies to be developed across the bottom half of the output transformer. Push pull action thus occurs and the sideband frequencies add to each other, causing both upper and lower sidebands to be developed and inductively coupled to the secondary of T2. The r-f carrier is suppressed, as explained earlier, and the original audio modulating signal is not developed due to the low reactance of T2 to the basic audio modulation frequencies. Therefore, only the upper and lower amplitude modulated sidebands are produced by the balanced modulator.

FAILURE ANALYSIS.

No Output. Since both modulator tubes perform the same function it is unlikely that failure of one tube or associated circuit would cause a no-output condition. A much more likely cause of no output would be failure of something common to both tubes such as the power supply, the cathode resistor or the circuits associated with the r-f carrier input or modulation input. Voltage checks on V1 and V2 with a voltmeter would reveal a defective component that could cause no output. Should all the voltages check good the cause of no output could be the lack of either r-f carrier or modulating signal. This can be easily checked with an oscilloscope. Check the grids for presence of both signals with the carrier oscillator operating and modulation applied. If the modulating signal is not present on the grids, check for presence of the modulation signal on the primary of T1. This will determine whether T1 or the preceding audio stages are at fault. Should the r-f carrier be missing check the output of the carrier oscillator. If there is an output from the carrier oscillator, signal trace the components linking the carrier oscillator to the grids of the modulator tubes. Should all the conditions necessary for proper operation be met, i.e. proper voltages on the tube elements, proper carrier and modulation inputs, and there is still no output, transformer T2 could be defective. Check all windings of T2 for proper resistance and check all windings for leakage to ground.

Low Output. Low output can be caused by a defective tube or tubes, improper power supply voltages or by a defective circuit component. Low output could also be caused by decreased amplitude of the r-f carrier signal voltage or possibly by decreased amplitude of the modulating signal. Check the power supply voltages. If the power supply voltages are good, voltage checks of the tube elements would reveal whether or not a defective circuit component was the cause of low output. Should these voltage checks reveal a discrepancy, resistance checks, with the circuit deenergized, would reveal the component at fault. The possibility of decreased amplitude r-f carrier signal or modulating signal input can be checked by observing these signals on an oscilloscope. If all the conditions necessary for proper operation are met, i.e. good tubes, proper power supply voltages, and good circuit components, poor operation could be the result of a defective output transformer. Since the resistance of the output transformers windings are relatively low a shorted winding could easily be overlooked when making resistance checks. Check the resistance of each half of the primary winding, each half should be equal, and check the resistance of the secondary winding. With the centertap disconnected check the windings for leakage to ground.

Distorted Output. It should be noted that distortion of intelligence will occur if the single sideband transmitter and receiver are not exactly on frequency. Distortion in single sideband transmitters is frequently caused by improper operation of the linear amplifiers, or by operating any stage beyond its capabilities. If system distortion is determined to be caused by the balanced modulator a likely cause could be improper voltages applied to the tubes, or defective tube or tubes, or failure of some circuit component. Check the power supply voltages, if they are good, voltage checks of the tube elements would indicate whether or not a defective circuit component is the cause of distorted output. Incorrect voltages found to be present on tube elements can be traced to the component at fault with resistance checks of associated circuit components. The possibility of a distorted audio input or possibly a distorted r-f carrier should not be overlooked. The existance of these conditions can be determined by observing these signals on an oscilloscope.

BALANCED BRIDGE MODULATOR.

APPLICATION.

The balanced bridge modulator is used in single sideband generators to produce amplitude modulated upper and lower sidebands while suppressing the r-f carrier.

CHARACTERISTICS.

Produces upper and lower sidebands while suppressing the r-f carrier.

Utilizes four diodes connected in a bridge configuration.

Produces sidebands by heterodyning action produced by nonlinear diodes.

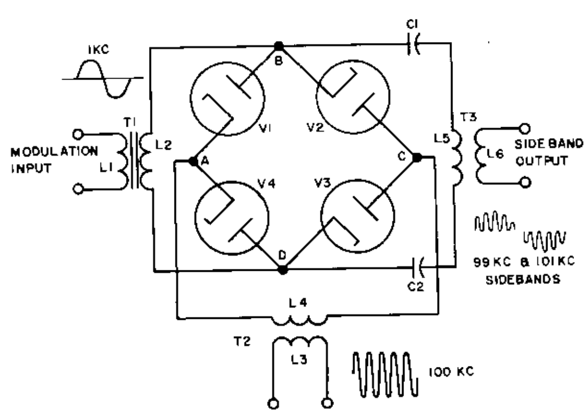
Requires both an r-f carrier and modulation applied simultaneously to produce an output.

CIRCUIT ANALYSIS.

General. The purpose of the balanced bridge balanced modulator is to produce amplitude modulated upper and lower sidebands and suppress the r-f carrier. Basically this is achieved in the balanced bridge modulator by arranging the circuit elements so that a balanced condition exists between the two legs of the bridge when only an r-f carrier is applied. This balanced condition will prevent an r-f output from being produced. Modulation is applied so that the bridge becomes unbalanced, that is, more current flows through one leg than the other. This causes current to flow through the output transformer, and an output is produced. The current flowing through the output transformer is the upper and lower sidebands generated by the heterodyning of the r-f carrier and modulating signal within the non-linear diodes.

Carrier suppression is achieved because the current through one leg represents the carrier and sideband currents plus the modulating signal current, while current through the other leg consists of only the carrier current. The overall effect is to cancel the r-f carrier currents. The audio frequency component is blocked from the output by capacitors whose reactance is high to audio frequencies. Only the sidebands are present in the output.

Circuit Operation. The accompaning diagram illustrates a typical balanced bridge modulator utilizing electron tube diodes.

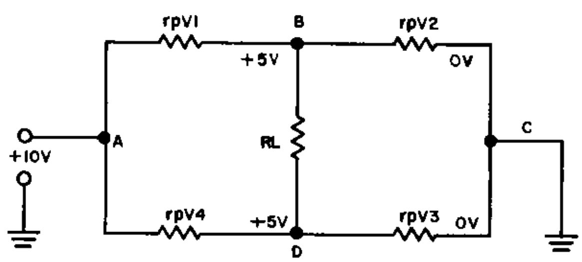


Balanced Bridge Modulator

Transformer T1 couples the modulation signal to the balanced bridge, and Transformer T2 couples the r-f carrier from the carrier oscillator to the balanced bridge. Diodes V1, V2, V3, and V4, form the balanced bridge. Capacitors C1 and C2 block audio frequencies, thereby preventing the primary of T3 from shunting the secondary of T2. This is necessary since T3 is an r-f transformer and would present a very low impedance to audio frequencies. Transformer T3 serves as an output transformer. Designations at points A, B, C, and D are used only to illustrate circuit operation.

To more easily analyze the operation of the balanced bridge modulator, assume first that only the r-f carrier is applied. Assume that during the first half-cycle of r-f, point A is positive with respect to point C. This back biases the diodes and no current flows, hence no output results, since the bridge appears as an open circuit.

When the negative half-cycle appears point A becomes negative with respect to point C. This forward biases the diodes and current flows from point A through V1 and V2 to point C. An equal current will flow from point A through V4 and V3 to point C. When the current through leg V1, V2 is equal to the current through leg V4, V3, a state of balance exists and no current will flow through winding L5 of the output transformer, T3. The accompanying illustration shows the equivalent circuit of the bridge in a balanced state.



Equivalent Circuit of Balanced Bridge Modulator With Only r-f Carrier Applied

The resistances represent the plate resistance of the diodes. Since the diodes are all of the same type and have the same characteristics, their conduction and plate resistances are the same. Resistor RL represents the load presented by the output transformer. There is no difference in potential between points B and D, and no current flows through the output transformer. Thus there is no output from the balanced bridge modulator when only the r-f carrier is applied.

When only the modulation signal is applied, circuit operation is as follows. Assume first that a positive half-cycle of modulating voltage is applied; causing point B to be more positive than point D. It can be seen that the instantaneous potential created by the positive half-cycle of modulation signal will cause current to flow from point D through V3 to point C. Since the plate of V2 is connected to point C, current will not flow through V2. Current will, however, flow from point C through the secondary, L4, of T2 to point A, and through V1 to point B. Current also will not flow through V4 since V4 like V2 is back-biased to current flow in this direction. The return path for current flow is through secondary L2, of T1. The primary, L5, of T3 does not effect the modulation signal since C1 and C2 offer a high impedance to the relatively low modulating frequency and prevent any shunting effects of L5 on L2. When the polarity of the modulating signal reverses, current flows from point B through V2 to point C. From point C current flows through the secondary, L4, of T2 to point A and then through V4 to point D. The return path is through the secondary, L2, of T1.

Under actual operating conditions with both r-f carrier and signal applied, the balance between the upper and lower legs of the bridge caused by the equal r-f carrier currents through each leg is disrupted by the modulating signal and a sideband output results.

To examine the circuit under actual operating conditions, consider first that r-f carrier current is flowing in equal amounts through the upper and lower legs, V1 and V2, and V4 and V3 respectively. When a positive going cycle of audio modulating signal is applied to T1, modulation signal current flows from point D through V3 to secondary L4 of T2 and to point A, and then through V1 to point B and back to secondary L2 of T1. Since the diode is a nonlinear device, mixing, or heterodyning, takes place between the r-f carrier currents and the modulating signal currents flowing through V1 and V3, and both upper and lower sidebands are produced. These sideband currents follow the same path as the modulating signal except that they flow through the output transformer T3 instead of the secondary L2 of T1. This is because transformer T1 offers a high impedance to the relatively high sideband frequencies. The sidebands are inductively coupled through T3 to the following stages. The overall effect is the same for a negative half-cycle of modulation except that sideband current flow is through V2 and V4 and the flow is through the output transformer in the opposite direction.

FAILURE ANALYSIS.

No Output. A no-output condition could be caused by an open or shorted winding on any of the three transformers. With the equipment de-energized, a resistance check of the transformer windings will indicate an open or partially shorted winding. Failure of one of the diodes will not be likely to cause no-output, however if the diode filaments are connected in series an open filament could cause the other diodes to be in operative. A visual check with the equipment energized will reveal whether or not any filament failures occur. Since a balanced modulator does not produce an output unless both r-f carrier and modulation signals are present, lack of either these signals could be a cause of no output. Presence of these signals can be determined with an oscilloscope. To check for the presence of the modulating signal, observe the waveform present at points B and D. If the modulating signal is not present at these points check for modulating signal on L1 the primary of T1. If the modulating signal is present here, but is absent at points B and D the fault most likely lies in transformer T1. If there is no signal present on the primary of T1 the trouble is likely to be in the preceding stages. The presence of the r-f carrier can be determined in the same manner by observing the waveform present at points A and C. if the r-f carrier is not present at A and C the trouble can be localized by signal tracing with an oscilloscope through T2.

Low Output. A common cause of low output can be from decreased emission of one or more of the diodes. If any tubes are replaced it would be good procedure to check all the tubes on a tube checker and use only tubes which have approximately the same emission. This is particularly advisable if a high degree of balance is desired within the bridge of diodes. If the tubes are good, another possible cause of low output could be insufficient modulation input or insufficient r-f carrier input. This condition can be checked by observing the amplitude of the waveforms present at the modulation inputs to the bridge, and at the r-f carrier inputs to the bridge. If one of the inputs are low the cause can be determined by signal tracing with an oscilloscope and noting any excessive attenuation through the input transformers. If the amplitude of either signal is proper on the primary of the respective input transformer but low on the secondary, the transformer is defective. If the amplitude of the input signal is low on the primary of the respective input transformer the trouble likely lies in the stages preceding the balanced modulator.

Distorted Output. Distortion could be caused by a defective tube. Another cause of distortion might be a low r-f carrier input. The r-f carrier should be 8 to 10 times the amplitude of the modulating signal for distortion to be at a minimum. Do not overlook the possibility that the modulation input is distorted before it reaches the balanced modulator. Analysis of the modulation input with an oscilloscope would reveal if this condition existed.

PRODUCT MODULATOR.

APPLICATION.

The product modulator is used in single sideband transmitters to produce amplitude modulated upper and lower sidebands while suppressing the r-f carrier.

CHARACTERISTICS.

The output of a product modulator is proportional to the product of the amplitudes of the input signals.

Does not require input transformers.

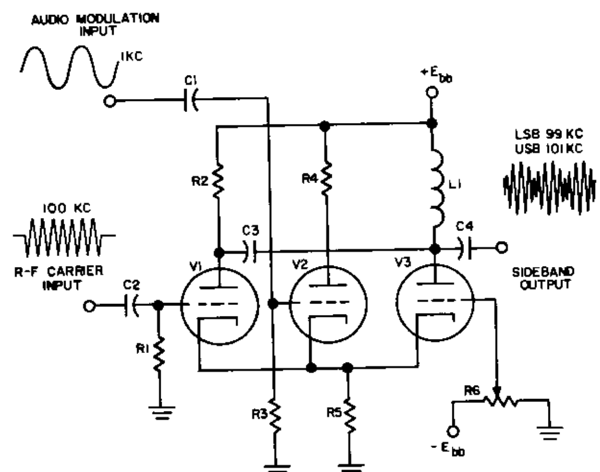
Utilizes three triodes with two of them operated as cathode followers.

Operates with class A bias.

CIRCUIT ANALYSIS.

General. The product modulator in single sideband applications produces amplitude modulated upper and lower sidebands while suppressing, or cancelling the r-f carrier. The single sideband product modulator utilizes three triodes with two of them operated as cathode followers. It is interesting to note that all three triodes have a common cathode resistor. The r-f carrier and the audio modulation are impressed on the grids of cathode followers, and r-f carrier and audio modulation are developed across the common cathode resistor. Since the modulator tube also uses the same cathode resistor, audio modulation and r-f carrier signal voltage appear on the cathode of the modulator tube. The r-f carrier and audio modulation beat together in the modulator tube and upper and lower sidebands are generated. Carrier suppression is achieved by coupling the r-f carrier signal developed at the plate of V1 to the plate of V3. Since there is 180° phase difference between the r-f carrier signal developed at the plate of V1 and at the plate of V3, the r-f carrier is effectively canceled. The product modulator when used in single sideband applications produces a sideband output only when both the r-f carrier and the audio modulator are applied simultaneously. The use of cathode followers eliminates the need for r-f carrier and audio modulation input transformers, since the cathode followers provid the necessary impedance match between the r-f carrier oscillator and the product modulator, and also between the audio amplifying circuits and the product modulator. The cathode followers also provide isolation between the r-f carrier oscillator and the audio circuits. By eliminating the carrier suppression provision the product modulator can also be used as a low distortion A-M modulator.

The following circuit diagram illustrates a typical product modulator for use in single sideband systems.



Product Modulator

Circuit Operation. Capacitor C1 couples the audio modulation to the grid of V2 and capacitor C2 couples the r-f carrier to the grid of V1. Resistor R1 and R3 are grid resistor for V1 and V2, respectively. Capacitor C3 couples the r-f carrier signal voltage from the plate of V1 to the plate of V3 for the purpose of carrier cancellation. Resistor R2 and R4 are plate dropping resistors and load for V1 and V2, respectively. Resistor R5 is a common cathode resistor for all three tubes and potentiometer R6 provides a carrier balance control by varying the fixed bias on V3. V1 and V2 which serve as cathode followers couple the r-f carrier input and the audio modulation input to the cathode of V3 which serves as the modulator tube. Inductor L1 is the plate load for V3, and C4 capacitively couples the generated sidebands to the following stages.

To more easily examine the operation of the single sideband product modulator, first assume that only the r-f carrier is applied to the modulator.

During the positive half cycle of r-f carrier input the conduction of V1 increase and the voltage drop across plate resistor R2 increase causing a negative going r-f carrier pulse to appear at the plate of V1, and the voltage drop across common cathode resistor R5 increases, causing a positive going r-f carrier pulse to appear at the cathode of V1. Since the cathode of V3 is directly connected to the cathode of V1, the positive r-f pulse appears on the cathode of V3 and decreases the conductor of V3 causing a positive going r-f pulse to appear at the plate of V3. The negative r-f pulse on the plate of V1, is coupled through capacitor C3 to the plate of V3. If the r-f pulses from V1 are equal in amplitude to the r-f pulses from V3 there will be complete cancellation, and the r-f carrier will not appear in the output. The relative amplitude of these r-f pulses may be varied by the adjustment of R6 which varies the gain of V3. The positive half cycle of r-f input was used only to illustrate circuit operation. Circuit operation is the same for a negative half cycle of r-f input.

Thus with only the r-f carrier applied there will be no output from the product modulator.

When audio modulation is applied in addition to the r-f carrier upper and lower sidebands are generated. Audio modulation is coupled through coupling capacitor C1 to the grid of cathode follower V2. Audio frequency voltage are developed across common cathode resistor R5 and are directly coupled to the cathode of V3. The r-f carrier and audio modulation beat together in V3 and four basic frequencies appear in the plate circuit of V3. These frequencies are the original audio modulation, the original r-f carrier, and newly generated sum and difference frequencies. The r-f carrier frequency present in the plate circuit of V3 will be canceled by the 180° out-of-phase r-f carrier signal coupled to V3 from V1, as explained in the previous paragraph. The audio madulator present in the plate circuit of V3 is not developed in the output since inductor L1 presents a low impedance to audio frequencies. The generated sideband frequencies, referred to earlier as sum and difference frequencies are developed across inductor L1 and capacitively coupled through C4 to the following stages.

FAILURE ANALYSIS.

No Output. Failure of almost any component cauld be a cause of no output in the product modulator. Check the power supply voltages to make certain that a defective power supply is not the cause of no-output. Voltage checks of tube elements will reveal if a component failure is the cause of no-output. Any discrepancies found during voltage checks can be followed up, with the equipment de-energized, by a resistive analysis of circuit components to reveal the component at fault. It should be noted that the product modulator will produce an output only when both r-f carrier and audio modulation are present on the cathode of V3. Presence of the r-f carrier and the audio modulation can be determined by observing the waveform with a oscilloscope on the cathode of V3 with modulation applied to the transmitter and the carrier oscillator operating. If either signal is missing the trouble can be localized by signal tracing from the signal source, either the carrier oscillator, or the audio amplifying circuits, to the cathode of V3.

Low Output. A likely cause of low output in the product modulator is decreased emission of the electron tubes. If proper operation is not restored, a defective circuit component could be the cause of low output. A resistive analysis of circuit components with the equipment de-energized would reveal a defective component that could be the cause of low output.

Another possible cause of low output is decreased amplitude r-f carrier input or decreased amplitude audio modulation input. The existence of this condition can be readily determined by observing the amplitude of the r-f carrier signal and audio modulation present on the cathode of V3, with an oscilloscope.

Distorted Output. It should be noted that distortion will occur in SSB systems if the transmitter and receiver are not exactly on frequency. Distortion in SSB transmitters usually results from improper operation of the linear power amplifiers or by operating any stage beyond its capabilities.

If the modulator is determined to be the cause of distortion a likely cause of distortion would be defective tubes or a defective circuit component. The tubes can easily checked by exchanging them with tubes known to be good. Resistance checks of circuit components would reveal if a defective circuit component is the cause of distorted output. Power supply voltages should be checked and adjusted if necessary to make certain that a defective power supply is not the cause of distorted output. Don't overlook the possibility that the audio modulation may be distorted before it reaches the product modulator. To check for this condition observe with an oscilloscope, the quality of the audio modulation present on the grid of V2, with a audio tone from a audio signal generator applied to the modulation input of the transmitter.

PHASE MODULATORS (PM).

In phase modulation, sometimes referred to as indirect frequency modulation, the audio signal is used to shift the phase and the frequency of the carrier frequency, resulting in a frequency variation in the output. The amount of phase deviation is directly proportional to the amplitude of the audio signal, and the amount of frequency deviation is proportional to the frequency of the audio signal. An illustration of phase modulation is shown below.

Result of Phase Modulation.

The solid line represents the carrier frequency. If an audio signal is introduced at the beginning of time T1, the next positive peak occurs, for example, at time T3, shown in dotted lines, instead of at a time T2, where it would normally occur. Since the peak following T1 now occurs at a later time, the phase of the output is now lagging the carrier. By the same token, the phase can be changed to a leading one by the applications of a signal of opposite polarity. Thus the amount and direction of phase shift varies in accordance with the amplitude and polarity of the audio input. A frequency variation also occurs in the output, because the frequency of the modulating signal determines the rate at which the phase of the carrier deviates, and thus determines the amount of frequency deviation.

The frequency of the carrier before a phase shift occurs is called the center frequency, and is generated by a crystal controlled oscillator, which accounts for the excellent frequency stability of the phase modulator.

The phase variations, called modulation, are not applied until after the carrier frequency is generated and it is this peculiarity which allows the use of a crystal oscillator. With no audio signal applied, only the carrier frequency, is transmitted.

Since random noise usually consists of higher frequencies, the signal to noise ratio at the higher audio frequencies may be lower. It is for this reason that the audio modulation is coupled through a pre-emphasis network before being applied to the modulator circuit. The pre-emphasis network increases the relative signal strength of the higher frequency components of the audio signal, and thereby compensates for any decrease in signal-to-noise ratio as caused by random high frequency noise. This creates a state of unbalance between the amplitudes of the high and low frequency components, but it is compensated for in the receiver by the use of a de-emphasis circuit, which performs the opposite function of pre-emphasis.

The greatest advantage of the phase modulator is, as previously mentioned, its excellent frequency stability, which results from the use of a crystal oscillator.

The advantage of this type of modulation over a-m is its noise reducing capabilities. Most noise signals produce amplitude modulation of the carrier, or the carrier-plus-modulation signal, which is applied to the demodulating circuit in the receiver. If the receiver is responsive to amplitude variations, as in a-m receivers, this random noise is detected and amplified. If the receiver is responsive only to changes in frequency, as in an f-m receiver, phase modulation makes possible a considerable increase in the signal-to-noise ratio. Actually, phase modulation is a form of f-m, the difference being that whereas f-m is responsive only to changes in amplitude, p-m is responsive to both the amplitude and the frequency of the audio modulation.

A better understanding of phase modulation can be obtained from the following descriptions of specific phase modulator circuits.

BASIC PHASE MODULATOR.

APPLICATION.

The phase modulator is used in transmitters to vary the frequency of an r-f signal in accordance with the intelligence to be transmitted.

CHARACTERISTICS.

Carrier frequency is supplied by a crystal controlled oscillator.

Frequency stability is excellent.

Has a high signal-to-noise ratio.

Operates over the linear portion of the E_g - I_p curve.

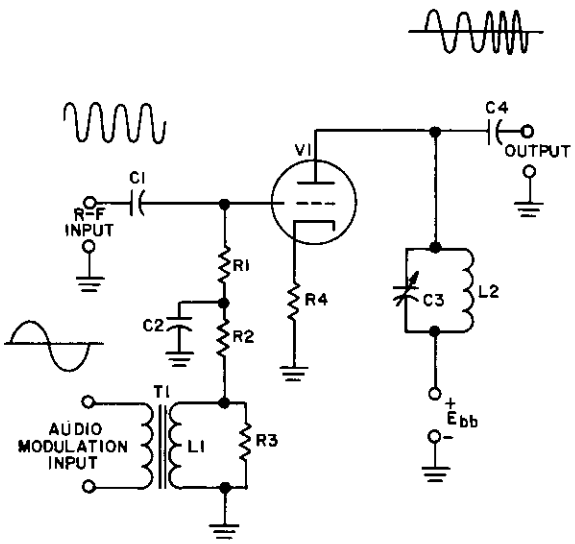
CIRCUIT ANALYSIS.

General. The purpose of the modulator stage is to convert an audio signal into a radio frequency containing the audio intelligence.

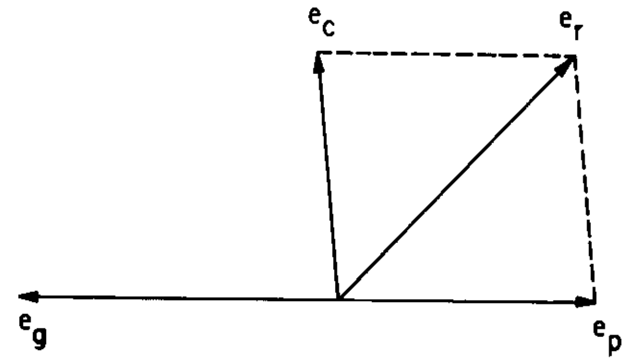
In the basic phase modulator, a crystal controlled oscillator supplies the desired basic frequency to the grid of a triode. A modulating (audio) signal is also applied to the grid of this modulator tube, and a phase shift occurs in the r-f output. The amount and direction of the phase shift is proportional to the amplitude and polarity as well as the frequency of the audio modulating signal.

Circuit Operation. A basic phase modulator is shown in the accompanying schematic diagram.

The crystal oscillator r-f output is coupled through coupling capacitor C1 to the grid of V1, and it is this crystal oscillator frequency which is the center frequency of the phase modulated output. Resistors R1, R2, and R3 form a voltage divider, across which both the oscillator r-f signal



Basic Phase Modulator



Vector Diagram Showing Effect of Modulation

and the audio modulation is applied. R2, in conjunction with C2, also performs the function of a decoupling network, which bypasses the lower end of R1 to ground and prevents the r-f carrier frequency component from feeding back into the audio circuits through T1. In effect, it isolates the r-f from the audio, despite the apparent common connection. The audio modulation is applied through transformer T1 and through R2 and R1 to the grid of V1. Cathode resistor R4 provides degenerative feedback, and the plate tank circuit, consisting of L2 and C3, is tuned to a frequency below the lowest output r-f frequency. Because R4 is unbypassed and causes degenerative feedback, the tube gain is relatively low.

The r-f signal (the carrier) is of constant amplitude and frequency, and with both positive and negative cycles equal in amplitude, no bias change is produced on V1 grid. Thus an amplified r-f carrier appears as the reproduced output, with the normal 180 degree grid to plate phase shift. The audio modulation, however, applied through transformer T1, provides, in effect a changing bias on V1 grid as it varies in amplitude and polarity. As a result, the gain of the tube is varied in accordance with the audio signal bias. The manner in which this variation in the gain of the triode is converted into a phase shift of the carrier, can be better understood through the use of vector diagrams.

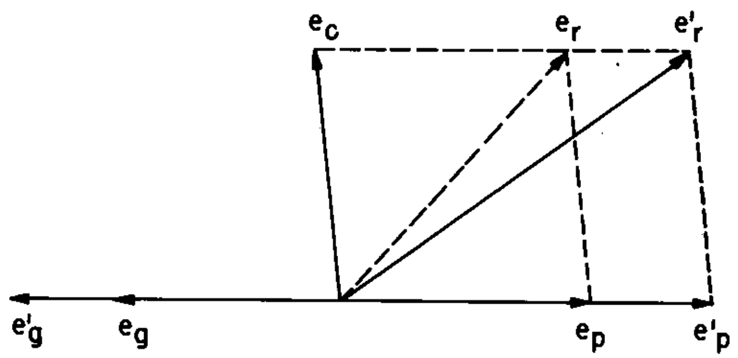
The voltage produced by normal amplifier action is represented as e_p. Another r-f voltage is produced by the grid to plate capacitance of the tube, and is represented as e_c, and the result of these two r-f plate voltages, which is the instantaneous plate voltage, is represented as e_r. Due to normal amplifier action, e_p is 180 degrees out of phase with e_g, the grid voltage and its amplitude is relatively low because of the degenerative effect of the unbypossed cathode resistor, R4. Since e_c lags e_g by some amount, e_r, which is the vector result of e_c and e_p it falls somewhere between these two voltages, as illustrated in the above diagram.

When the signal on the grid increases in a positive direction, the amplitude of the plate signal also increases, with the following result. The vectors which change as a result of this increase in grid signal are designated as e'_g, e'_r, and e'_p. Voltages e_g, e_r, and e_p are shown in order to compare this example with the previous one. It can be seen therefore, that with a larger signal on the grid (e'_g), the closer e'_p and e'_r become in phase.

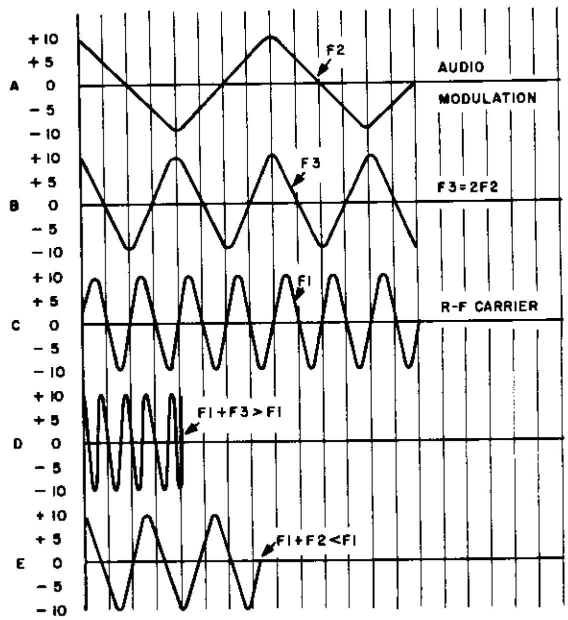
Conversely, when the grid signal (e'_g) decreases in amplitude, the plate signal, e'_p decreases, as illustrated below.

As a result, the vector e_r shifts further out of phase with e_p (to e'_r) than it was under the first condition illustrated. By comparing these three illustrated circumstances, it can be seen that the phase relationship between e_r and e_g constantly changes in phase as e_g varies in amplitude and polarity.

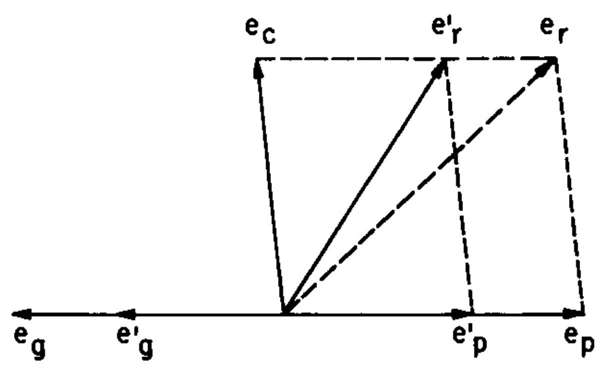
The overall effect is that the amplitude of the modulating signal determines the amount and direction of phase deviation of the carrier in the output. The frequency of the modulating signal determines the rate at which the phase of the carrier deviates, and thus determines the amount of frequency deviation. This effect can be more clearing seen by referring to the accompanying illustration showing the different frequencies produced by adding F1 and F2, and F1 and F3.



Vector Diagram For Increasing Grid Voltage



Effect of Frequency and Amplitude Changes of Modulating Signal



Vector Diagram For Decreasing Grid Voltage

The carrier (oscillator) frequency is represented by F1 in part C of the figure. F2 (shown in part A of the figure) represents the modulation frequency, and the result of adding or combining $F_1 + F_2$ is shown in part E of the figure. As shown in the figure F_2 starts at 10-volts positive and assume for ease of explanation that this positive 10-volts modulation causes a full 90 degree phase shift in the carrier. Now, since the carrier frequency F_1 is at 0 at the same instant, the sum value (F1 + F2) is at +10 volts and by assumption leads F_1 by 90 degrees. As the modulation voltage (F2) decreases to +5 volts, the phase shift is reduced to one-half maximum or 45 degrees. At this point, F1 has completed 180 degrees of its cycle and is at 0 voltage, except that the 45 degree advance makes the sum of F_1 and F_2 a minus 5-volts instead, as shown in part E of the figure. As modulation Voltage F_2 continues to decrease and reaches 0 voltage no further phase shift occurs and the carrier and modulator voltages are again in-phase (at this point F1 has just completed 360 degrees of its cycle and by coincidence happens to be at 0 voltage also). The negative modulation cycle now continues, and, when F2 reaches −5 volts it also causes a 45 degrees phase shift, but this time the shift is in a lagging direction. Therefore, although F1 is actually at 0 the lagging sum produces a +5 volts combined signal as shown at E. In this manner, the phase shift follows the modulating voltage, leading on the positive half cycle of modulation and lagging over the negative half cycle, with the amount of phase shift being proportional to the instantaneous amplitude of the modulating signal.

By following the relationship between F_1 and F_3 (part B of the figure) in the same manner as for F_1 and F_2 as just explained, we see that when a modulation frequency twice that of F_2 is used, the sum shown in part D of the figure is an increasing frequency. Since frequency deviation increases with an increase in the modulation frequency, this is the result to be expected and proves our previous assumptions to be correct.

FAILURE ANALYSIS.

No Output. A defect in nearly any component in the circuit can cause a no output condition to exist. Check with an oscilloscope to make sure that both the oscillator and the audio modulation are present at the inputs to the circuit. If either one is missing, the modulator is probably not defective, and the output will probably be restored with the restoration of the missing input. If both inputs are present, disable the oscillator, and check for the modulation input of the grid. If not present, check transformer T1 for continuity with an ohmmeter. Check R1, R2 and R3 for a change in value, and C2 for a short. Disable the audio input, and check for the presence of oscillator frequency on the grid. If absent, check C1 for an open. If both signals are present on the grid, check R4 for value, and L2 for continuity. Check for the presence of plate voltage with an voltmeter. Check C3 for a short, and C4 for an open. If a no-output condition still exists, check all capacitors with an in-circuit capacitor checker.

Low or Distorted Output. A low or distorted output can also be caused by a defect in nearly any component in the circuit. Check for the proper amplitude of each input signal on the grid of tube V1 with an oscilloscope. If low, determine whether it is low due to a defective oscillator or audio stage, or if it is a defect in the modulator circuit itself. If localized to the modulator, check transformer T1 continuity and resistors R1 and R3 with an ohmmeter. Check C2 for proper value with an in-circuit capacitor checker. Check R4 for value. Check plate voltage and determine whether or not the power supply is defective. Check C3 and C4 with an in-circuit capacitor checker, and check the continuity of L2 with an ohmmeter.

PHASITRON MODULATOR.

APPLICATION.

The phasitron is used in transmitters to vary the frequency of an r-f signal in accordance with the intelligence to be transmitted.

CHARACTERISTICS.

Utilizes a special phasitron tube.

Carrier frequency is supplied by a crystal controlled oscillator.

Has a high signal-to-noise ratio.

Operates Class "A".

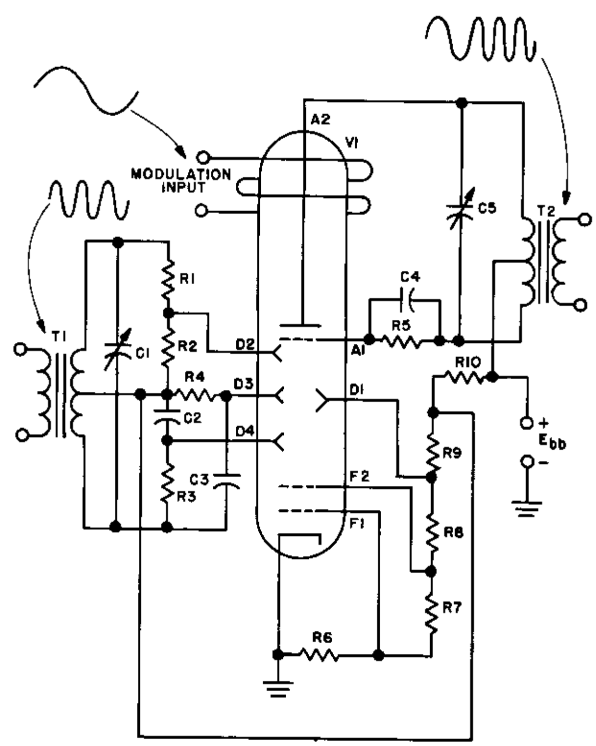
Frequency stability is excellent.

Output modulation proportional to both amplitude and the frequency of the audio modulation.

CIRCUIT ANALYSIS.

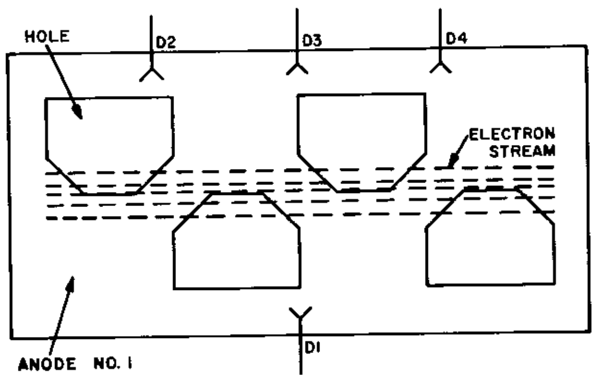
General. The phasitron performs the function of a phase modulator through the use of a special tube, called the phasitron tube. The carrier frequency is generated by a crystal controlled oscillator, and coupled through a phase splitting network to the tube. The modulation is applied inductively to the tube through a coil arranged around the outside of the tube, and the result in the output is a phase and frequency modulated carrier.

Circuit Operation. A schematic diagram of a Phasitron is illustrated below.



Phasitron Modulator.

Before attempting to understand the operation of the phasitron circuit, a basic understanding of the special tube utilized is essential. The illustration below shows the basic configuration of the structure of anode number 1, the four deflection grids, D1, D2, D3, D4, and the electron stream, with no potential applied to the deflection plates.

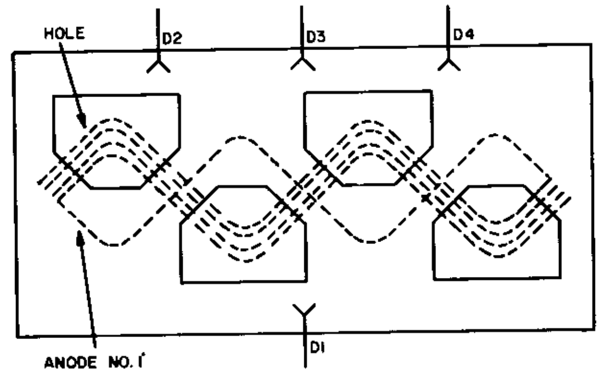


Phasitron Anode Structure and Electron-Beam Configuration with no Potential Applied to Deflector Grids

Anode number 1 has holes punched at regular intervals above and below a dividing line. The two focusing grids, F1 and F2, are such that it shapes the electron stream into a flat disc, which strikes anode number 1 as shown. Behind anode number 1 is another anode, which receives the electrons which are permitted to pass through the holes in anode number 1. Thus, with no potential applied to the deflector grids, nearly equal current flows in each plate.

In operation, however, potentials are applied to these deflector grids, and they are each 120 degrees out of phase with each other. Upon re-examining the electron disc, but this time with the potentials applied to the deflector plates, the result is illustrated below.

Now a greater portion of the stream passes through the holes in the first anode, and strike the second anode. Hence the plate current in anode number 2 is now greater than that of anode number 1. Since the potentials on D2, D3, and D4 are constantly changing (though always 120 degrees apart), the shape of the disc is also constantly changing, and shortly the disc is as shown by the dotted lines, resulting in maximum plate current in anode number 1, and minimum current in anode number 2. For any phase between these two extremes, each anode receives correspondingly more or less current. The modulation is applied to the coil around the outside of the tube, and the magnetic



Phasitron Anode Structure and Electron-Beam Configuration with Potential Applied to Deflector Grids.

fields developed around this coil tends to increase or decrease the speed of rotation of the electron disc. By increasing or decreasing the speed of rotation, the frequency at which the anode current increases or decreases changes, and the output frequency is either increased or decreased.

In actual circuit operation, the carrier frequency is applied through transformer T1. The secondary of T1, together with C1, form a tank circuit tuned to this carrier frequency. Resistors R1, R2, R3, and R4, together with capacitors C2 and C3, form a phase splitting network, and the result is that the signals applied to D2, D3, and D4 are 120 degrees out of phase with each other. Also applied to the phase shifting network is a constant potential, tapped from the common point of R9 and R10. Resistors R6, R7, R8, R9, and R10 perform the function of voltage dividers in order to apply the proper voltages to the respective elements of the tube. R5 is a voltage dropping resistor, and C4 is an a-c bypass. The primary of T2, together with C5, form a tank circuit, tuned to the center frequency.

Referring to the construction of the first anode and the shape of the electron stream, it can be seen that there is a time during which all of the electrons strike the first anode, but never a time at which all of the electrons strike the second anode. This characteristic is overcome with R5, which causes a lower potential to be applied to the first anode than to the second anode. This same resistor would also cause degeneration of the a-c component of plate current however, and for this reason C4, an a-c bypass, is placed in parallel with R5. The overall effect, with no modulation applied is that the plate current is constantly alternating between the two anodes in such a way that when one is maximum, the other is minimum, and conversely. The rate at which these currents rotate is equal to the crystal oscillator frequency, and it is to this frequency that the plate tank circuit is tuned.

When modulation is applied to the coil surrounding the tube, a magnetic field is developed, and this field advances or delays the rate of phase change of the electron stream. Thus the phase of the output leads or lags the oscillator frequency by an amount which is proportional to the amplitude and polarity of the modulation. The frequency of the modulation determines the rate at which the electron disc rotates. When the speed of disc rotation is increased, the output tank excitation frequency is higher, and when the speed of the disc rotation is decreased, the output frequency is lower.

The overall result in the output is therefore a signal which changes in phase and frequency as the audio modulation varies in amplitude and frequency.

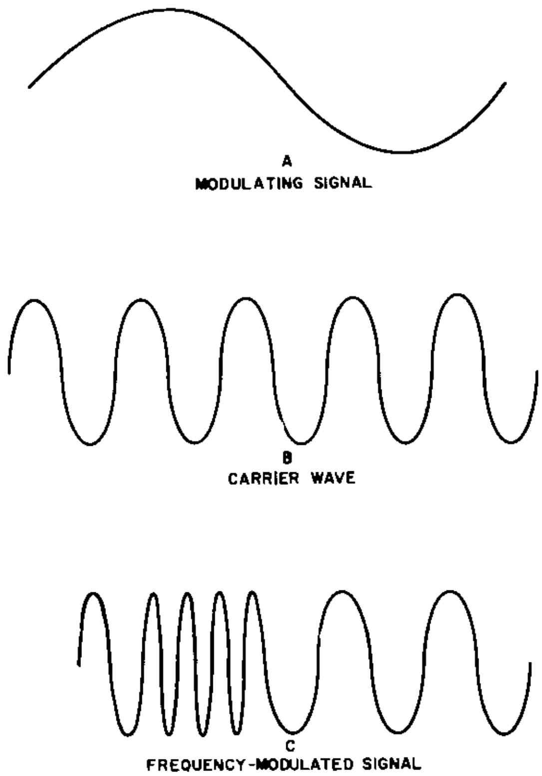
FAILURE ANALYSIS.

No Output. A no output condition can be caused by a defective V1, and open R5, a shorted C1 or C5, a defective T1 or T2, or a loss of the plate supply voltage. Check for the proper plate supply voltage with a voltmeter. Check both transformers with an ohmmeter. Check R5 for value, and C1 and C5 for a possible short with an in-circuit capacitor checker. Do not overlook the possibility of either of the tank circuits being misaligned.

Low or Distorted Output. A low or distorted output can be caused by a defect in any component in the circuit. Check for the proper value of plate supply voltage with a voltmeter. With an oscilloscope, check the presence of both the carrier and modulation inputs on their respective elements of the tube, as the absence of either input will produce a distorted output. Check the alignment of both tank circuits. With an in-circuit capacitor checker, check the value of all capacitors, especially for a distorted output condition. Check all resistors with an ohmmeter for proper value, and the transformer for partial shorts.

FREQUENCY MODULATORS (FM).

In frequency modulation, an audio signal is used to shift the frequency of an oscillator at an audio rate. The rate at which the oscillator changes its frequency depends upon the frequency of the modulating signal, and the deviation (the amount that the frequency shifts from the center frequency) depends upon the amplitude of the modulating signal, as illustrated below.



Frequency Modulation Waveforms

The frequency of the carrier is called the center frequency. When this carrier is modulated by a positive signal, its frequency changes; for example, it may become higher in frequency, proportional to the amount that the signal goes positive. Conversely, when the signal goes negative, the frequency becomes lower. Thus, when the sine wave shown in part A of the illustration is applied to a carrier, shown in part B, the carrier frequency changes from the normal center frequency to higher frequency, back to normal, to a lower frequency, and back to normal again as shown in part C. This variation is in direct accordance with the polarity and amplitude of the voltage of the sine wave. The maximum frequency change from center frequency, which depends upon the amplitude of the signal, is called the deviation. Note, in part C of the figure, that the amplitude of the modulated carrier is constant. As a result, frequency modulation is not so susceptible to static as in amplitude modulation, and it is for this reason that it is used for high-quality transmission of sound, such as for music.

Since random noise usually consists of higher frequencies, the signal-to-noise ratio at the higher frequencies may be lower. It is for this reason that the audio modulation is coupled through a pre-emphasis network before being applied to the modulator circuit. The pre-emphasis network increases the relative signal strength of the higher frequency components of the audio signal, and thereby compensates for any decrease in signal-to-noise ratio as caused by random high frequency noise. This creates a state of unbalance between the amplitudes of the high and low frequency components, but it is compensated for in the receiver by the use of a de-emphasis circuit, which performs the opposite function of pre-emphasis.

The primary difference between f-m and a-m is that the amplitude of the f-m signal is constant, while a-m depends upon amplitude variations for the transmission of intelligence.

The advantage of this type of modulation over a-m is its noise reducing capabilities. Most noise signals produce amplitude modulation of the carrier, or the carrier-plus-modulation signal, which is applied to the demodulating circuit in the receiver. If the receiver is responsive to amplitude variations, as in a-m receivers, this random noise is detected and amplified. If the receiver is responsive only to changes in frequency, as in f-m receivers, frequency modulation makes possible a considerable increase in the signal-to-noise ratio.

BASIC REACTANCE-TUBE MODULATOR.

APPLICATION.

The frequency modulator is used in fm transmitters to vary the frequency of an r-f signal in accordance with the intelligence to be transmitted.

CHARACTERISTICS.

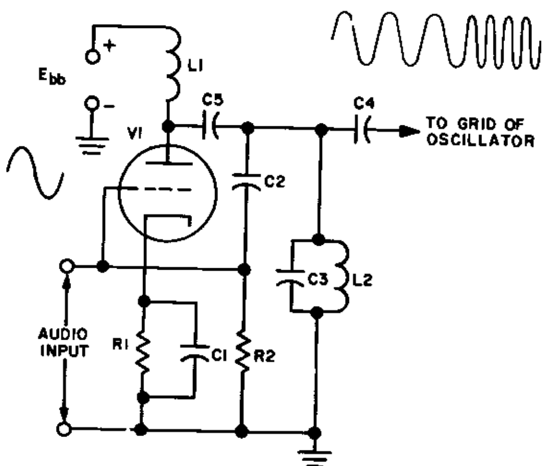
Output is used to change the frequency of an oscillator.
Has a high signal-to-noise ratio.
Output frequency is independent of modulating frequency.
Has relatively low inherent distortion.

CIRCUIT ANALYSIS.

General. The purpose of the modulator stage is to convert an audio signal into a radio frequency containing the audio intelligence.

In the basic reactance tube modulator, a tube is used to change the resonant frequency of an oscillator by an amount proportional to the amplitude of the modulating signal. The polarity of the modulation determines the direction of the frequency shift; for example, an increase in oscillator frequency for a positive polarity, and a decrease in frequency for a negative polarity. The rate at which this frequency deviation occurs is determined by the frequency of the audio modulation.

Circuit Operation. A schematic diagram of a basic reactance tube modulator is illustrated below.

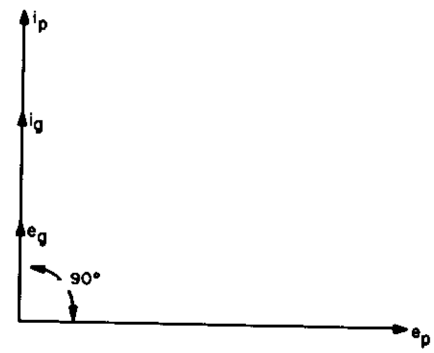


Basic Reactance Tube Modulator

V1 performs the function of the reactance tube, using cathode bias, supplied by R1 and C1. L1 is an r-f choke which acts as the plate load, and keeps the a-c component of plate current out of the power supply. Capacitor C2 and resistor R2, in parallel with the oscillator tank circuit consisting of C3 and L2, performs the function of a variable reactance. C4 and C5 are grid and plate coupling capacitors, respectively.

With no audio signal applied to the grid of V1, the only voltage present across the C2, R2, network is the voltage across the oscillator tank circuit, C3 and L2. The values of C2 and R2 are chosen so that the reactance of C2 is large in comparison to the resistance of R2. This factor permits the capacitive reactance to be the current controlling component, and causes the voltage across it to lag the current through it by approximately 90 degrees. This same current flows through R2 and another voltage drop is produced which leads the applied voltage by 90 degrees. Actually, the current and voltage at the resistor are in phase, but since the current through the resistor leads the applied voltage (because of the capacitive reactance of C2), the voltage developed by this current also leads the applied voltage by the same amount. The reactance tube is effectively in shunt with the oscillator tank (C3 and L2) and the phase shift network (C2 and R2). Capacitor C5 allows the a-c component of current to pass through it, and at the same time, blocks the d-c plate voltage from the phase-shift circuit and the tank.

The relationship of the currents and the voltages in the circuit can be best explained through the use of a vector diagram, as illustrated below.



Relationships of Currents and Voltage with no Modulation Inputs

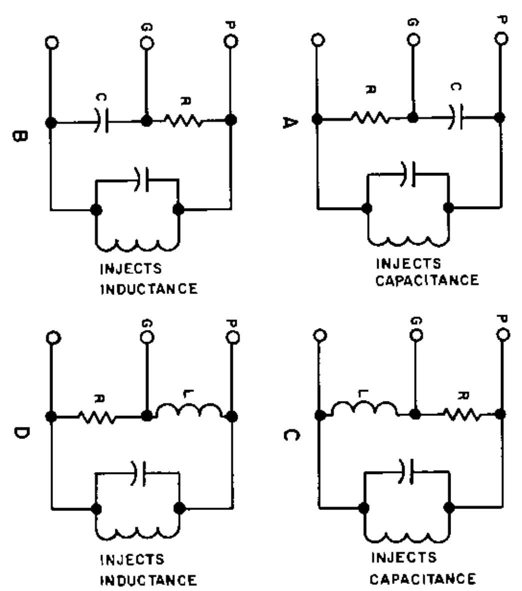
Voltage e_p is the alternating component of the plate to ground voltage which appears simultaneously across the reactance tube, the phase-shift network, and the oscillator tank circuit. The reactance tube receives its a-c grid-input voltage, e_g, across R2. This voltage is the voltage drop across R, and is in phase with the plate current i_p and the grid current, i_g. This relationship is characteristic of amplifier tubes.

Since both i_p and i_g are in phase with e_g, and since e_g leads e_p by approximately 90 degrees, i_p and i_g also lead e_p by 90 degrees. Both of these currents are supplied by the oscillator tank circuit, and since they lead the tank voltage, they act like the current in a capacitor. Thus the injection of these currents into the tank circuit accomplishes the same effect as placing a capacitor across the oscillator tank circuit. The frequency of the tank in this case is, therefore, decreased. With no audio modulation input, this frequency is the operating, or center frequency of the modulator.

Consider now the application of audio modulation to the grid of the tube. It is important to keep in mind that we are not speaking of actual capacitive reactance or capacitance changes. Our concern here is an **effective** capacitance produced by the leading currents in the R2, C2, combination. If the signal applied on the grid of V1 increases in a positive direction, the plate current of V1 also increases, and since this current is an effective capacitance shunt across the oscillator tank circuit, the frequency of the oscillator is decreased. Conversely, when the grid signal shifts in a negative direction under audio modulation, V1 plate current decreases, and since this current is an effective reduction in capacitance across (shunting) the oscillator tank circuit, the frequency of the oscillator is increased.

The frequency of the audio modulation does not actually affect the frequency of the output. Its only effect is that it determines the number of times per second that the oscillator changes its frequency. The amount and direction of the frequency change is determined solely by the amplitude and the polarity of the modulation input. That is, a positive signal causes an increase of frequency, while a negative signal causes a decrease in frequency. Likewise, a larger amplitude signal causes a greater frequency change than a smaller amplitude signal.

Circuit Variations. There are several circuit variations of the basic reactance tube modulator, but most of these variations are only differences in the arrangement of the phase shifting circuit (the R2, C2, combination in the previous example). The illustration below shows how the circuit variations cause the phase shift to be either inductive or capacitive. There is no particular advantage to any one of them over any of the others.



Circuit Variations

Part A of the figure has been explained in the previous discussion. In part B of the figure, R and C are connected in the opposite manner, and the reactance values are chosen so that the resistance of R is large in comparison to the reactance of C. Since the resistive component is so much larger, the r-f voltage applied to the plate load by the tank circuit causes the current to be in phase with the r-f voltage. The current through C, however, leads the applied voltage by 90 degrees. The voltage across C, therefore, lags both the current and the applied voltage by 90 degrees. This voltage is coupled to the grid of the reactance tube, and causes an r-f variation in the plate current that is in phase with the grid voltage. This r-f current is coupled to the oscillator tank and since it is in phase with the grid voltage, it must lag the current in the tank by 90 degrees. This produces the same result as injecting inductance into the tank circuit.

By substituting a small inductor in the place of C in part C of the figure, it is also possible to inject an effective capacitance into the tank circuit. The oscillator voltage applied across the plate load of the reactance tube causes a current to flow whose phase is controlled by the large resistance of R. This current is in phase with the applied voltage, since R is large with respect to L. Since the voltage across L leads the current through it by 90 degrees, this voltage also leads the applied voltage by 90 degrees. This voltage is coupled to the grid of the reactance tube, and r-f plate current flows which is in phase with the grid voltage and 90 degrees leading in respect to the oscillator tank voltage. The effect is, therefore, the same as injecting capacitance into the tank circuit, and the frequency is decreased.

By the same token, the reversing of R and L produces the same result as injecting inductance into the tank circuit as shown in part D of the figure. The inductive reactance of L, of course, must be large in comparison to the resistance of R. The r-f voltage from the oscillator tank circuit causes a current to flow through the plate load which lags the applied voltage by 90 degrees. This voltage then is applied to the grid of the reactance tube, producing an r-f plate current which is lagging the current in the tank circuit by 90 degrees, producing the effect of injecting inductance into the tank circuit.

FAILURE ANALYSIS.

No Output. An open or shorted L2, an open or shorted C3, or an open C4 are the only components that can cause a no output condition to exist. Check L2 for continuity and C3 and C4 for value with an in-circuit capacitor checker.

Unmodulated Output. The absence of plate voltage, an open L1, and open C5, an open R1, an open C2 or R2, or a defective V1, can cause an unmodulated output condition to exist. Check for the presence of plate voltage with a voltmeter. Check L1 for continuity and C5 for an open or short with an ohmmeter. Also check R1 and R2 for proper value, and C2 for an open or short with an ohmmeter. If a modulated output is not restored, check all capacitors with an in-circuit capacitor checker.

BALANCED REACTANCE-TUBE MODULATOR

APPLICATION.

The balanced reactance tube modulator is used in fm transmitters to vary the frequency of an r-f signal in accordance with the intelligence to be transmitted.

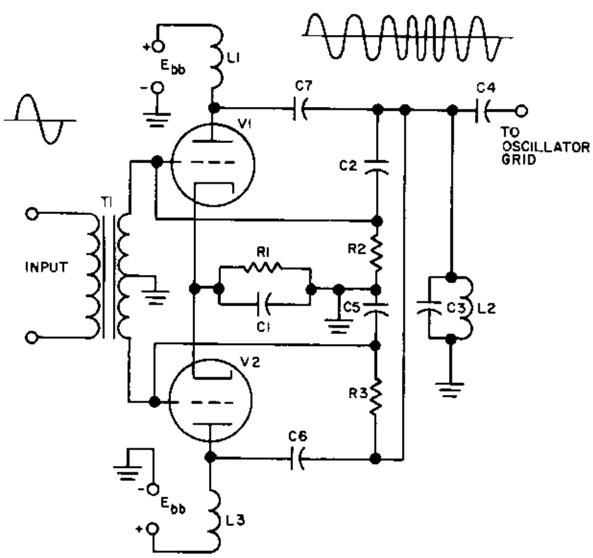
CHARACTERISTICS.

Has relatively high degree of frequency shift.
Has low inherent distortion.
Has high signal-to-noise ratio.

CIRCUIT ANALYSIS.

General. The purpose of the modulator stage is to convert an audio signal into a radio frequency containing the audio intelligence. In the balanced reactance tube modulatar, two tubes are used to change the resonant frequency of an oscillator by an amount proportional to the amplitude of the modulating signal. The polarity of the modulation determines the direction of the frequency shift, for example, an increase in oscillator frequency for a positive polarity, and a decrease in frequency for a negative polarity. The rate at which this frequency deviation occurs is determined by the frequency of the audio modulation.

Circuit Operation. A schematic diagram of a balanced reactance tube modulator is shown in the accompanying illustration.



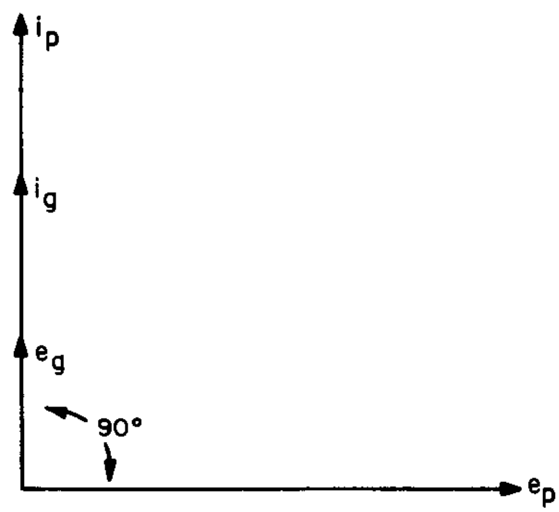
Balanced Reactance Tube Modulator.

V1 performs the function of one of the reactance tubes, and operates in conjuction with V2, in a push-pull manner. C1 and R1 form a cathode bias circuit, which is common to both of the tubes. L1 and L3 are r-f chokes which act as plate loads for the tubes, and keeps the a-c component of plate current out of the power supply. The C2-R2 combination, together with the C5-R3 combination, both in parallel with the oscillator tank circuit, made up of L2 and C3, perform the function of a variable reactance. C4, C6, and C7, are grid and plate coupling capacitors, respectively.

Circuit operation can be easiest understood, if analyzed and discussed as two separate circuits. One circuit, consists of V1, L1, C7, C2, and R2, while the other circuit consists of V2, L3, C6, R3, and C5. The remaining components are common to both of the circuits.

We shall first consider the operation of the circuit consisting of V1 and its associated components. With no audio signal applied to the grid of V1, the only voltage present across the C2-R2 network is the voltage across the oscillator tank circuit. The values of C2 and R2 are chosen so that the reactance of C2 is large in comparison to the resistance of R2. This factor permits the capacitive reactance to be the current controlling component, and causes the voltage across it to lag the current through it by approximately 90 degrees. This same current flows through R2 and another voltage drop is produced which leads the applied voltage by 90 degrees. Actually, the current and voltage at the resistor are in phase, but since the current through the resistor leads the applied voltage (because of the capacitive reactance of C2), the voltage developed by this current also leads the applied voltage by the same amount. The reactance tube, V1, is effectively in shunt with the oscillator tank and the phase shift network. Capacitor C7 allows the a-c component of current to pass through it, and at the same time, blocks the d-c plate voltage from the phase-shift circuit and the tank.

The relationship of the currents and the voltages in the circuit can be best explained through the use of a vector diagram, as illustrated below.



Relationship of Currents and voltages with no Modulation Input.

Voltage e_p is the alternating component of the plate to ground voltage which appears simultaneously across the reactance tube, the phase-shift network, and the oscillator tank circuit. The reactance tube receives its a-c grid-input voltage, e_g, across R_g. This voltage is the voltage drop across R_g and is in phase with the plate current i_p and the grid current, i_g. This relationship is characteristic of amplifier tubes.

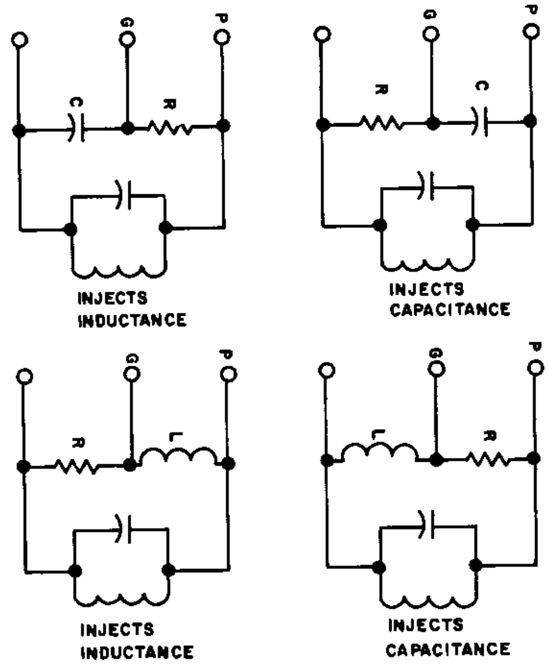
Since both i_p and i_g are in phase with e_g, and since e_g leads e_p by approximately 90 degrees, i_p and i_g also lead e_p by 90 degrees. Both of these currents are supplied by the oscillator tank circuit, and since they lead the tank voltage, they are acting like the current in a capacitor. Thus the injection of these currents into the tank circuit accomplishes the same effect as placing a capacitor across the oscillator tank circuit. The frequency of the tank in this case is therefore decreased. With no audio modulation input, this frequency is the operating, or center frequency of the modulator.

Consider now the application of audio modulation to the grid of the tube. It is important to keep in mind that we are not speaking of actual capacitive reactance or capacitance changes. Our concern here is an **effective** capacitance produced by the leading currents in the R2-C2 combination. If the signal applied on the grid of V1 increases in a positive direction, the plate current of V1 also increases, and since this current is an effective capacitance shunt across the oscillator tank circuit, the frequency of the oscillator is decreased. Conversely, when the grid signal shifts in a negative direction under audio modulation, V1 plate current decreases, and since this current is an effective capacitance across (shunting) the oscillator tank circuit, the frequency of the oscillator is increased.

Before attempting to explain the operation of the circuit made up of V2, it should be pointed out that there are several minor circuit variations of the previously discussed circuit. Most of these variations concern differences in the phase shifting circuit (the R2-C2 combination in the previous example). The illustration below shows the variations which cause the phase shift to be either inductive or capacitive. There is no particular advantage to any one of them over any of the others.

Part A of the figure has been explained in the previous discussion. In part B of the figure, R and C are connected in the opposite manner, and the reactance values are chosen so that the resistance of R is large in comparison to the reactance of C. (This is the manner in which operation of V2 yet to be explained is connected.) Since the resistive component is so much larger, the r-f voltage applied to the plate load by the tank circuit causes the current to be in phase with the r-f voltage. The current through C, however, leads the applied voltage by 90 degrees. The voltage across C, therefore, lags both the current and the applied voltage by 90 degrees. This voltage is coupled to the grid of the reactance tube, and causes an r-f variation in the plate current that is in phase with the grid voltage. This r-f current is coupled to the oscillator tank and since it is in phase with the grid voltage, it must lag the current in the tank by 90 degrees. This produces the same result as injecting inductance into the tank circuit.

By substituting a small inductor in the place of capacitor C in part C of the figure, it is also possible to inject an effective capacitance into the tank circuit. The oscillator voltage applied across the plate load of the reactance tube causes a current flow whose phase is controlled by the large resistance of R. This current is in phase with the



Circuit Variations

applied voltage, since R is large with respect to L. Since the voltage across L leads the current through it by 90 degree, this voltage also leads the applied voltage by 90 degrees. This voltage is coupled to the grid of the reactance tube, and an r-f plate current flows which is in phase with the grid voltage and 90 degrees leading in respect to the oscillator tank voltage. The effect is, therefore, the same as injecting capacitance into the tank circuit, and the frequency is decreased.

By the same token, the reversing of R and L produces the same result as injecting inductance into the tank circuit, as shown in part D of the figure. The inductive reactance of L, of course, must be large in comparison to the resistance of R. The r-f voltage from the oscillator tank circuit causes a current to flow through the plate load which lags the applied voltage by 90 degrees. This voltage is then applied to the grid of the reactance tube, producing an r-f plate current which is lagging the current in the tank circuit by 90 degrees, producing the effect of injecting inductance into the tank circuit.

The V2 circuit operates in the same manner as the V1 circuit, only instead of injecting a capacitive reactance into the oscillator tank, it injects an inductive reactance. Upon close examination of the V2 circuit, it can be seen that the phase shifting circuit, R3 and C5, are connected in the opposite manner to the R2-C2 combination in the first example.

By referring to the illustration of circuit variations, it can be seen that this type of connection (Part B of the figure) produces the effect of inductance in parallel with the tank circuit. It should be noted here that an increase in plate current in the first example caused an increase in the capacitive reactance injected into the tank, and hence the oscillator frequency decreased. In the V2 circuit, the inductive reactance is decreased with an increase in plate current, and thus produces an increase in the oscillator frequency. Now let us see what occurs when both circuits are connected as shown, and an audio signal is applied to the transformer T1.

When the input signal is such that the grid of V1 is positive, and the grid of V2 is negative, the following action results. The negative signal on the grid of V2 drives V2 into cut-off, and a further negative increase produces no further change. V1, however, conducts a greater as the signal on the grid becomes more positive, and thus additional capacitive reactance is injected into the oscillator tank circuit, resulting in a decreasing frequency. As the signal on the grid reaches its positive peak, and begins decreasing towards zero, the oscillator frequency begins increasing, and when the grid is returned to zero, the oscillator is again at the center frequency. The signal now continues in a negative direction and V1 is driven into cut-off. V2, the grid of which is connected to the opposite end of T1, is now brought into conduction, and begins to inject an inductive reactance into the tank circuit, resulting in an increasing frequency. As the signal on the grid reaches its positive peak, and begins decreasing towards zero, the oscillator frequency begins decreasing and as the signal reaches zero the oscillator is again at the center frequency. The overall result of one cycle of audio modulation is illustrated below.

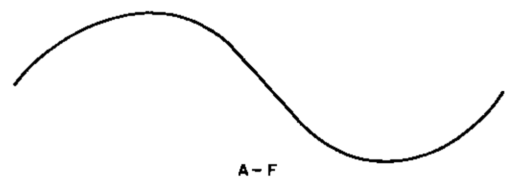
Thus, it can be seen that the frequency of the audio modulation does not actually have an effect on the frequency of the output. The only effect is that it determines the number of times per second that the oscillator changes its frequency. The amount and direction of the frequency change is determined by the amplitude and the polarity of the modulation input.

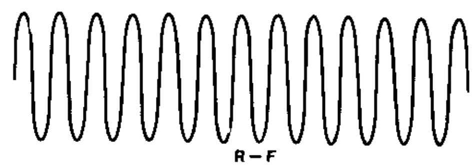
FAILURE ANALYSIS.

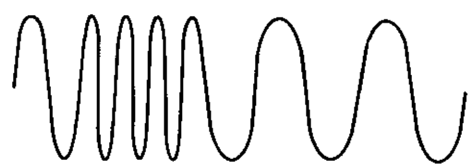
No Output. An open or shorted L2, an open or shorted C3, or an open C4 are the only components that can cause a no-output condition to exist. Check L2 for continuity and C3 and C4 for value with an in-circuit capacitor checker.

Distorted or Unmodulated Output. A defective V1 or V2, a defective T1, an open or shorted L1 or L3, an open or shorted C2 or C5, or an open R2 or R3 can cause a distorted output condition to exist. With an ohmmeter, check the continuity of L1 and L3, and check R2 and R3 for proper value. Also check C2, C5, C6, and C7 for opens or shorts with an ohmmeter. Check transformer T1 for continuity, as one half of the secondary may be open. If a distorted output still exists, check all capacitors with an in-circuit capacitor checker.

An unmodulated output can be caused by a defective T1, an open or shorted R1, or an open or shorted C1. With an ohmmeter, check the continuity of T1 and the value of R1. Check C1 for an open or short with an ohmmeter. An unmodulated output may also be caused by components being defective in pairs, that is, V1 and V2, L1 and L3, C6 and C7, etc. Check all components in this case, in the manner described in the preceding paragraph.







Effect of Modulation

PULSE MODULATORS.

Radio frequency energy in radar is transmitted in short pulses whose time duration may vary from 1 to 50 microseconds or more. If the transmitter is turned off before the reflected energy returns from the target, the receiver can distinguish between the transmitted pulse and the reflected pulse. After all reflections have returned, the transmitter can again be turned on and the process repeated. The receiver output is applied to an indicator which measures the time interval between the transmission of energy and its return as a reflection. Since the energy travels at a constant velocity, the time interval becomes a measure of the distance traveled (range). Since this method does not depend on the relative frequency of the returned signal or on the motion of the target, difficulties experienced in cw and fm methods are not encountered. The pulse modulation method is used in practically all military and naval applications.

Since most radar oscillators operate at pulse voltages between 5 Kv and 20 Kv, and require currents of several amperes during the pulse, the requirements of the modulator are quite severe. The function of the high-vacuum tube modulator is to act as a switch to turn a pulse on and off at the transmitter in response to a control signal. The best device for this purpose is one which requires the least signal power for control and which allows the transfer of power from the transmitter power source to the oscillator with the least loss. The pulse modulator circuits discussed in this section are typical pulse modulators used in radar equipments.

SPARK GAP MODULATOR.

APPLICATION.

The spark gap modulator is used in radar equipments to generate the pulse which controls the operation of the transmitter.

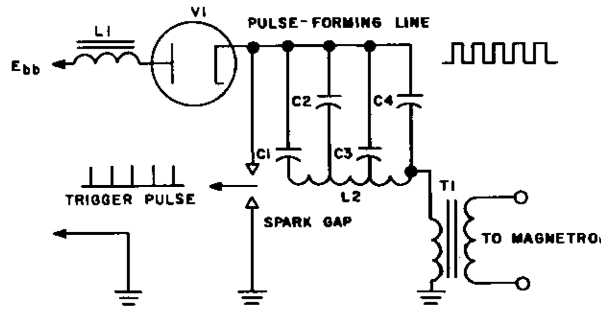
CHARACTERISTICS.

Capable of handling high peak current and voltage.
Generated pulses have high peak power.
Generated pulses have low average power.
Generated pulses have a specific repetition rate.
Generated pulses have controlled duration and shape
Output pulse is somewhat erratic in timing

CIRCUIT ANALYSIS.

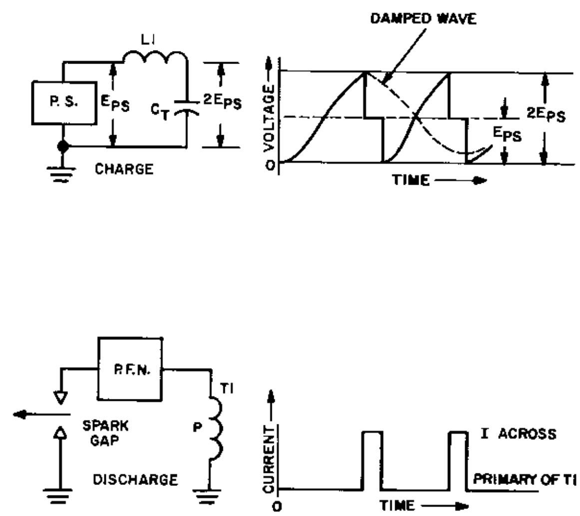
General. Different types of pulse modulators are used for triggering radar transmitters, depending on the particular requirements of the system. Each type contains a circuit for storing energy, a circuit for rapidly discharging the storage circuit, a pulse transformer, and an a-c power source. The circuit for storing energy is essentially a short section of artificial transmission line which is known as the pulse forming line. In the spark gap modulator, the pulse forming line is discharged by a spark gap. Two types of spark gaps are in use: fixed gaps and rotary gaps. The fixed gap, discussed in this section, uses a trigger pulse to ionize the air between the contacts of the spark gap and initiate the discharge of the pulse forming line. The rotary gap is similar to a mechanically driven switch.

Circuit Operation. A typical fixed spark gap modulator circuit is shown in the accompanying illustration.



Fixed Spark Gap Modulator Circuit

Between trigger pulses the spark gap is an open circuit, and current flows through the pulse transformer T1, the pulse forming line L2, the diode V1, and inductor L1 to the plate supply voltage Ebb. These components form the charging circuit for the pulse forming line, and the entire circuit may be reduced to a series resonant circuit as shown in the accompanying illustration.



Equivalent Pulse-Modulator Circuits, With Waveforms

The impedance of the primary of T1 is negligible as far as the charging circuit is concerned, the inductance of the pulse forming line may be considered to be short circuited because of the slow charging rate, and the diode, when conducting, is effectively a short circuit; therefore, these components are omitted from the figure. In effect, then, the total capacitance (Ct) of the pulse forming line is in series with the inductor L1 across the power supply. Assuming that diode V1 and the spark gap were not present, this circuit when shock-excited by the sudden application of voltage would produce a damped-wave oscillation. On the first peak, the voltage across the entire pulse forming line approaches twice the value of the supply voltage as shown in the illustration, and at this time the current in the inductor L1 is zero since the diode stops conducting at full charge. As the peak voltage is reached, the spark gap is triggered by a synchronous separate trigger placing the pulse-forming network in series with the primary of T1 to ground. At this time approximately half the voltage (Eps) appears across the pulse-forming network (PFN) and the other half appears across T1, since the network impedance is equal to that of T1 in this instance because of the rapidity of discharge. The action of the pulse-forming line is such as to cause voltage Eps to continue at the same amplitude until the complete discharge of the circuit by a time interval depending upon twice its delay period. The waveforms and time relationships of the circuit action are shown in the illustration. The pulse waveform is coupled through transformer T1 to the magnetron.

The spark gap is actually triggered (ionized) by the combined action of the charging voltage across the pulse-forming line and the trigger pulse. The air between the trigger-pulse injection point and ground is ionized by the trigger voltage, and this in turn initiates the ionization of the complete gap by the charging voltage.

Coincidence between the peak of the voltage swing across C_t and the trigger pulse used to fire the spark gap is required, in order that maximum power output may be obtained from the circuit. In order to ensure correct timing diode V1 is used and the design of the charging circuit is such that its resonant frequency is higher than half the repetition rate of the spark-gap trigger pulse. Since the diode is nonconductive when maximum charge is reached on C_t, the maximum charge is retained until the spark gap is triggered.

Inductor L1 prevents current surge through V1 when the spark gap is triggered. Where humidity or pressure may affect the ionization of the spark gap, it is enclosed in a sealed container.

In some circuits a resistor and capacitor in series are connected across the primary of T1. The function of these components is to eliminate the spike (sometimes encountered on the magnetron pulse) which is caused by delay between the time the pulse is presented to the magnetron and the time the magnetron conducts.

FAILURE ANALYSIS.

No Output. A no output condition can be caused by one of the following; an open L1, a defective V1, an open L2, or a defective T1. Determine that the plate supply voltage (Ebb) and the trigger pulse are present. If they are not present, the trouble is in the preceding stages and the circuit is probably not at fault. If the plate supply voltage is not present on the anode of V1, L1 is defective. If plate voltage is present on the anode of V1 and no output appears, the tube is defective. Check L2 and the windings of T1 with an ohmmeter for an open or short.

Low Output. A low output can be caused by a low plate supply voltage, a weak V1, leaky or shorted capacitors, shorted windings on L1, L2, or transformer T1. Check the plate supply voltage with a VTVM, if it is not the proper value the trouble is in the preceding stages and the modulator circuit is probably not at fault. Check the capacitors in the circuit with an in-circuit capacitor checker. Inductors L1 and L2 and transformer T1 can be checked with an ohmmeter for shorted turns.

Distorted Output. A distorted output could occur if the pulse-forming line had shorted or leaky capacitors or if the inductor windings became shorted or open. Check the capacitors with a capacitance cheker and the inductor for continuity with an ohmmeter.

THYRATRON (GAS-TUBE) MODULATOR.

APPLICATION.

The thyratron modulator is used in radar equipment to generate the pulse which controls the operation of the transmitter.

CHARACTERISTICS.

Possesses heavy current handling capacity.

Is relatively independent of ambient temperatures.

Has positive grid control.

Has stable timing.

Can be triggered with a low amplitude pulse.

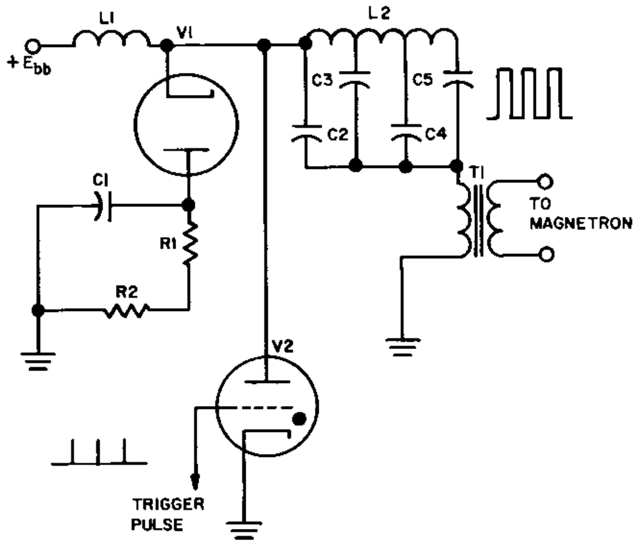
Operates over a wide range of anode voltages without readjustment.

CIRCUIT ANALYSIS.

General. The hydrogen thyratron is a versatile electronic switch which requires a positive trigger of only 150 volts rising at the rate of 100 volts per microsecond. In contrast to spark devices, the hydrogen thyratron operates over a wide range of anode voltages and repetition rates. Its grid has complete control of initiation of cathode emission over a wide range of voltages. The anode is completely shielded from the cathode by the grid. Thus, effective grid action results in very smooth firing over a wide range of anode voltages and repetition frequencies. Unlike most other thyratrons, the positive grid control characteristic ensures stable operation. In addition, the deionization time is reduced by using the hydrogen filled tube. This makes the performance of the tube relatively independent of ambient temperature so false triggering is avoided.

The hydrogen thyratron modulator provides improved timing because the synchronized trigger pulse is applied to the control grid of the thyratron and instantaneous firing is obtained. In addition, only one gas tube is required to discharge the pulse forming line, and a low amplitude trigger pulse is sufficient to initiate discharge. A damping diode is used to prevent breakdown of the thyratron by reverse voltage transients. The thyratron requires, for a driver pulse, a sharp leading edge and depends on a sudden drop in anode voltage (controlled by the pulse-forming line) to terminate the pulse and turn off the tube.

Circuit Operation. The schematic of a typical thyratron gas tube modulator circuit is shown in the accompanying illustration.



Typical Thyratron Gas Tube Modulator Circuit

L1 is a charging inductance. The damping circuit consists of damping diode V1, current limiting resistors R1 and R2, together with r-f bypass capacitor C1, which hold the plate of V2 at ground level during each negative half cycle of operation, thus eliminating the possibility of a negative overshoot and the production of damped oscillations. Inductor L2 with capacitors C2, C3, C4 and C5 form the pulse-forming line which develops and shapes the output pulse. Transformer T1 couples the shaped pulse output of the circuit inductively to the magnetron.

With no trigger pulse applied, as the circuit is turned on, the pulse forming line charges through the primary of T1, the pulse forming line, charging inductor L1, and the power supply to ground. When the pulse-forming line reaches maximum charge, a synchronized trigger pulse is applied to the grid of thyratron V2, ionizing the tube (which acts like a closed switch) and provides a discharge path for the primary of T1 and the pulse-forming network to discharge to ground, through V2. As the voltage across the pulse forming network discharges and falls below the ionization level of the thyratron tube, the tube shuts off like opening a switch. However, there is a tendency for the positive discharge voltage to swing negative as it is abruptly stopped and cause negative overshoot because of the inductive properties of the discharging circuit. This negative overshoot is prevented from affecting the output of the circuit by the insertion of damping diode V1 and the damping circuit consisting of R1, R2, and C1. This damping circuit provides a path for the overshoot transient through V1, and it is dissipated by R1, and R2. C1 is a high frequency bypass to ground to preserve the sharp leading and trailing edge of the rectangularly shaped pulse.

FAILURE ANALYSIS.

No Output. The following defects can cause a no-output condition. Low plate supply voltage, an open charging choke L1, or pulse-forming line choke L2, the windings of T1 being shorted or open, a defective tube V2, or a trigger pulse of insufficient voltage to ionize V2.

Check the plate supply voltage, if it is not normal, the trouble is probably in the power supply and the modulator circuit is probably not at fault. If plate voltage is normal, check the voltage on the cathode of V1. If no voltage is present, L1 is open.

If no voltage is present on the primary of T1, pulse-forming line inductor L2 is open.

Make a point to point check with d-c voltmeter (make certain you observe all high-voltage safety regulations) for the proper voltages in the charging circuit. Should no voltage be present at any of the points, the component or components associated with that portion of the circuit is defective; check the inductors with an ohmmeter (be careful to use a shorting stick to make certain the line is discharged) and the capacitors with an in-circuit capacitor checker. With an oscilloscope, check for the proper trigger pulse (both amplitude and repetition rate).

Low Output. Insufficient plate voltage, an improper trigger pulse, a defective pulse-forming network, or a defective magnatron transformer, T1, can cause a low output. Use an ohmmeter for checking the inductors and transformer T1 (make certain the pulse network is discharged first), and an in-circuit capacitor checker for checking the capacitors in the pulse-forming line.

Distorted Output. With the proper trigger signal and plate supply voltage, a distorted output can be caused by shorted turns on inductors L1, and L2 or on the windings of T1. Use an ohmmeter to check for proper values. The pulse-forming line components, if defective, can also cause the output to become distorted. These can be roughly checked with an ohmmeter and an in-circuit capacitor checker.

HARD-TUBE MODULATOR.

APPLICATION.

The hard-tube pulse modulator is used in radar equipments to develop the pulse which controls the operation of the transmitter.

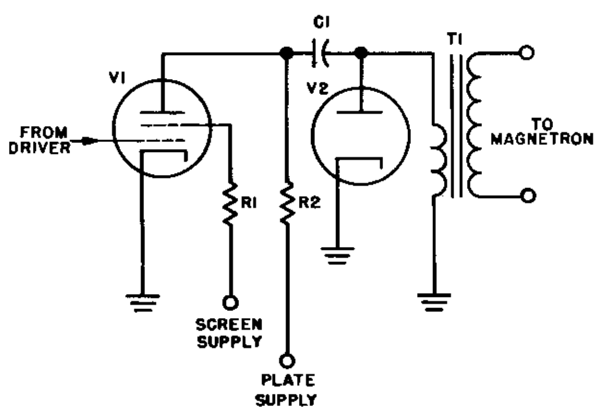
CHARACTERISTICS.

Needs a shaped high-voltage pulse for operation.
Biased to cutoff.
Has gain of about 10.

CIRCUIT ANALYSIS.

General. The hard-tube pulse modulator operates as an amplifier tube with a gain of about 10. The modulator tube is normally biased to cutoff. The application of a positive pulse of about 1300 volts to the grid is necessary to overcome the bias, causing V1 to conduct and dropping the plate-to-cathode potential from the plate supply value established by the cutoff condition. Because of the large resistance of the plate load resistor, the negative voltage pulse developed by this action is effectively applied to the output transformer and the modulator tube in series. Since the impedance of the modulator tube is about one-tenth that of the output transformer, about nine-tenths of the voltage pulse appears across the output transformer. The time between pulses is known as the charging time. A damping diode is in the circuit to damp out the oscillations produced by a negative overshoot when the positive pulse applied to the grid of the modulator is terminated. The damping is accomplished on the first oscillatory swing by shorting it to ground (the negative pulse on the cathode causes the diode to conduct).

Circuit Operation. The schematic of a typical hard-tube modulator is shown in the accompanying illustration.



Typical Hard-Tube Pulse Modulator

V1 is the modulator tube, R1 is the screen voltage dropping resistor, and R2 is the plate load resistor for V1. Capacitor C1 couples the output of the modulator to output transformer T1. Tube V2 is the damping diode, and T1 is the step-up output (magnetron) transformer.

With no trigger pulse applied from the driver, coupling capacitor C1 charges to the plate supply voltage through the primary of T1, R2, the power supply and ground. Tube V1 is biased at cutoff and the plate-to-cathode potential is established by the cutoff condition. A synchronized trigger pulse from the driver circuit is applied to the grid of V1 taking the tube out of cutoff and causing it to conduct. This is similar to closing a switch, and provides a path for C1 to discharge through both the primary of T1 and V1 to ground. This discharge occurs only for the duration of the trigger pulse applied to the grid of V1. When the trigger pulse terminates, the modulator is again cutoff and the magnetic field in the primary of T1 collapses, causing a reverse flow of electrons in the circuit. This reverse flow of electrons is prevented from causing negative oscillations by diode V2, which conducts as soon as the plate goes in a positive direction (when a negative pulse appears on the cathode). Thus, diode V2 dampens any oscillations which would effect the output pulse of the modulator circuit.

FAILURE ANALYSIS.

No Output. Should plate load resistor R2 open, coupling capacitor C1 open, damping diode V2 short, or the windings of transformer T1 be open or shorted, no output would appear on the secondary winding of T1. First check for plate supply voltage at the source. If the supply voltage is present, a drop should appear across R1. At the junction of R2, C1, if no voltage is present, R2 is open. Check the windings of T1 for continuity or a short, with an ohmmeter.

Low Output. An incorrect plate or screen supply voltage, a weak V1, shorted turns on transformer T1, or any of the components in the circuit changing value could cause a low output. Check all supply voltages and the trigger voltage from the driver. If any of these voltages are incorrect, the trouble is in that stage and the modulator circuit is probably not at fault. Check screen and plate load resistors R1 and R2, respectively, with an ohmmeter. Check coupling capacitor C1 with an in-circuit capacitor checker, and transformer T1 with an ohmmeter.

Distorted Output. Distortion can occur from any of the following: an improper trigger pulse, a change in screen or plate supply voltage, a defective V1 or T1, a leaky coupling capacitor C1, or load resistors R1 or R2 changing value. If the driver output pulse applied to the grid of the modulator is not the proper pulse repetition rate or amplitude, the trouble is in the preceeding stages and the modulator is probably not at fault. If the screen and plate voltages are correct, and the output is still distorted, determine that C1 is not leaky by using an in-circuit capacitor checker. Determine that load resistors R1 and R2 are the correct value and that output transformer T1 has no shorted windings.

scope will permit waveform distortion to be observed and located. In the case of failure of the a-f modulation, an unmodulated r-f output will be obtained. Under special circumstances with high a-f drive and no r-f drive, it is possible that the audio waveform may be observed on an oscilloscope (because of capacitive leakage across the transistor); however, this is a rather remote possibility. In any event, the proper method of determining whether distortion exists and of locating the origin of distortion are to use an oscilloscope to observe the waveform, to make a resistance and voltage analysis to check the components, and to determine that the values of the element voltages are correct for normal operation.

If the tank circuit is too sharp (that is, has too high a Q), sideband clipping will result and the higher modulation frequencies will be lost. However, this is only of academic interest since such a condition could result only from an unauthorized modification of Navy equipment.

EMITTER-INJECTION MODULATOR.

APPLICATION.

The emitter-injection modulator is used to produce low level modulation in equipment operating at very low power levels. It is particularly well suited for small portable transmitters, such as walkie talkies, and for test equipment.

CHARACTERISTICS.

Operates by varying the emitter bias at the modulating frequency.

Is restricted to low-level, small signal operation.

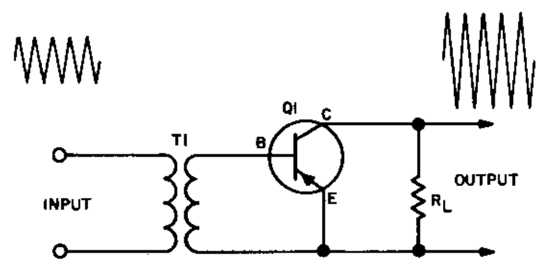
Uses common-emitter configuration.

Modulating signal amplitude is limited to less than that of the emitter bias voltage.

CIRCUIT ANALYSIS.

General. Emitter injection is very similar to base injection, since both methods vary the emitter-base bias. The carrier signal input is coupled to the base region of the transistor, while the modulating signal is applied across the emitter swamping resistor to regulate the gain of the transistor in accordance with the modulation. Consequently very little modulator power is required. Much less than that required for electron tube cathode modulation which is the electron tube counterpart of this circuit. Since the transistor is operating under small-signal conditions, the r-f carrier input (drive) is also small. Under these conditions the transistor is operated either Class A or Class AB. Injection of the modulation in the emitter circuit may be made by either the shunt or series method. In the series method a transformer is used in series with the emitter. Either method, however, operates similarly.

Circuit Operation. Amplitude modulation by emitter injection depends upon a widely separated r-f frequency and modulation (audio) frequency. There are two basic circuits involved, namely, the r-f amplifier and the modulating (bias gain control) circuit. A simplified schematic of the basic r-f amplifier is shown in the accompanying figure. For simplicity, the r-f circuit is shown without bias supplies and a resistive load in place of the tank circuit. It is assumed that normal forward bias is applied the emitter-base junction, and that a reverse bias is applied the collector junction. The secondary of T1 is effectively connected across the emitter-base junction, and the load is connected between emitter and collector as shown.

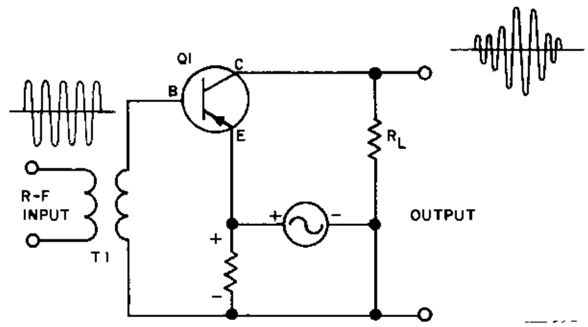


Simplified R F Amplifier Circuit

With normal Class A bias applied, the r-f signal will vary the base voltage equally above and below the operating point (assuming a sine-wave signal), and a corresponding base current will flow. A similar but larger (amplified) collector current will flow through the load resistor, developing an oppositely polarized output voltage. This is the action of a conventional r-f amplifier.

Consider now the method by which modulation is accomplished in the bias circuit, using the accompanying schematic. For simplicity, the modulator circuit is also shown without bias supplies and a load resistor in place of the tank circuit. It is assumed that normal bias is applied the emitter-base junction, and that a reverse bias is applied to the collector junction. The modulation is injected across the emitter swamping resistor. Since the modulating signal is effectively connected in series with the emitter circuit it adds to the emitter bias when of the same polarity. When this voltage is opposite in polarity to the emitter bias it partially cancels and reduces the total emitter bias.

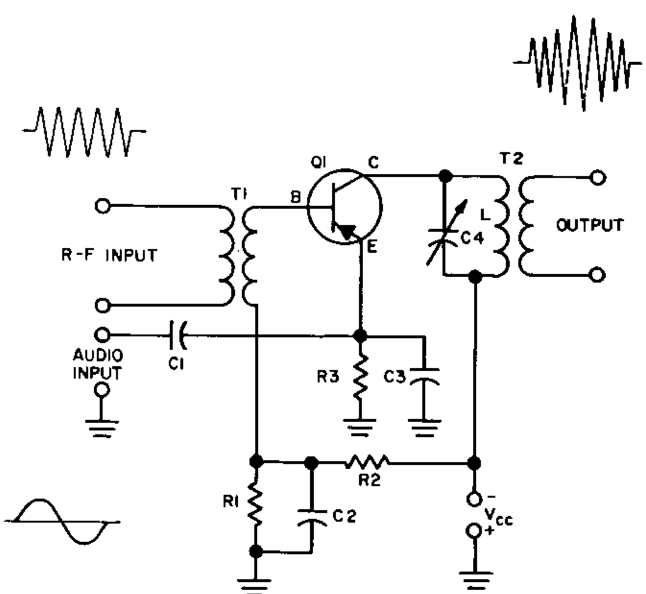
Thus the bias on the transistor is made to vary instantaneously above and below the fixed emitter bias level in accordance with the modulating signal. Assuming a sinusoidal modulating signal, it is evident that the instantaneous bias will also vary sinusoidally. Since a change in bias will produce a change in gain, the instantaneous gain will also vary similarly. Consequently, the instantaneous amplification of the r-f carrier signal will also vary in accordance with the modulation, but in a different and opposite direction. (Common-emitter output polarity is opposite the input polarity.) For maximum modulation the a-f signal must be slightly greater than the



Simplified Modulator Circuit

r-f carrier input signal. To prevent distortion produced by driving the transistor into cutoff or into saturation, the modulation signal voltage must never exceed the d-c bias value.

The circuit of a typical capacitance-coupled emitter injection modulator is shown in the following illustration.



Emitter-Injection Modulator

The r-f input is applied to the base of Q1 through r-f transformer T1 shown untuned for simplicity. Resistor R1 and R2 form a base bias voltage divider from the supply to ground, which places a fixed forward bias on Q1. Capacitor C2 bypasses the divider to ground to prevent r-f feedback into the bias supply. Resistor R3 and capacitor C3 form a conventional emitter swamping resistor bypassed to prevent degeneration. Only very slowly varying temperature changes produce a voltage across R3. (See section 3, paragraph 3.4.1 for an explanation of BIAS CIRCUITS and paragraph 3.4.2 for an explanation of BIAS STABILIZATION for more detailed information on this portion of the circuit, if desired). Transformer T2 is the collector output transformer with tuned primary L and C4 acting as a conventional tank circuit across which the output signal is developed. The secondary of T2 is connected to the next amplifier stage, or to a load (an antenna in special cases).

The bias voltage appearing across R1 is the effective bias applied to the base of Q1 through the secondary of r-f transformer T1. Thus the r-f input voltage is applied in series with the d-c bias provided by R1. However, capacitor C2 bypasses R1 to ground for rf and together with C3 effectively connects the secondary of T1 from base to emitter. As the input signal varies between positive and negative alternations, the emitter current varies similarly but oppositely (decreases on the positive part of the cycle and increases on the negative part of the cycle). The pulses of collector current applied across the tank load C4 and L produce an amplified sine wave of r-f of the same frequency as the input.

Consider now the effect of the modulating signal. Since the modulating signal is coupled through capacitor C1, it appears as a varying af voltage across R3. While C3 bypasses R3 for rf, it is not large enough to bypass the a-f modulation. Thus the emitter voltage is alternately increased and decreased by the modulation which changes the base bias accordingly, so that the bias varies at the modulation rate. Consequently, the gain of the transistor is also changed at the modulation rate. The transistor is not exactly linear in its emitter-collector relationships, but is more linear than the base-collector relationship. While the output is not an exact replica of the input modulation, it will be similar in shape with troughs and valleys occurring at the same time but slightly distorted. Modulation is effectively linear from about zero to 96 per cent before the transfer characteristic rounds off. Above this range the distortion tends to become excessive. Therefore, applications requiring full 100 per cent modulation generally employ the collector injection circuit, which will be discussed later in this section.

While a resistive collector load has been assumed for ease of explanation in the simplified circuit discussions, in practice a tuned (LC) tank is necessary to select the proper output frequency. In every modulator, there are sum and difference frequencies, and spurious frequencies are also generated (even in so-called linear modulators). Therefore, it is necessary to select the desired output frequency. In this case it is the frequency of the r-f carrier plus the sidebands generated in the modulation process.

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 voltohmmeters. Be careful also to observe proper polarity when checking continuity with the ohmmeter, since a forward bias through any of the transistor junctions will cause a false low-resistance reading.

No Output. A defective transistor or open base circuit caused by a defective input transformer, or an open bias resistor will prevent operation. An open bias capacitor also can produce cutoff bias through degeneration if the r-f drive and the resistance in the circuit are sufficient to block operation. Either of these conditions can be checked by means of a resistance or a continuity check with an ohmmeter. An open-circuited emitter, possibly caused by a defective swamping resistor, R3, will also stop operation. An open circuited collector will also stop operation; this condition can result from an open tank coil or a defective soldered joint, causing an extremely high resistance. Checking the collector voltage to ground will determine if this circuit is open. Improper supply polarity will reverse the bias, stop operation, and most likely ruin the transistor. In most cases, a simple resistance and continuity check combined with a voltage analysis, using a high impedance voltmeter, will locate any of the no-output troubles.

Low Output. Too low or too high a bias will cause clipping of the output signal, resulting in a low output with distortion. For maximum modulation, the a-f signal must be slightly greater than the r-f carrier input signal. Therefore, lack of audio gain, a defective coupling capacitor (C1), or shorting the a-f signal to ground by a defective bypass capacitor (C3) can cause loss of or low audio, and produce a low output condition. The use of an oscilloscope to check the waveform will permit the point in the circuit where the waveform is changed or lost to be observed. Lack of sufficient r-f drive will also produce a low-output condition, since the a-f functions merely to modulate the r-f carrier. A defective or mistuned tank circuit can also cause a low output condition, since the maximum output is developed on the same frequency as that of the input (carrier). Where the modulation is present but r-f drive is lacking no output will appear with normal af drive, since the collector load impedance (tank circuit) is too low to develop any voltage across it since it is tuned to the r-f signal.

Distorted or Incorrect Output. Distortion will be caused by improper bias and collector voltage, or by excessive input signals. Check the collector bias and voltage with a high resistance voltmeter. The r-f signal must not exceed to d-c bias; otherwise, rectification of the rf will occur, and change the bias, and, as a result, produce clipping on the modulation peaks. If the a-f modulation is not of sufficient amplitude the peaks of modulation will also be lost and distortion will occur. In a similar manner, too great an a-f drive will send the collector current into the saturation region, and the troughs (negative peaks) will be cutoff, and distortion will result. The use of an oscilloscope permits waveform distortion to be observed and located. In the case of failure of the a-f modulation an unmodulated r-f output will be obtained.

If the tank circuit is too sharp (that is has too high a Q), sideband clipping will also result and the higher modulation frequencies will be lost. However, such a condition is not likely to be found in military equipment that meets specifications.

COLLECTOR-INJECTION MODULATOR.

APPLICATION.

The collector-injection modulator is used to produce modulation at either low or relatively high levels, and up to a maximum of 100 per cent for semiconductor transmitting equipment.

CHARACTERISTIC.

Is operable under either small signal or large signal conditions.

Uses fixed bias.

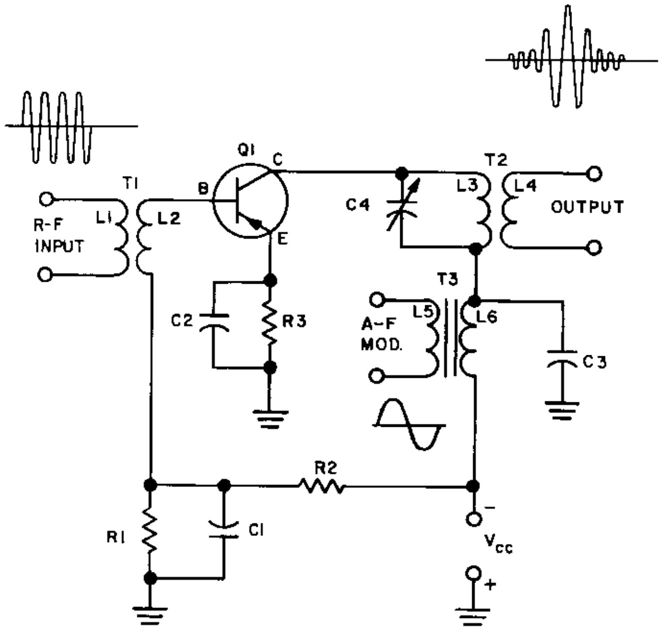
Is capable of full 100 per cent modulation.

CIRCUIT ANALYSIS.

General. Collector-injection is the semiconductor counterpart of electron tube plate modulation. While plate modulation is usually always at a high level, collector-injection can be at very low levels. In fact, at the present state of the art, linear modulation for high frequency transistors is limited to a maximum change of one tenth of a volt or less which is a very low level of operation. In addition, the transistor ratings must be such that normal d-c collector voltage does not exceed one half of the collector breakdown rating, otherwise the peak swing on large signal operation may cause breakdown. When inputs larger than the emitter bias are applied, rectification occurs in the base circuit and causes an increase of bias. However, this slight bias shift does not create as much distortion when collector-injection is used as it would if either base-or-emitter injection were used.

Circuit Operation. The accompanying illustration is a schematic of a typical collector-injection modulator circuit.

The r-f drive voltage is applied to the base of Q1, through r-f transformer T1, inductively from primary L1 to secondary L2. The base is held at a fixed forward bias by bias voltage divider R1 and R2. C1 is the r-f bypass for R1, preventing feedback of r-f into the bias supply and possible regeneration. Emitter resistor R3 provides thermal compensation and is bypassed by C2 to prevent degeneration. With the emitter at ground potential, only slowly varying d-c current changes caused by a temperature change will bias off the emitter and counteract the tendancy of increased current flow with increasing temperature. The audio modulation is inserted in series with the collector of Q1 through audio transformer T3 by connecting secondary L6 between the collector supply and the output tank. The secondary of T3 is also bypassed for r-f by C3 to prevent r-f squeal in the audio circuits caused by feedback. Output transformer T2 has its primary tuned, with L3 and C4 forming the tank, which is inductively coupled



Collector-Injection Modulator

to secondary L4 providing a modulated output.

The fixed negative base bias causes heavy forward conduction in Q1, and base current flows from the supply through R2, L2 secondary, and through Q1 emitter-base junction back to ground through emitter swamping resistor R3. Thus the base is held near cutoff for large signal operation (and is Class A biased for small signal operation). With only the r-f drive signal applied, collector current is decreased during the positive half-cycles and increased during the negative half-cycle. This is conventional r-f amplifier operation and provides the normal r-f carrier.

Assume now, that modulation is applied to the input of L5, The signal is transformer coupled into the secondary. Thus during the positive half-cycles of modulation (assuming an in-phase connection) the collector voltage is opposed decreasing the effective collector voltage. On the negative half-cycle the polarity of the modulation adds to the collector voltage, increasing it. Thus the transistor gain is alternately decreased or increased in accordance with the modulation swing. When the gain is increased a peak of modulation occurs, when decreased a trough in the modulation occurs. If the transistor gain varies linearly, 100 percent modulation is achieved when the collector voltage is doubled on the negative half-cycle. Although secondary L6 of T3 is bypassed by C3, the bypassing is effective for rf only and the af signal remains effective in changing the instantaneous collector voltage. The output tank circuit varies in accordance with the modulation and inductively couples the output to L4 secondary of T2. In small-signal, Class A operation the tank circuit determines the output frequency. In large-signal, Class B or C operation, the tank supplies the missing half cycle which is lost during cutoff, and also determines the output frequency. Thus distortion is kept to a minimum for either small-or large-signal operation.

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 voltmeters. Be careful, also, to observe proper polarity when checking continuity with the ohmmeter, since a forward bias through any of the transistor junctions will cause a false low-resistance reading.

No Output. A defective transistor, open base, emitter, or collector circuit, or a loss of bias will prevent operation. An open base circuit can be caused by lack of continuity in the windings of T1. Check L1 and L2 for continuity with an ohmmeter. Likewise, an open bias circuit may be caused by either R1 or R2 open. If R2 is open the operation is certain to cease, but with only R1 open some bias will be produced through R2 and the transistor, so complete output should not be lost. Check the values of R1 and R2 with an ohmmeter. An open circuited emitter, possibly caused by a defective swamping resistor R3, will also stop operation. Check the value of R3 using an ohmmeter. An open circuited collector will also stop operation; this can be caused by an open tank coil L3, a high resistance soldered joint, or by shorting of tank capacitor C4. An open modulation transformer will also prevent collector voltage from appearing if it is in the secondary of T3, as well as a short on C3. Use an ohmmeter to check the winding for continuity and an ohmmeter to check C3 for a short. If all the circuits thus far are found to have continuity and correct value there are still two possibilities. Transistor Q1 may be defective or output winding L4 of T2 may be open. Check L6 and L4 for continuity with an ohmmeter. Improper supply polarity will reverse the bias, stop operation, and most likely ruin the transistor. In most cases a continuity check combined with a voltage analysis, using a high impedance voltmeter, will locate any of the no-output troubles.

Low Output. Improper bias can result in a low output with distortion. Check R1 for proper value with an ohmmeter. Low output can also be caused by low collector voltage. First check the unmodulated value to be certain it is normal, and then check the instantaneous value with modulation using an oscilloscope. The modulation should be able to drive the collector from zero to twice normal voltage, less than this will produce less than 100 per cent modulation. Check the waveform with an oscilloscope. Lack of sufficient r-f drive will also produce a low-output condition, since the af merely functions to modulate the carrier. A defective or mistuned tank circuit can also cause a low-output condition, since the maximum output is developed on the same frequency as that of the input (carrier). With no a-f applied and low drive, the carrier amplitude will show on an oscilloscope as being less than normal or less than one-half the maximum possible amplitude at peak modulation. To determine if the tuning is correct adjust the tank for maximum r-f output (minimum current) if there is no sharp dip in current or pronounced peak output as the tuning capacitor is rotated, check the tuning capacitor for an open or short.

Distortion or Incorrect Output. Distortion will be caused by improper bias or collector voltage, and by excessive input signals. The r-f signal must not exceed the d-c bias; otherwise, rectification of the r-f will occur and change the bias, and, as a result, produce a slight modulation shift on peaks. This will not be as pronounced a distortion as if the injection were of base or emitter type, since only a small fraction of the signal is affected in collector modulation. Too great a modulation signal will cause peak clipping and distortion since the negative peaks will enter saturation and be lost. Use of an oscilloscope will permit this type of waveform distortion to be observed and located. It is also possible that excessive modulation peaks can exceed the maximum inverse voltage, and likewise cause peak clipping effects and possibly damage the transistor.

SINGLE SIDEBAND MODULATORS

Amplitude modulotion is the process by which the amplitude of a signal called the carrier frequency (usually r-f), is varied by another signal (usually a-f). The resultant modulated r-f signal can be separated into three different frequencies. They are the original r-f carrier and the upper and lower sidebands. These sidebands are actually sum and difference frequencies generated through the process of frequency conversion. Two thirds of the average radiated power of a fully modulated AM transmission is contained in the r-f carrier. Since all of the intelligence contained in the modulating signal is transposed to the upper and lower sidebands, which are identical to each other, the carrier and one of the sidebands may be eliminated from the output without changing the remaining sideband. This allows the available transmitter power to be utilized to a much greater advantage in a single sideband. This type of transmission is generally known as suppressed carrier single sideband. The discussion of electron tube single sideband modulators in section 14.2 of this Handbook is generally applicable to semiconductor single sideband modulators. In general, semiconductor versions of electron tube single sideband modulators provide all the advantages one would expect to find in semiconductor circuits such as greater reliability, cooler operation, greater power efficiency and small size, in light-weight units.

In single sideband transmitters the carrier is usually suppressed or eliminated by the use of a balanced modulator. The basic principle of a balanced modulator is to introduce the r-f carrier to the balanced modulator in such a way that it does not appear in the output. There is only an output signal when both the audio modulation and the r-f carrier are present simultaneously at the modulator input. This output signal consists of only the upper and the lower sideband frequencies generated in the balanced modulator by the mixing of these two input signals across the nonlinear resistance of the transistor. The original audio modulation and the r-f carrier inputs are suppressed because of the operational characteristics of the circuit. All types of balanced modulator circuits function somewhat alike. Semiconductor balanced modulators are discussed in detail in the following paragraphs.

BASIC BALANCED MODULATOR.

APPLICATION.

The semiconductor basic balanced modulator is used to produce amplitude modulated upper and lower sideband frequencies for use in single sideband transmitters.

CHARACTERISTICS.

Utilizes nonlinear characteristics of transistors to produce sidebands.

Produces amplitude modulated upper and lower sidebands while suppressing the r-f carrier.

Uses push pull output and parallel input to cancel out the carrier.

Modulation is accomplished at low power levels; therefore, no large modulator power supplies and transformers are needed.

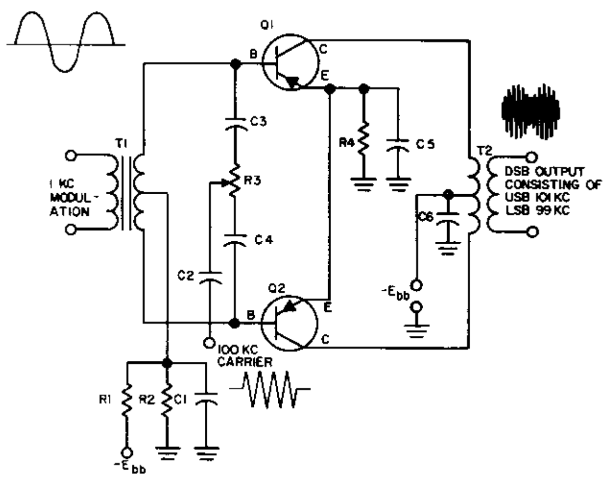
Can provide conversion gain, i.e., sideband output greater than modulation input.

CIRCUIT ANALYSIS.

General. The basic balanced modulator produces amplitude modulated upper and lower sidebands and suppresses the r-f carrier. This is achieved by coupling the r-f carrier, in-phase, to the bases of two transistors whose output is connected in push-pull, (out of phase). The r-f carrier is kept 8 to 10 times as large as the modulating voltage to keep distortion to a minimum. In push-pull amplifiers an input signal must be out of phase to produce an output since any in-phase inputs cancel in the output. The modulating signal is applied to the base of each transistor in push-pull (180 degrees out of phase) through a center tapped transformer. When both r-f carrier and audio modulating signals are applied simultaneously to the bases of the balanced modulators, sum and difference frequencies (sidebands) are produced by the modulating frequencies beating against the carrier, since any amplitude modulation process is essentially the same as heterodyning. As in a frequency converter, any modulation which exists on one of the mixing frequencies is linearly transposed to the resultant sum and difference frequencies. The collector circuit contains the upper and lower sidebands which are the sum and difference frequencies, respectively, the r-f carrier, and the audio modulation. The carrier is cancelled out by push-pull action in the output transformer, and the output transformer also presents a low impedance to the audio modulating signal. Therefore, the original modulating signal also is not developed in the output. The generated sidebands are out-of-phase with each other at the collectors of the transistors, since the modulating signal is out of phase at the bases. These out-of-phase signals add in the output transformer rather than cancel as in-phase signals do, and they are inductively coupled to the following stages through the output transformer.

Circuit Operation. The accompanying diagram illustrates a basic semiconductor balanced modulator.

Audio transformer T1 couples the audio modulation to the bases of transistors Q1 and Q2. Resistors R1 and R2 form a base bias voltage divider which provides the proper bias for the transistor. Capacitor C1 places the center tap of T1 at a-f ground potential to supply an out-of-phase (push-pull) input. Capacitor C2 couples the r-f carrier from the carrier oscillator to the slider of carrier balance potentiometer R3. Potentiometer R3 can be adjusted, to vary the relative amplitude of the r-f carrier signal voltage on the bases of Q1 and Q2, to provide a carrier balance control, so that the r-f carrier can be completely suppressed in the output. Capacitors C3 and C4 couple the r-f carrier from balance potentiometer R3 to the bases of Q1 and Q2, and also act as d-c bias blocking capacitors to prevent base shorting. Transistors Q1 and Q2 are the nonlinear devices used for generating the sidebands. Resistor R4,



Basic Balanced Modulator (Common Emitter).

which is bypassed by C5 is a conventional emitter stabilization resistor intended to prevent changes in temperature from altering transistor characteristics. Center-tapped output transformer T2 provides a push-pull collector load for the modulators. Capacitor C6 places the center-tap of the primary of T2 at r-f ground potential.

To more easily examine the operation of the basic balanced modulator, assume first that only the r-f carrier is applied. The r-f carrier generated in the carrier oscillator is coupled through C2 to the slider of potentiometer R3. Hence, the carrier signal appears at both ends of R3 and is coupled through capacitors C3 and C4 to the bases of Q1 and Q2, respectively. The carrier signal voltage is in-phase on the bases of Q1 and Q2 (they are parallel connected) and the amplitude of the carrier signal at the base of each transistor is controlled by the adjustment of R3. Assuming that the r-f input is operating on the negative half cycle, the negative forward base bias is increased and both collectors draw an increasing amount of collector current, (the base input is in phase). Thus, the voltage drop produced across each half of output transformer T2 is positive-going, and equal but opposing voltages are developed in each half of the transformer primary by current flowing in opposite directions which cancel, so that no output is obtained from the secondary winding. Likewise, on the positive half cycle of r-f input the forward bias is reduced and less collector current is drawn. Thus, the drop across transformer T2 primary windings is negative going and equal and opposing voltages are developed in the primary because the current flow through each primary is opposite. These voltages also cancel out (since they are out-of-phase) so no carrier again is developed in the output. If the circuit is properly balanced by the adjustment of R3, the opposing signals are exactly equal in amplitude and the carrier is completely suppressed. Thus, it can be seen that an output is not produced with only an r-f carrier input applied.

When audio modulation and the r-f carrier are both applied simultaneously, a different situation arises. The audio modulation is applied through transformer T1. Since the secondary of T1 is effectively center-tapped by C1, R2, and the bias supply, modulation signal voltages are developed across each half of the secondary winding of T1 which are out of phase with each other. The out-of-phase modulating signals are applied directly to the base of each transistor. Capacitors C3 and C4 are of such a value that they present a high reactive impedance to audio frequencies and thus prevent any audio modulation from feeding back from one base to the other and cancelling each other out. Meanwhile, the audio modulating signal modulates the inserted r-f carrier and produces upper and lower sidebands in the collector circuit of transistors Q1 and Q2. These sidebands are produced by mixing the r-f carrier frequency and the modulation signal together across a nonlinear device. (Detailed information concerning frequency conversion, (mixing or heterodyning), can be found in the introduction to Section 13 of this Handbook.) To better illustrate the operation of the basic balanced modulator with both r-f carrier and modulation applied, assume that the first half cycle of the modulating signal voltage applied to the base of Q1 is positive and the first half cycle of the modulating signal applied to the base of Q2 is negative.

The conduction of Q1 decreases as a result of the positive half cycle of modulation input opposing the forward bias of the emitter base junction. This results in negative going sideband frequencies being developed across the top half of the output transformer. At the same instant the conduction of Q2 increases as a result of the negative going half cycle of modulation input aiding the forward bias of the emitter base junction, and causing positive-going sideband voltages to be developed across the bottom half of the output transformer T2. Push-pull action occurs and the side band frequency signal voltages add to each other causing both upper and lower sidebands to be developed and inductively coupled to the secondary of T2. The r-f carrier is suppressed, as explained earlier, and the original audio modulating signal is not developed due to the low reactance of T2 to audio frequencies. Therefore, only the upper and lower sidebands are produced by the balanced modulator.

FAILURE ANALYSIS.

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

No Output. Since each leg of the basic balanced modulator performs essentially the same function, failure of one leg of the balanced modulator is not likely to cause a no-output condition to exist, unless the failure occurred in a manner that would affect the power supply such as a shorted transistor or a shorted C6. Failure of the power supply itself is a likely cause of no output. If the power supply measures normal when checked separately and no collector voltage appears on Q1 or Q2, check T2 primary and C6 for a short or ground. An open or shorted R1 or R2 or a shorted C1 would remove the bias from transistors Q1 and Q2 and could also cause a no-output condition to exist. Since R4 is a common emitter resistor for both transistors a no-output condition would also result if R4 opened. Check for proper value with an ohmmeter. Since any balanced modulator produces an output only when both the r-f carrier and the modulating signal are present, absence of either of these signals on the base of each transistor would cause the balanced modulator to be inoperative. Presence of the input signals can readily be determined by observing, with an oscilloscope, the waveform present at these points with the carrier oscillator operating and with modulation applied to the transmitter. Absence of the audio modulation on the bases of the transistors could be caused by a defective audio input transformer, T1, or by failure of the audio stages preceding the balanced modulator. Presence of audio modulation on the primary of T1 indicates that the preceding audio stages are functioning properly. Should the modulation be present on the primary of T1 but absent on the bases of the transistors, T1 is most likely defective (check the primary and secondary for continuity with an ohmmeter). Presence of the r-f carrier at the input to coupling capacitor C2 indicates that the carrier oscillator is operating. In the event that the r-f carrier is present at the input of C2 but is absent on the bases the transistors, capacitor C2 or potentiometer R3 may be open. Check R3 for proper value and C2 for value with an in-circuit capacity meter. Failure of C3 or C4 would only disable one leg of the balanced modulator and an output would still result. Signal tracing from C2 to the bases of the transistors will reveal which component is at fault. Another possible cause of no output is a defect in output transformer T2. Continuity checks of the transformer windings and checks for leakage between the primary and secondary and between each winding and ground will reveal whether or not a defect exists in the transformer.

Low Output. A low output condition could be caused by a defective transistor, a faulty circuit component, o defective power supply, or by low amplitude r-f carrier or modulation input. Voltage checks should be made of the power supply voltage and of transistor elements to determine whether or not a defective power supply or a faulty component is the cause of low output. A change in value of resistors R1 or R2 or leakage in capacitor C1 would change the base bias of transistors Q1 and Q2 and could cause a low output condition. If C5 opens the resulting degeneration would lower the gain of the modulator circuits and could cause low output to result. Likewise, an increase in value of emitter stabilization resistor R4 would alter the operating bias of the transistors and could cause a decreased output. Check the value of R4 with an ohmmeter. The amplitude of the inputs to the balanced modulator can be checked by observing with an oscilloscope the waveform present at the base of each transistor. If either input signal is low in amplitude, the cause can be determined by signal tracing from the bases of the transistors to the stages preceding the balanced modulator. If either C3 or C4 opens, one leg of the balanced modulator would be inoperative and low output would result. Do not overlook the possibility that a defective output transformer can also cause low output. Check the resistance to ground with an ohmmeter.

Distorted Output. Distortion of intelligence will result in SSB systems if the receiver and transmitter are not exactly on frequency. Distortion in SSB transmitters is usually the result of improper operation of the linear power amplifier or of operating any stage beyond its capabilities. Should the distortion be determined to be caused by the balanced modulator, check the modulation level to make sure that the audio circuits are not overdriving the balanced modulator. If the modulation level is correct, distortion could still be caused by a defective transistor. If the transistors are determined to be good and distortion persists, voltage checks of transistor elements with a high resistance voltmeter would reveal whether or not a defective component or a defective power supply is the cause of distortion. Low amplitude r-f carrier input could also cause distortion. The r-f carrier input should be 8 to 10 times the amplitude of the modulating signal.

BALANCED COMPLEMENTARY SYMMETRY MODULATOR

APPLICATION.

The balanced complementary symmetry modulator is used in single sideband transmitters to produce amplitude modulated upper and lower sidebands.

CHARACTERISTICS.

Produces amplitude modulated upper and lower sidebands while suppressing the r-f carrier.

Utilizes a PNP and an NPN transistor connected in a complementary symmetry circuit.

Requires two collector power supplies (one positive and one negative supply).

Static current does not flow through the output transformer.

Utilizes the common collector configuration.

Requires two separate bias supplies.

CIRCUIT ANALYSIS.

General. The balanced complementary symmetry modulator produces amplitude modulated upper and lower sidebands and suppresses or cancels the r-f carrier, which is used to generate the sidebands. Basically this is achieved by coupling the audio modulation in parallel (in-phase) to the bases of two opposite polarity (PNP and NPN) transistors connected in a complementary symmetry configuration, and simultaneously coupling the r-f carrier in push pull (180° out-of-phase) to the bases of the transistors. It