INSTRUCTION SHEET

This sheet provides instructions for inserting CHANGE 2 (NAVSHIPS 0967-000-0122) to the Electronics Circuits Handbook, NAVSHIPS 0967-000-0120.

1. Remove superseded pages and insert new pages as indicated below:

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2. Record the insertion of this change on the Record of Corrections Made Page.

3. Insert the User Activity Technical Manual Comment Sheet as the last page of the handbook.

*The RECORD OF CORRECTIONS MADE and NOTES pages, pages A and B Change 2, may be inserted or the present RECORD OF CORRECTIONS MADE and NOTES pages (pages v and vi Change 1) may be inserted as the A and B pages. If the old Change 1 pages are to be used, correct the Change number to read Change 2; correct page v number to read page A; and correct page vi number to read page B.

NAVSHIPS 0967-000-0120
(Formerly NAVSHIPS 900, 000. 102)

NON-REGISTERED

ELECTRONICS INSTALLATION AND MAINTENANCE BOOK

ELECTRONIC CIRCUITS

DEPARTMENT OF THE NAVY
NAVAL SHIP ENGINEERING CENTER

PUBLISHED: APRIL 1965
CHANGE 2: SEPTEMBER 1968 (0967-000-0122)

BOX SCORE
ELECTRONIC CIRCUITS HANDBOOK
NAVSHIPS 0967-000-0120

EDITION	PUBLICATION DATE	STOCK NUMBER
Basic	April 1965	0967–000–0120
Change 1	December 1966	0967–000–0121
Change 2	September 1968	0967–000–0122

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**To be issued in later changes

**To be issued in later changes

PREFACE

POLICY AND PURPOSE

The Electronics Installation and Maintenance Book (EIMB) has been established as the medium for collecting, publishing, and distributing, in one convenient documentation source, those subordinate maintenance and repair policies, installation practices, and overall electronics equipment and material-handling procedures required to implement the major policies set forth in Chapter 9670 of the Naval Ships Technical Manual. All data contained within the EIMB are authoritative, and derive their authority from Chapter 9670 of the Naval Ships Technical Manual, as established in accordance with Article 1201, U. S. Navy Regulations.

Since its inception, however, the EIMB has been expanded to include selected information of general interest to electronic installation and maintenance personnel. These items are such as would generally be contained in textbooks, periodicals, or technical papers, and form (along with the information cited above) a comprehensive, single-source reference document. In application, the EIMB is to be used for information and guidance by all military and civilian personnel involved in the installation, maintenance, and repair of electronic equipment under cognizance, or technical control, of the Naval Ship Systems Command (NAVSHIPS). All information, instructions, and procedures in the EIMB supplement such instructions and data supplied in equipment technical manuals and other approved maintenance publications.

ORGANIZATION

The EIMB is organized into a series of handbooks to afford maximum flexibility and ease in handling. The handbooks are stocked and issued as separate items so that activities requiring extra copies of any handbook may obtain them with relative ease.

The handbooks fall within two categories general information handbooks and equipment-oriented handbooks. The general information handbooks contain data which are of interest to all personnel involved in installation and maintenance, regardless of their equipment specialty. The titles of the various general information handbooks give only an overall idea of their data content; a more complete description of each handbook is provided in the General Handbook.

The equipment handbooks are devoted to information on a particular equipment class; they provide general test procedures, adjustments, general servicing information, and field change identification data.

The following table lists all handbooks of the series, together with their old and new NAVSHIPS numbers. (The old NAVSHIPS numbers are shown in parentheses.) The new NAVSHIPS numbers, although not presently imprinted on all handbooks of the EIMB series, serve also as the stock numbers which are to be used on any requisitions submitted.

HANDBOOK TITLE	NAVSHIPS NUMBER
(General Information Handbooks)	
General	0967-000-0100 (900,000.100)
Installation Standards	0967-000-0110 (900,000.101)
Electronic Circuits	0967-000-0120 (900,000.102)
Test Methods and Practices	0967-000-0130 (900,000.103)
Reference Data	0967-000-0140 (900,000.104)
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(Equipment-Oriented Handbooks)	
Communicarions	0967-000-0010 (900,000.1)
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Test Equipment	0967-000-0040 (900,000.4)
Radiac	0967-000-0050 (900,000.5)
Countermeasures	0967-000-0070 (900,000.7)

PREFACE

INFORMATION SOURCES

Periodic revisions are made to provide the best current data in the EIMB and keep abreast of new developments. In doing this, many source documents are researched to obtain pertinent information. Some of these sources include the Electronics Information Bulletin (EIB), the Naval Ship Systems Command Technical News, electronics and other textbooks, industry magazines and periodicals, and various military installation and maintenance-related publications. In certain cases, NAVSHIPS publications have been incorporated into the EIMB in their entirety and, as a result, have been cancelled. A list of the documents which have been superseded by the EIMB and are no longer available is given in Section 1 of the General Handbook.

SUGGESTIONS

NAVSHIPS recognizes that users of the EIMB will have occasion to offer comments or suggestions. To encourage more active participation, a self-addressed comment sheet is frequently provided in the back of each handbook change. Complete information should be given when preparing suggestions. It is most desirable that the suggestor include his name and mailing address on the form to facilitate direct correspondence in the event clarification is required and an immediate reply can be supplied regarding the suggestion. Any communication will be made through a personal letter to the individual concerned.

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Report all inaccuracies and deficiencies noted in all NAVSHIPS technical publications (including this manual, ship information books, equipment manuals, drawings, and such) by a "Planned Maintenance System (PMS) Feedback Report, OPNAV 4700.7 (REV. 5-65)" or superseding form. If PMS is not yet installed in this ship, report technical publication deficiencies by any convenient means .

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The Electronics Installation and Maintenance Book is transmitted to using activities through automatic disrribution procedures. Activities not already on the EIMB distribution list and those requiring changes to the list should submit correspondence to the following:

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RECORD OF CORRECTIONS MADE

CHANGE NO	DATE	CHANGES MADE	SIGNATURE

NOTES

capacitor C1, if used, may cause hum or reduced output because of inadequate filtering of the input power, $+E_{bb}$. A decreased value of input power, $+E_{bb}$, due to a defective power supply, would also be a cause of reduced output.

PUSH-PULL DIRECT-COUPLED (D-C) AMPLIFIER.

APPLICATION.

The push-pull direct-coupled amplifier (as well as the single-ended direct-coupled amplifier) can be used where it is necessary to amplify signals having a wide band of frequencies, especially in the lower-frequency range, which may extend down to and include zero frequency (direct-current). When, in addition, the requirements demand the amplification of a signal which has a larger voltage swing above and below a zero voltage level than can be handled by the single-ended type, the use of the push-pull direct-coupled amplifier is mandatory. One application is in certain types of d-c vacuum-tube voltmeters, while another is in the signal amplifiers of an oscilloscope that is capable of displaying waveforms of various values of direct current. The push-pull d-c amplifier is often utilized in the video circuitry of radar display systems. In communications, it may be used as the amplifier for those teletype mark and space signals that consist of two voltage levels of direct current.

CHARACTERISTICS.

The connections between the plates (outputs) of one stage and the grids (inputs) of the push-pull d-c amplifier are direct, metallic connections; no intervening coupling devices such as capacitors, impedances, or transformers are used.

Amplification of direct-current signals of varying voltage levels, as well as signals of very low frequency, is realized without distortion and with uniform response.

Distortion due to differentiation is eliminated; pulse signals of large amplitude may be amplified without change in waveform.

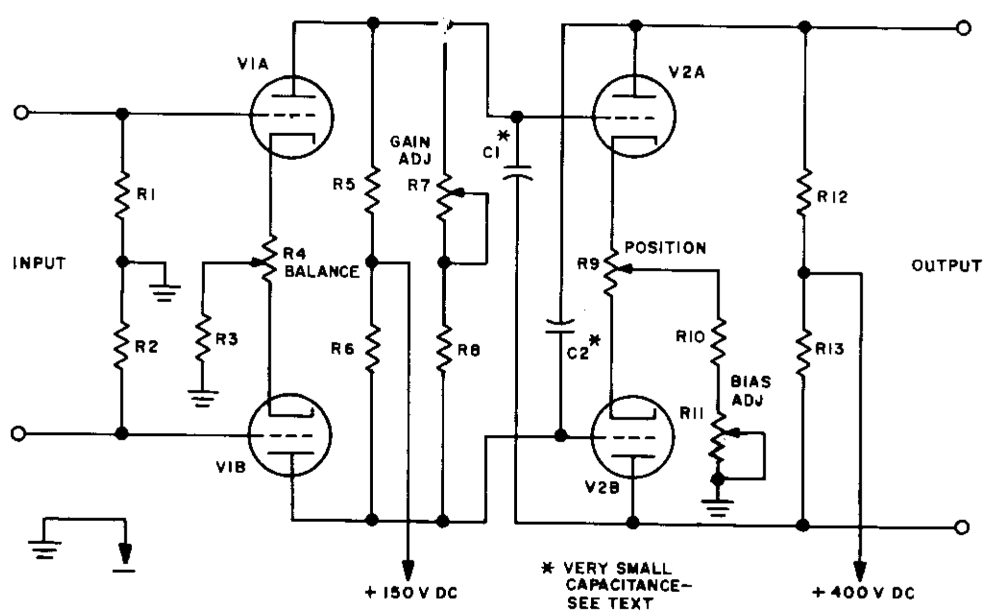
Speed of response is practically instantaneous.

Input impedance is high; Class A operation allows no grid current to flow.

Relative phase (with respect to ground) of the output signal is reversed over that of the input signal when a single stage, or odd number of stages, is used.

CIRCUIT ANALYSIS.

General. The gain of an ordinary R-C coupled amplifier falls off rapidly as the frequency of the input signal is decreased below 40 cycles, because of the rapid increase in reactance of the coupling capacitor with a decrease in frequency. Therefore, the R-C amplifier is unsuitable for use in applications which require the amplification of very



Typical Two-Stage Push-Pull Direct-Coupled (D-C) Amplifier

low frequencies, including zero frequency or direct current, without substantial loss of gain.

The push-pull direct-coupled amplifier is well suited for such applications, since the input signal is applied directly to the grids of two tubes, without the use of coupling capacitors. Frequency response is flat down to and including zero frequency, allowing the use of this circuit for amplification of steady-state d-c voltages. The response at very high frequencies is limited by the stray capacitances in the circuit, which have a shunting effect, similar to that of the ordinary R-C coupled amplifier.

Circuit Operation. The schematic shown above illustrates a typical two-stage push-pull direct-coupled (d-c) amplifier. This type of circuit may be found in applications such as the deflection amplifiers of radar scopes designed for electrostatic deflection, and the signal amplifiers (vertical-deflection amplifiers) of high-quality test oscilloscopes designed for direct-current waveform analysis.

The input signal, which may consist of positive or negative pulses, or both, or simply of a positive or negative d-c level, is applied across the grids of V1A and V1B. These two triodes may be enclosed in the single envelope of a twin-triode such as type 12AU7A. Self-bias is provided both triodes by means of the common cathode resistor, R3, in combination with potentiometer R4, which provides a balance control for use in equalizing the gain of V1A and V1B. Plate voltage of a medium value (+150 volts) is applied through plate load resistors R5 and R6. Variable resistor R7 functions as a gain adjust control, and fixed resistor R8 connected in series with it sets the low limit for the variable value of the total resistance between the two triode plates. This combination, R7 and R8, affords a relatively simple means, from the standpoint of circuit components, of adjusting the over-all gain of the amplifier, and thereby the amount of vertical deflection in oscilloscope applications. Resistor R8 should have a minimum resistance value on the order of 1.5K, in order to maintain this minimum value of resistance as a plate-to-plate load when R7 is adjusted to its zero-resistance position. As R7 is adjusted from its maximum value, toward zero resistance, loading of the signal output from V1A and V1B is increased, reaching a minimum value when R7 is adjusted to remove its resistance from the circuit. The maximum positive and maximum negative excursions of the signal to be amplified may thereby be adjusted, while maintaining the over-all frequency response of the amplifier.

The amplified output signal from the plates of both triodes, V1A and V1B, is applied directly to the grids of the second stage triodes, V2A and V2B. Since the grids of the second stages are at the same positive potential as the plates of the first stage (some value less than +150 volts due to the voltage drop through R5 and R6), the cathodes of V2A and V2B must be placed at a somewhat greater potential than +150 volts (above ground), in order that the grids may be properly biased, i.e., negative with respect to cathodes. In this circuit, which utilizes self-bias, this is accomplished by the use of a large value of cathode resistance, composed of potentiometer R9 and resistors R10 and R11. Potentiometer R9 serves as a balance adjustment to equalize the gain in both halves of the second stage; in this application, it serves to "position" the waveform under observation on the oscilloscope screen. The bias on the cathodes is adjusted by means of variable resistor R11, while the total resistance of the combination R9, R10, and R11 establishes the total bias voltage at the cathodes of V2A and V2B. This relatively large value of cathode resistance, which amounts to approximately 12K, would introduce degeneration into the circuit, resulting in a decrease in gain, if this were an unbalanced (single-ended) stage. In this (push-pull) circuit, however, the degenerative effect of one half of the circuit at any instant immediately cancels an opposite effect of the other half of the circuit, and no loss of gain occurs. Conversely, any tendency toward an unbalance in one half of the circuit introduces degeneration which acts in opposition to the initial tendency, thereby keeping both halves of the circuit balanced. Such a tendency toward an unbalanced condition might be caused by circuit drift, due to unequal cathode emission in the two triodes.

Plate voltage for the second stage triodes is applied, from a considerably higher voltage source than that of the first stage, through plate load resistors R12 and R13. Although an applied voltage of +400 volts, dc may appear to be excessive, it should be noted that the actual voltage at the plates of V1A and V1B cannot exceed 250 volts positive with respect to the voltage at the grids, under any conditions (within Class A operating limits). Under normal operating conditions, with plate current flowing, the voltage at the plates will be considerably less than 250 volts positive with respect to the grids, due to the voltage drop in the plate load resistors, assuming that similar tubes are used in both stages (V1 and V2) with similar plate load resistors, and that no input signal is applied.

In the circuit illustrated, capacitors C1 and C2 are used in a compensation circuit; C1 connected between the ouput plate of one half of the circuit and the input grid of the opposite half, and C2 connected between the output plate of the second half of the circuit and the input grid of the first half. These capacitors are of very low value of capacitance, such as 0.5 mmf, and function to allow positive (in-phase) feedback of the high frequencies only, leaving the mid-frequency and low-frequency response unaffected. When the proper values of capacitance are used (these values vary with the values of plate resistance, operating voltages, and tube types), the response of the over-all circuit, which normally drops off with increasing frequency, may be maintained flat to a considerably higher frequency than would be possible without this compensation. The value of capacitance used is somewhat critical, in that if the capacitance is too high the amount of positive feedback will be excessive, resulting in oscillation and severe frequency distortion. In addition to maintaining the high-frequency response over an extended range, the use of high-frequency feedback offers an additional advantage: When direct current input waveforms are being amplified, in the case of the circuit illustrated, the extended high-frequency response acts tc decrease the rise time of the leading edge of the input waveform. If, for instance, the input waveform is a direct current whose voltage increases instantaneously (the leading edge of a square wave) from one value of voltage to a more positive value, this perpendicular wavefront will be found, upon analysis, to be composed of an infinite number of frequencies. If all of these test frequencies could be passed by

Self-bias is used with RB and the internal base-emitter resistance providing the bias (it acts as a voltage divider connected across the supply). Emitter resistor RE serves as an emitter swamping resistor to provide thermal compensation. (See Section 3, paragraph 3.4.1, of this Handbook for a discussion of bias, and paragraph 3.4.2 for a discussion of stabilization action.) The collector input, which is the signal from the d-c amplifier stage, is direct-coupled, while the chopper (sometimes called "carrier") input may be either direct- or a-c-coupled. In either instance, the circuit bias voltage must be arranged so that the direct coupling does not bias off Q1 in an undesirable mode of operation. Note that the direct-coupled collector input is actually the collector supply voltage. Note also that the a-c waveform shown as the d-c input signal on the schematic represents the signal component produced by increasing the d-c input above the level representing zero to produce a positive waveform, and decreasing the d-c level below this zero level to produce the negative waveform. It actually is a d-c voltage which varies at the signal frequency.

The operation is such that the transistor acts as a switch, being off when de-energized and on when energized. The switching action is obtained from the chopper input signal, which is a rectangular pulse of constant amplitude (usually in the audio range). On the positive peak, the forward base bias is reduced to a value which stops conduction through the transistor. On the negative peak, the foward base bias is increased and the emitter conducts heavily in the saturation region. During the vertical rise and fall times, the bias changes rapidly from one state to the other. It is during this time that the transistor is in its normal operating region, but because of the short duration of the rise and fall time no actual amplification occurs during this period.

Let us consider one cycle of operation. Assume that the transistor is resting in its quiescent state with a small self-bias and with no inputs applied. Transistor Q1 will draw its quiescent value of collector current. Assume that a 1000-cps rectangular pulse is applied as the chopper input to the base electrode. With equal on and off times the transistor will conduct heavily during the negative chopper-pulse when the forward bias is increased. Assume that the d-c input signal is also simultaneously applied to the collector, and that it is positive. This will place a forward bias on the collector (instead of the normal reverse bias), and the transistor will quickly reach a steady saturation current. Note that the d-c amplifier input signal is actually acting as the collector supply voltage. At point A on the schematic the input waveform will appear; however, at point B the input voltage is entirely dropped across collector resistor RC, as a result of the heavy conduction, and no output appears. When the chopper input signal goes positive the forward base bias is opposed, and, since the square-wave input is always of greater amplitude than the bias, the base is reverse-biased and collector current is effectively reduced to zero. It is not exactly zero because a small reverse current, I_{ceo}, flows through the internal resistance of the base-collector and emitter-base junctions of the transistor. This reverse current produces a voltage drop through collector resistor RC in opposition to normal collector current flow, from points B to A instead of from points A to B. Therefore, the polarity of this reverse-generated voltage is in opposition to the d-c input signal, and thus reduces it a small amount. However, for the present we may ignore this small loss of input voltage and say that during the nonconducting period the full amplitude of input voltage appears at the output. During the entire positive excursion of the d-c input signal, the output will consist of a series of pulses having approximately the same amplitude as the input signal at the instant the transistor is turned off. When passed through coupling capacitor C_{cc}, this waveform will look exactly like the input since the d-c portion is eliminated and only the varying a-c portion appears at the output. As stated previously, this amplitude is slightly less than that of the input because of the reverse drop through RC. Therefore, although called a "chopper-amplifier," it is clear that the gain is always less than unity and the function is mainly one of converting the d-c signal to an a-c signal.

Consiser now the operation on the opposite half-cycle of the d-c input signal. In this instance the collector voltage is always negative, which is the normal reverse-biased collector condition. With the same rectangular chopper input signal, the base bias is alternately reduced and aided. In the reduced condition, effective zero collector current is obtained; during the aiding port of the chopper signal, the forward bias is increased. Thus, the same operating conditions prevail, with the transistor alternately driven to saturation (this time by the chopper signal alone) and to effective cutoff. During saturation (the on period) the collector input signal is dropped to zero through the collector resistor, and during effective cutoff (the off period) the signal appears at the output. In this instance, again, there is also a flow of reverse current, which produces a slight opposing voltage so that the input signal is slightly reduced. The output appears as a negative varying voltage which is identical in shape to the input signal. In the collector circuit it consists of a group of pulses with an amplitude equal to the input signal amplitude (minus the reverse drop) during the off period.

The unique property of the transistor which permits it to operate with either a forward-biased or reverse-biased collector also serves to switch the functions of these elements. Thus, with forward bias the collector becomes an emitter, and the emitter functions as the collector. This allows the designer the choice of either connecting the transistor as a common emitter, or of reversing the collector and emitter connections and have it operate in the inverted fashion. In either case the operation is identical except that the terms **collector** and **emitter** must be interchanged in the places they appear in the circuit discussion.

In some applications the emitter resistor is not used since its function is for temperature stabilization by small or incremental changes of emitter current, and the large and leakage inductance, while the low-frequency response is determined by the combination of load resistance and magnetizing inductance. In addition, the shunting capacitance and inductance form resonant circuits which produce humps in the response curve. Practically speaking, the response is very similar to that of the electron-tube transformer-coupled audio stage, with somewhat less high-frequency response. Loss of low-frequency response as compared with the electron-tube circuit becomes apparent when miniaturized transformers are used, because of the difficulty of building transformers with a sufficiently large iron core to provide a high inductance with the limited number of turns available in the space allocated.

Despite the apparent loss of response in the transistor transformer-coupled amplifier as compared with other forms of coupling and the use of electron tubes, relatively good response is obtained by using more stages and low-and-high-frequency peaking circuits where necessary. A maximum efficiency of about 50 percent is obtained as compared with 25 to 30 percent for resistance-coupled stages.

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 to observe 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 may be caused by an open-or short-circuited transformer winding, by improper bias or loss of collector voltage, or by a defective transistor. A voltage check will determine whether the bias and collector voltages are normal; also, a VTVM will indicate audio input and output voltages. With the few components involved, simple voltage and resistance checks will usually indicate the source of the trouble. If the bias voltage divider is open because return resistor R_B is defective, the base bias will be sufficient to cut off the transistor. With R1 open, only contact bias exists and the transistor will very likely conduct heavily in the saturation region. If the primary of T1 is open, there will be no voltage measured between the collector and ground. If emitter resistor R_E is open, the circuit will not operate; however, if emitter bypass capacitor C_E is shorted, the circuit will operate but it will be temperature-sensitive. Likewise, if the emitter bypass capacitor is open, it may reduce the output because of degenerative feedback, but normally it will not cause complete stoppage of operation. If the input transformer or the output transformer is open, no output will be obtained. Check the input and output circuits with an oscilloscope; disappearance of the signal will indicate the location of the defective winding. If the transistor is shorted or otherwise defective, a no-output condition will occur. However, the transistor should be replaced only after all other checks have been made and there is still no output. A rough check of transistor operation can be made (if the transistor can be easily removed from the circuit) by measuring the forward and reverse resistance with an ohmmeter. A high reverse resistance and low forward resistance indicates that the transistor is operable, but does not indicate whether the gain is normal. Be certain to observe the correct polarities.

Reduced Output. Improper bias voltage or a change in the value of a component, as well as a defective transistor or transformer, can cause reduced output. If the transistor gain is low, the output will also be low; however, transistors should be replaced only after all other checks have been made, unless there is good reason to suspect that improper voltage have been applied. If either of the base voltage-divider bias resistors changes in value, the bias will be either too low or too high and the output will be reduced, with accompanying distortion. A simple voltmeter check will determine whether the bias is correct. If the collector winding of T2 develops a high resistance, the output will be decreased because of the extra d-c voltage drop .

Distorted Output. If the base bias is too high (reduced forward bias), the transistor will operate on the lower portion of its dynamic transfer characteristic, and the negative input peaks will be clipped (positive collector swings). Likewise, if the bias is too low (increased forward bias), the transistor will conduct heavily and operate on the upper portion of its dynamic transfer characteristic, with corresponding clipping of the positive peaks (negative collector swings). In both cases extreme distortion will be caused. If the bias is proper but the collector voltage is not, similar effects may be caused. If the collector voltage is too high, the negative collector swing will be clipped, and if too low the positive collector swing will be clipped; in either instance heavy distortion will result. An open emitter bypass capacitor will permit degenerative feedback to occur, and, depending upon the amount, will show either as distortion or as reduced output. A change in load resistance produced by a defective output transformer (T2) or a load resistance change usually shows as a distorted output with reduced volume because of the mismatching. Use an oscilloscope to follow the signal through the circuit and determine the point at which the waveform departs from normal. In most instances the defective component will then be apparent. Do not overlook the possibility that distortion may be occurring in a previous stage, merely being amplified by the stage under suspicion. Too large an input (overdrive) will cause both positive and negative peak clipping with distortion, just as in an electron-tube amplifier. Apply a square-wave input from an audio signal generator and observe the output on an oscilloscope. Frequency distortion will be shown by a sloping rise and fall time (poor high-frequency response); a sloping flat top indicates poor low-frequency response. Electron-tube techniques for locating distortion may generally be used for transistor trouble shooting if the proper voltages and polarities are employed.

AUDIO POWER (CLASS A, AB, AND B) AMPLIFIER, PUSH-PULL, TRANSFORMER-COUPLED.

APPLICATION.

The push-pull transformer-coupled transistor audio amplifier is used where high power output and good fidelity are required. For example, it is used in receiver output stages, public address amplifiers, and AM modulators.

CHARACTERISTICS.

Collector efficiency is high with moderate power gain.

Requires twice the drive of a single transistor stage.

Power output is more than twice that of the single transistor stage.

Second and higher even-order harmonic distortion is cancelled.

Distortion varies with the class of operation; it is least for Class A operation, and greatest for Class B operation.

Collector efficiency varies with the class of amplifier, from 50 percent maximum in Class A to 78 percent maximum in Class B, with an intermediate value for Class AB.

Fixed bias is usually used, but self-bias may be encountered in some Class A applications.

Operates as a large-signal amplifier for all except very small inputs.

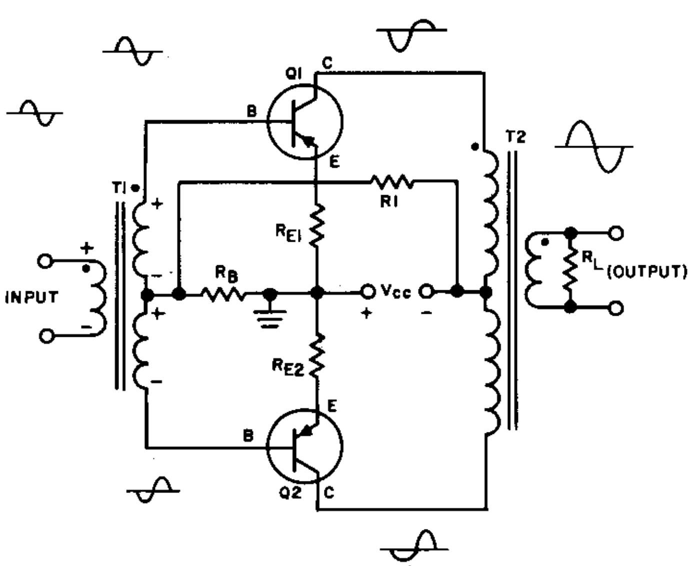
Emitter swamping is used for thermal stabilization.

CIRCUIT ANALYSIS.

General. The push-pull transformer-coupled transistor amplifier is similar in general sense to the push-pull transformer-coupled electron tube audio amplifier discussed in Part A of this section of the Handbook. Use of the common (grounded) emitter circuit allows use of the analogy that the base of the transistor is equivalent to the electron tube grid, the emitter equivalent to the cathode, and the collector equivalent to the tube plate. Examination of the accompanying schematic reveals that the transistor push-pull circuit is practically identical to the electron tube push-pull circuit. Any differences are due to the transistor internal parameters and the matching requirements to obtain maximum power output with minimum distortion.

Push-pull amplifiers can be operated Class A, Class AB, or Class B, as determined by the amount of forward bias. Like the electron tube push-pull circuit, the least amount of distortion and power output is produced in Class A operation, and the greatest amount of distortion and power output is obtained in Class B operation. Class AB stages operate between these levels of distortion and power output. For a given equipment and type of transistor, selection of the operating bias, distortion, and power output is a design problem. The following discussion will cover each type of operation; although the different types of operation are similar, there are significant differences among them.

Circuit Operation. The following schematic shows a PNP push-pull, transformer-coupled output stage. The load resistance may be a loudspeaker, a Class C r-f stage, or other type of load. The load is considered to be resistive unless stated otherwise in the text.



Push-Pull Transformer-Coupled Transistor Power Amplifier

duce a square wave properly, the entire audio range may be checked by applying only two different square-wave frequencies, such as 60 cps and 1000 cps. The video response can likewise be checked every 5 kc up to 50 kc (the usual limit of generator range). A sloping response to the leading or trailing edge of the waveform indicates poor high-frequency response, while a sloping flat top indicates poor low-frequency response. By temporarily short-circuiting a specific compensating circuit, the effectiveness of the portion under suspicion can be gauged. Distortion caused by regeneration (positive feedback) sometimes occurs in high-gain amplifiers, and is shown by a large-amplitude response peak (sometimes by oscillation), usually over a small range of frequencies. In comparison with a wide-band amplifier known to be operating properly, it will show as a hump or peak in what ordinarily would be a flat curve of uniform response.

R-F AMPLIFIERS.

General. The transistors used for r-f amplifiers differ in a number of respects from electron tubes. The forward transfer admittance is roughly 15 to 40 times larger than the corresponding tube transconductance. Both the input admittance and the input capacitance are also correspondingly larger. The base-to-collector capacitance may be equal to, or even less than, the grid-to-plate capacitance of an electron tube. However, because of the lower impedance levels involved in the transistor, this capacitance does not have as much importance as it has in tube circuits. The series resistances of the transistor elements also become higher at radio frequencies and produce a number of effects. For example, the base spreading resistance increases the amount of drive power required and causes instability in the amplifier. The emitter series resistance decreases the amount of drive power required, and also limits the amount of usable amplification because of the additional degeneration produced. The collector series resistance adds to the total output impedance to increase the gain, but also reduces circuit stability because of the possibility of regenerative feedback due to the higher gain. A phase shift is also produced in the output because of this collector resistance. Each of the above items will be discussed in more detail at the appropriate points below.

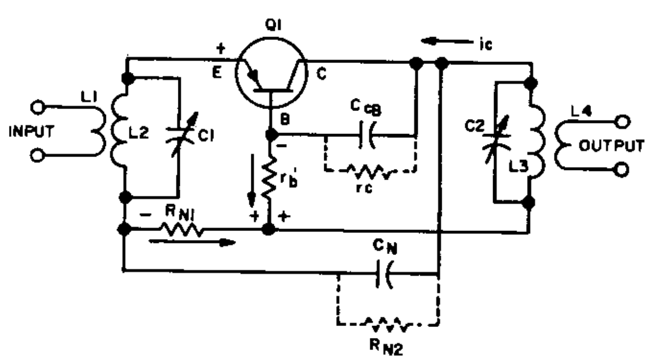
The tuned r-f amplifier is considered to be a narrow-band amplifier rather than a wide-band amplifier because it passes only a relatively small range of frequencies about the center of its band pass. Whereas the video (wide-band) amplifier passes frequencies from zero to 6 mc or more, the r-f amplifier used in communications equipment usually does not pass more than 10 to 15 kc, and in most instances less than this range. On the other hand, it should be noted that the r-f amplifiers used in television service, or for pulsed modulation, require a much larger bandwidth to accomodate the many sideband frequencies associated with these types of transmissions. Such amplifiers are considered to be special wide-band r-f amplifiers, except when the carrier frequency is so high that the modulation frequency is a small percentage of this figure. For example, a 3000-mc carrier with a 10-mc modulating frequency would be adequately handled by a narrow-band r-f amplifier, but a 30-mc carrier containing a 10-mc modulation frequency would require a wide-band r-f amplifier. Since semiconductor wide-band r-f amplifiers are not yet commonly used, the circuits to be discussed later in this section concern the conventional narrow-band r-f amplifier.

R-F amplifiers are used for both receiving and transmitting. A receiver uses a low-power, small-signal amplifier, while a transmitter uses a high-power, large-signal amplifier. Except for the conditions required by the power consideration, both types of amplifiers are similar and operate identically. Unfortunately, however, the transistor response or power gain is reduced as the frequency is increased. The response curve of a transistor is similar to that of a low-pass filter. That is, up to a certain frequency the gain is fairly uniform, and beyond this cutoff frequency the output drops rapidly toward zero. The limit of this upper cutoff frequency and the rapidity of dropoff depend to a great extent on the type of transistor and its composition. Many different types of transistors have been developed to extend the usable high-frequency range, such as the surface barrier transistor, the drift transistor, and others.

In addition to the loss of gain at the higher frequencies, the action of the transistor becomes complex; the transistor does not operate exactly the same at high frequencies as it does at lower frequencies. The internal resistance changes, and the effects of the junction capacitances become more pronounced. In high-frequency-amplifier applications, the collector-to-base capacitance causes positive feedback that may result in oscillation. The average value of collector-to-base capacitance for high-frequency transistors is on the order of 2 picofarads, as compared with 50 picofarads or more for transistors used at the lower (audio) frequencies. The base spreading resistance (resistance of bulk material of base) of the transistor increases at high frequencies, and the shunting effects of the low-resistance path produced by forward conduction of the base emitter junction tend to lower the input resistance, while the forward bias acts to reduce the width of the depletion areas and thus increase the base-to-emitter capacitance. At the same time, the internal flow of emitter current through the base-collector junction also reduces the width of the PN junction and increases the capacitance between the base and collector. It is this capacitance which causes feedback and tendency toward oscillation as the operating frequency is increased. At high frequencies the collector-to-emitter capacitance may be as high as 100 times that of the base-collector junction capacitance. For this reason, the common-base circuit generally gives better high-frequency response than the common-emitter circuit, but lacks the high gain of the common-emitter circuit. Since the common-emitter circuit tends to be more stable at the higher frequencies than either the common-base circuit or the common-collector circuit, the design trend is to use transistors with a high alpha cutoff frequency, and the CE configuration for higher gain. Both CB and CE circuits will be discussed later in this section.

Unilateralization and Neutralization. In electron-tube r-f amplifiers used at the higher radio frequencies, interelectrode capacitance causes positive feedback and oscillation. Neutralizing circuits are usually provided to prevent oscillation and to insure maximum gain with stability. Likewise, in the transistor r-f amplifier, the effect of the base-collector capacitance and the development of negative resistance through a change in internal parameters also causes oscillation. Neutralization circuits are used to prevent this oscillation and to obtain maximum gain. Neutralization represents a special form of unilateralization at a single frequency. When we speak of **unilateralization**, we are talking about the the methods of making the transistor a one-way device. In other words, the input circuit is unaffected by the output circuit. Recall from basic theory that there is a reverse current effect and common impedance coupling within the transistor. This means that any change of current in the output circuit also develops a feedback current which affects the input circuit, and vice versa. Thus in tuned amplifiers a change of tuning in the output stage reflects back as a change of capacitance in the input circuit, and also as a change in the amount of output fed back into the input. In cascaded tuned stages such effects would cause alignment problems. As each stage was adjusted the preceding stages would have to be readjusted, since each adjustment would change the previous adjustment. The result would be that no two alignments would be alike and, likewise, neither would the performance and selectivity of the r-f amplifiers stages be comparable. Unilateralization deals with the method or circuitry whereby both the resistive and reactive portions of the circuit are cancelled so that there is no feedback from output to input, and, power flows unilaterally in only one direction, from input to output. Unilateralization of the circuit is not frequency-responsive; it is effective for all frequencies. On the other hand, neutralization is effective for only a single frequency or a relatively small range of frequencies. For example, it is only necessary to neutralize an i-f stage because it operates at a fixed center frequency. However, an r-f amplifier used in a multi-band receiver requires unilateralization to prevent the possibility of feedback or oscillation on any of the frequency ranges over which it operates.

A typical example showing the feedback elements and unilateralization elements involved in a common-base amplifier is illustrated schematically in the accompanying figure. The elements r'_b, r_c, and C_{cb} in the illustration



Feedback and Unilateralization Elements

are the internal parameters which cause feedback and oscillation at radio frequencies. Resistor r'_b is the **base spreading resistance,** r_c is the resistance of the collector-base junction, and C_{cb} is the capacitance of the collector-base junction. The resistance of the collector-base junction is very high because of the reverse bias placed on the collector. At very high frequencies C_{cb} effectively shunts r_c. Assume that an input signal adds to the forward bias on the base (the base and collector bias supplies are not shown on the schematic for simplicity) and causes the emitter to be more positive than the base. Collector current i_c increases in the direction shown by the arrow. A portion of the increase in collector current is fed through C_{cb} and r'_b in the direction shown by the arrow, and produces a voltage with the indicated polarity. This internal feedback voltage developed across r'_b is of the same polarity and adds to the input voltage, causing a further increase in i_c; this action is regenerative and represents positive feedback, which will produce oscillation. The external circuit elements inserted to neutralize this action are R_{N_1}, R_{N_2}, and C_N; they correspond respectively, to r'_b r_c, and C_{cb}. Since at high frequencies C_N shunts R_{N_2}, this resistance is necessary only at the lower radio frequencies. It is clearly seen that when the input signal causes a feedback voltage across r'_b, a portion of increased collector current i_c is also fed back through C_N and R_{N_1} to the base. The direction of this external feedback voltage is as indicated on the schematic, and is direct opposition to the voltage developed across r'_b. When the internal and external feedback voltages are made equal, since they are of opposite polarity, they cancel and no positive or negative feedback occurs; thus, the circuit is unilateralized. In the common-emitter circuit, since the polarity of the collector is opposite that of the input, it is necessary to develop an out-of-phase voltage and feed it back to the input. This is done through the use of a transformer, using the secondary winding to invert the feedback voltage, through a tapped tank circuit, or by use of a bridge circuit, as will be shown in some of the following circuit explanations. In some instances an inductance connected in series with a blocking capacitor is used between the collector and the base, with the inductor and the distributed capacitance in the collection circuit operating as a tuned, parallel-resonant circuit. However, inductive arrangements tend to be critical in adjustment since they are resonant only over a small range of frequencies near the center resonance point, and thus are not as frequently used. Partial emitter degeneration is sometimes employed in a similar manner to provide the feedback voltage. The accompanying figure shows some typical feedback circuits used for neutralizing the common-emitter configuration. The parts identifications are identical with those used in the common-base circuit explained above, and operate in exactly the same manner; therefore, no further explanation is included to supplement the figure.

SECTION 7

OSCILLATOR CIRCUITS

PART A. ELECTRON TUBE CIRCUITS

L-C OSCILLATORS.

The L-C type of oscillator uses a tuned circuit consisting of lumped and distributed inductance and lumped and distributed capacitance connected as a series or parallel resonant (tank) circuit to determine the frequency of operation. Series resonant tanks are sometimes, but not often, used depending on the oscillator circuit selected. Operation is normally in the radio-frequency range (operation in audio range may occasionally be used). Oscillation is achieved by the application of positive (regenerative) feedback from plate (or any other element) to grid through external or internal capacitance or inductive coupling, depending upon the particular circuit configuration.

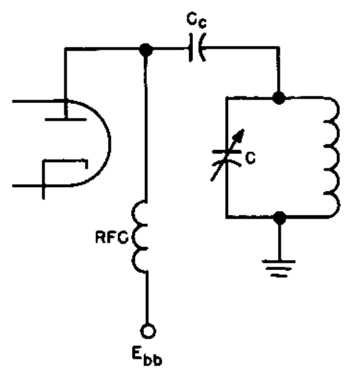
Class C operation is usually employed for power oscillators, and Class A operation is used for test equipment oscillators where waveform linearity is important. Class B operation is normally not used, but may occasionally be encountered.

Efficient circuit operation and maximum frequency stability are achieved with a tank circuit having a high loaded Q (this is equivalent to low Q, or high C to L ratio). This is produced for parallel-tuned tanks by using a large tuning capacitance (high C) with a small inductance. For series-tuned tanks a high L to C ratio is used to achieve the same effect. Normally the inductance of the tank circuit remains fixed, and the capacitance is the variable tuning element. Inductive tuninq may be encountered, particularly in the low- and very-low-frequency r-f ranges.

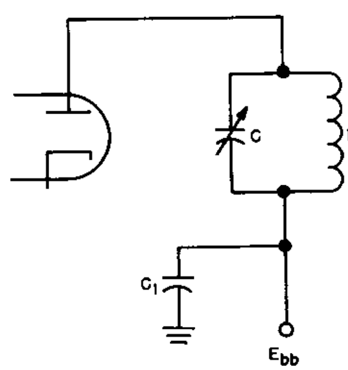
Grid-leak bias is generally used for self-excited oscillators and may be either shunt or series (see Section 2, paragraph 2.2.2), with the series form predominatinq. Either shunt or series type plate feed is employed, with shunt feed being used for those applications where it is desired to isolate the tank circuit from dc. Generally speaking, oscillator operation is basically independent of the type of bias or method of plate feed. For design purposes the oscillator is considered as a Class C amplifier with a feedback loop, operating at the same voltages and currents as an amplifier, but with a lower over-all power output because of feedback and circuit losses.

Although there are a number of types of L-C oscillators, and each type has a particular advantage or feature claimed for it, they are usually all operable over the range for which tuned circuits can be developed. Therefore, their ranges of operation many times overlap, and the particular circuit used may be selected only because of the designer's preference or previous familiarity with the circuit. In addition to the constant frequency, and thermal and mechanical considerations afforded by the tank circuit, the plate resistance and amplification factor of the tube used, plus tube element capacitances and stray wiring capacitances, determine the oscillator performance to a great extent. Most circuits can be arranged so that the tuning element can be grounded to prevent hand capacitance effects, although it may be mechanically or economically unfeasible to use some of these circuits.

The figure shows both series and shunt plate-voltage feed arrangements. The series feed arrangement is easily recognized by the fact that the plate voltage is applied through the tank circuit. Capacitor C_1 bypasses the tank to ground for rf, so one end of the tank is at r-f ground potential, and the tuning capacitor is effectively grounded to eliminate hand capacitance effects. The tank, however, is at full d-c (and r-f) potential and dangerous if touched (for high applied voltage). The identifying characteristic of the shunt feed arrangement is that the plate of the tube is connected to B+ through an r-f choke, and coupled through C_c to the tank. Effectively, the tank is isolated from dc, but is coupled for rf. In most shunt-feed circuits the tank capacitor can be grounded directly rather than through a bypass capacitor. Usually shunt feed is avoided where a large range of frequencies is to be covered (particularly at the higher frequencies) because of parasitic oscillations, or dead spots, resulting from unwanted resonances of the r-f choke and tube or wiring capacitances.



SHUNT FEED



SERIES FEED

Methods of Plate-Voltage Feed

TICKLER-COIL OSCILLATOR.

APPLICATION.

48

The L-C tickler-coil oscillator is used to produce a sine-wave output of relatively constant amplitude and fairly constant frequency within the r-f range. The circuit is generally used as a local oscillator or beat-frequency oscillator in a superheterodyne receiver.

CHARACTERISTICS.

Utilizes an L-C tuned grid circuit to establish the frequency of oscillation. Feedback is accomplished by mutual inductive coupling between the tickler coil and the L-C tuned grid circuit.

Operates Class C with automatic self-bias.

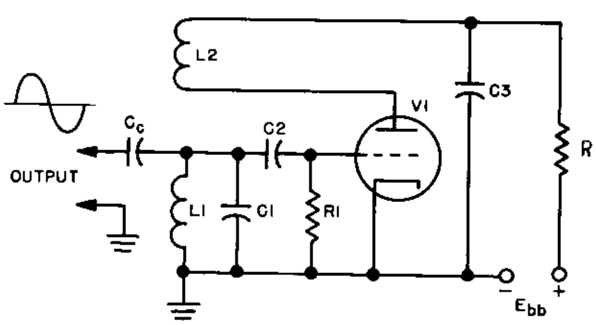
Frequency stability is fair.

Output amplitude is relatively constant.

CIRCUIT ANALYSIS.

General. Oscillations of a tuned circuit will tend to die out at an exponential rate and will finally cease, unless energy is replaced at regular intervals. For oscillations to be sustained, sufficient energy must be supplied to overcome circuit losses. The use of an electron tube as an amplifier provides the additional energy necessary to sustain oscillations. The energy applied to the tuned circuit must be of the correct phase relationship to aid the initial oscillations and of sufficient amplitude to overcome circuit losses in the tuned circuit.

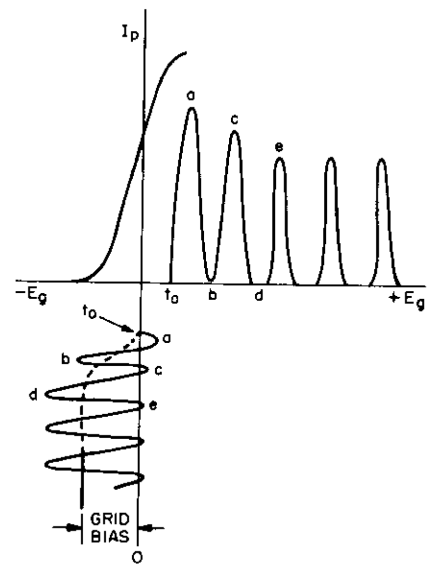
The circuit used to provide this type of feedback is called a **regenerative circuit**, and the energy supplied is called **positive feedback.** In the accompanying circuit schematic the tuned L-C circuit is designated as L1, C1; the tickler (feedback) coil is designated as L2.



L-C Tickler-Coil (Armstrong) Oscillator

Circuit Operation. The accompanying circuit schematic illustrates a triode electron tube in an L-C tickler-coil oscillator circuit. Inductance L1 and capacitor C1 form the resonant grid circuit. Inductance L2 is the plate, or tickler, coil and is mutually coupled to L1, to couple a feedback voltage to inductance L1 by transformer action. Capacitor C2 and resistor R1 form an R-C circuit which is used to develop the operating bias. Capacitor C3 functions as an r-f bypass to place the B+ terminal of tickler coil L2 at signal ground potentiol. Resistor R2 isolates the B+ line from the r-f signal and and also serves to reduce the input voltage applied to the oscillator circuit. Capacitor C_c is the output coupling capacitor.

For the following discussion of circuit operation, refer to the accompanying illustration of oscillator grid-signal voltage and plate-current waveforms.



Theoretical Grid-Voltage and Plate-Current Waveforms

Initially the tube is at zero bias (t_o on waveform illustration) to permit the circuit to be self-starting. When input power is applied to the circuit, the tube conducts because of the lack of operating bias. As the plate current increases through tickler coil L2, an expanding magnetic field is built up around the tickler coil. This expanding field causes an increasing voltage to be induced in inductance L1 of the tuned circuit, and this voltage is of such polarity that the grid of V1 is made positive with respect to the cathode. The positive grid condition increases the flow of plate current, which further increases the field about tickler coil L2; consequently, the voltage induced in inductance L1 increases and the grid is driven further in the positive direction. This process continues until saturation is reached, at which time no further increase in plate current can take place (point **a** on waveforms).

During the period of time that a charging voltage is induced in inductance L1, capacitor C1 charges to maximum; also, capacitor C2 receives a charge as the result of grid-current flow through the low internal cathode-to-grid resistance of the tube.

of the multivibrator; other factors that limit the switching speed are the operating level of the transistors, collector capacitance, and external circuit elements.

Minority carrier storage can be prevented by limiting the excursion of the collector voltage of a switching stage to an area outside the saturation region of the transistor. In this case, the collector current is not limited by the collector circuit resistance, but rather by the maximum current limitation of the transistor. This is the basis of operation of the "nonsaturating multivibrator"; this circuit is discussed in detail later in this section, as are several other semiconductor bistable multivibrator circuits and bistable multivibrator triggering techniques.

BASIC FLIP-FLOP MULTIVIBRATOR.

APPLICATION.

The basic flip-flop multivibrator produces a square-or rectangular-wave output for use as gating or timing signals in radar sets. It is also used in switching-circuit applications, and for computer logic operations which include counting, shift-registers, clock pulses, and memory circuitry. This circuit is often used for relay-control functions, and for a variety of similar applications in radar and communications systems.

CHARACTERISTICS.

Circuit assumes one of two stable states: one transistor normally conducts while the other transistor is cut off, and vice versa.

Requires two input triggers to complete one cycle of operation; the circuit assumes a stable state upon completion of each half-cycle of operation.

For a constant-frequency input, the output frequency is one-half that of the input trigger frequency.

Input triggers can be either positive or negative (positive trigger may be applied to base of conducting transistor, and negative trigger may be applied to base of cut-off transistor in common-emitter circuit configuration).

Symmetrical triggering occurs when the same trigger pulse is applied simultaneously; unsymmetrical triggering occurs when triggers are applied separately.

Symmetrical or unsymmetrical output gate depends on timing sequence of input trigger pulses; input triggers from different sources (turn-on and turn-off triggers) produce unsymmetrical output gate.

Collector-to-base feedback coupling is direct (through resistors), with bypass capacitors used to speed up switching from one stable state to the other.

Circuit can be made to assume the same initial stable state whenever voltages are applied by incorporating a definite imbalance within the circuit, or by using a manually controlled "reset" signal.

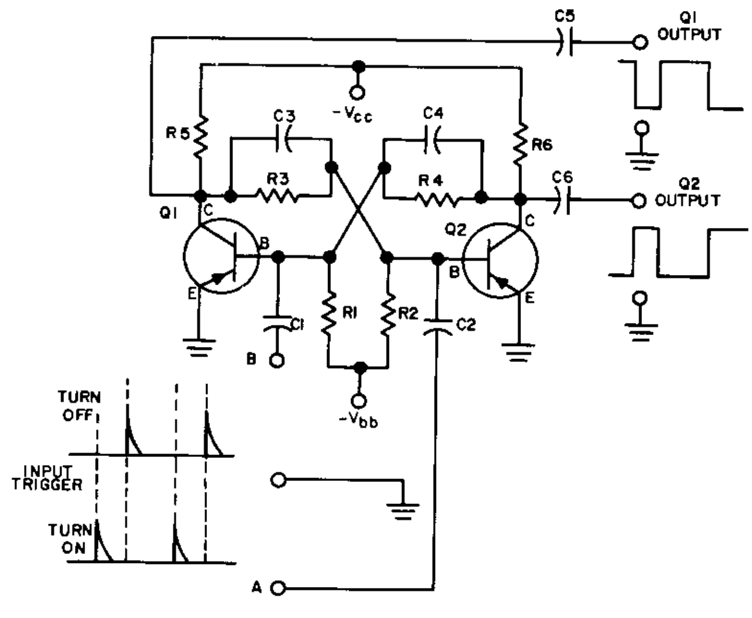
Output is taken from collector of either transistor in common-emitter circuit configuration.

Output impedance is low when transistor is in conducting (on) state; output impedance is approximately equal to collector load resistance when transistor is in cutoff (off) state.

CIRCUIT ANALYSIS.

General. The basic flip-flop multivibrator is capable of producing a square- or rectangular-wave output pulse (gate) in response to two input triggers. This type of multivibrator has two stable (bistable) states – one transistor is normally conducting while the other transistor is normally held cut off – each one functions for only one-half cycle when triggered. Feedback from the collector of one transistor to the base of the other is direct through a coupling resistor bypassed by a capacitor. The capacity shunts the high-frequency components of the pulse from collector to base around the coupling resistor so that the rapid change taking place at one collector is coupled, with minimum attenuation, to the base of the other transistor. Because two input triggers (turn-on and turn-off) are required to complete one cycle of operation, the output gate frequency of the flip-flop multivibrator is one-half the input trigger frequency. The output gate length is determined by the time interval between the turn-on and turn-off triggers. Output signals are taken from the collector of either or both transistors in the common-emitter circuit configuration.

Circuit Operation. The accompanying circuit schematic illustrates two transistors in a basic flip-flop multivibrator circuit. Transistors Q1 and Q2 are identical PNP transistors used in a common-emitter circuit configuration; either junction or point-contact transistors may be used in this circuit. Resistors R1 and R2 are the base-biasing resistors for Q1 and Q2, respectively. Resistor R3 provides the direct coupling from the collector of Q1 to the base of Q2, and resistor R4 provides the direct coupling from the collector



Basic Flip-Flop Multivibrator Using PNP Transistors

of Q2 to the base of Q1. Feedback resistors R3 and R4 are bypassed with capacitors C3 and C4, respectively; these capacitors permit faster switching action from one transistor to the other. Resistors R5 and R6 are the collector-load and output resistors for Q1 and Q2, respectively. Capacitors C1 and C2 are the input trigger coupling capacitors for Q1 and Q2, respectively; they provide unsymmetrical triggering. Capacitors C5 and C6 are the output-gate coupling capacitors for Q1 and Q2, respectively. An output waveform can be taken from the collector element of either transistor, or output waveforms can be taken from the collector elements of both transistors simultaneously.

Fixed bias for the PNP transistors of this flip-flop multivibrator is obtained from two separate d-c voltage sources via voltage-divider networks. Resistors R1, R4, and R6 form one voltage divider between the positive d-c (+V_{BB}) and negative d-c (-V_{CC}) supply voltages. The resistor values are selected so that the voltage at the top of R1 is negative with respect to the grounded P-type emitter of Q1; thus, the emitter of Q1 is forward biased with respect to the N-type base. Another voltage divider, consisting of resistors R2, R3, and R5 between the positive and negative supply voltages, forward biases the emitter of Q2 in the same manner. That is, the voltage at the top of R2 (at the N-type base of Q2) is negative with respect ot the P-type emitter of Q2. Because of the voltage-divider action, the voltage at the collector of each transistor is more negative than the voltage at its base; thus, the collector-base junction of each PNP transistor is reverse biased.

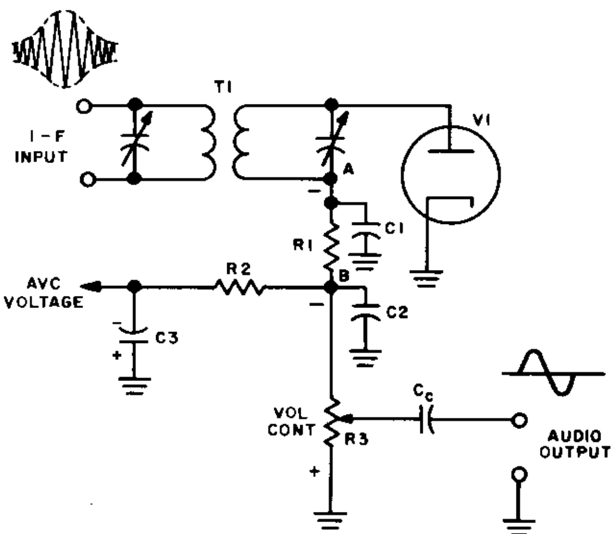
When voltage is first applied to the circuit, the current which flows in each collector load resistor (R5 and R6) is determined by the effective resistance offered by transistors Q1 and Q2 for a given value of base-bias voltage. Although the multivibrator shown in the schematic appears to be a balanced circuit, and in spite of the use of close-tolerance components, there is always minor differences in internal resistance within the transistors. As a result of this inherent imbalance, the initial collector current (resulting from the forward-bias conditions set up by the emitter-base junction resistances and bias resistors R1 and R2) for each transistor is different, and the immediate effect produced by regenerative action between the coupled stages is that one transistor conducts while the other is cut off.

For the purpose of this explanation, assume initially that more collector current flows through transistor Q1 than through transistor Q2; thus, as the collector current of Q1 increases, the negative voltage at the collector of Q1 decreases with respect to its emitter, or ground. Thus, the collector of Q1 becomes less negative and this, in effect, acts as a positive-going pulse, which is directly coupled through resistor R3 to the base of transistor Q2. The positive-going pulse at the base of Q2 makes the base positive with respect to the emitter (ground) and, as a result, Q2 is reverse-biased and approaches cutoff. The collector current of Q2 decreases because of the reverse-bias action between its base and emitter, and the voltage at the collector of Q2 increases, rising towards the value of the supply voltage. In other words, as the collector of Q2 becomes more negative a negative-going pulse is developed across R6, which is directly coupled through resistor R4 to the base of transistor Q1. The negative-going pulse at the base

CIRCUIT ANALYSIS.

General. The diode detector with AVC is identical to the diode detector without AVC, except for the circuit arrangements provided for AVC take-off. Discussion of the operation of the detector in stripping-off the modulation from the carrier is covered completely in the discussion of the Diode Detector earlier in this section of the Handbook. The reader should refer to the previous discussion for proper background before proceding with this discussion.

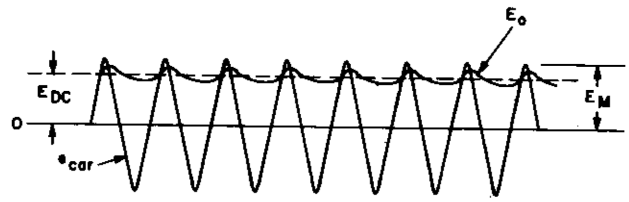
Circuit Operation. The schematic of a typical diode detector arranged for AVC take-off is shown in the accompanying illustration.



Diode Detector With AVC

The plate of V1 is connected to IF input transformer T1 and the cathode is grounded. Resistor R1 with capacitors C1 and C2 form low-pass RF filters, while C3 and R2 are audio and decoupling filters. The audio voltage is developed across volume control R3, and applied through coupling capacitor Cc to the following audio amplifier stages.

When unmodulated, the input consists of a single frequency. When modulated, the input consists of a basic carrier frequency plus an upper and lower sideband containing the modulation. Thus the diode detector output always contains a d-c component which is directly proportional to the carrier amplitude or strength. This is the voltage which is used for AVC. For large signal detection the diode detector is considered to be a simple half-wave rectifier, which conducts as long as VI plate is positive with respect to the cathode. When VI conducts, election flow is from the grounded cathode to the plate, through the secondary coil of IF transformer T1, Rl, and R3 to ground. Thus current flow through Rl produces a negative voltage at point A (which is not used), and the AVC voltage is developed across volume control R3 at point B. This negative voltage drop is applied through R2, back to the grids of the r-f and i-f stages. Because the feedback of the AVC bias is to the grids of the preceding stages it is clear that there must be no extraneous modulation or RF on this lead. Otherwise, both the audio and RF components could again be amplified and re-detected causing distortion and unwanted feedback. Therefore, Rl and Cl and C2 are connected as a conventional low-pass filter in series with the current flowing through R3. The output waveform at point A consists of the d-c and r-f component as shown in the accompanying waveform illustration for an unmodulated carrier for ease of discussion. The instantaneous r-f



Detector Voltage Relationships

carrier component (e_{car}) is bypassed to ground partially by Cl. During the positive portion of each carrier cycle C2 is charged through Rl, and during the negative portion of the carrier signal the capacitor tends to discharge. The result is the heavy curve labelled E_o. The average value of pulsating voltage E_{DC} is the actual AVC voltage. Since these pulsations occur at radio frequency rates, the effective voltage variation between charge and discharge of the capacitor is so small as to be negligible. Recall from the above discussion that the modulation component of the signal is also present, However, when modulated signals are detected, these audio ripples are smoothed out by another low-pass filter consisting of R2 and C3. In this instance, the value of the filter time constant are such that output voltage Eo appears as a straight line (pure DC). The time constant of R2 and C3 is made sufficiently large so that it takes more than a single audio cycle to charge or discharge. Although this increase of time constant prevents an instantaneous change of AVC voltage for an instantaneous change in carrier level it is usually satisfactory for most types of fading encountered. Particularly, since decoupling RC networks similar to R2 and C3 are also inserted at each tube grid associated with the AVC and increase the effective values of R2 and C3. The fast time constant response necessary for single sideband or CW use is obtained by making the value of C3 much lower than is normally used in AM circuits. Since the grids of the controlled stages do not draw grid current, there is no flow of current through R2, other than that required to charge the other decoupling capacitors on the AVC line. Hence there is no large voltage drop, and the RC filter can be used without encountering any losses because of excessive current drain. The detected audio or a-c component appears across volume control R3 and is applied through coupling capacitor Cc to the audio amplifier stage.

FAILURE ANALYSIS.

No Output. Lack of an input signal due to failure of the associated receiver circuits, a detuned or defective IF transformer, T1, a defective diode, V1, or open or short circuited parts will cause a no-output condition. Measure the voltage to ground at points A and B with a high resistance voltmeter. A negative voltage at these points indicates normal functioning. Lack of voltage at these points indicates either lack of an input signal or a defective component. Use a VTVM or an oscilloscope to determine if an input is present. With an r-f signal on the primary, but not on the secondary, T1 is defective. If the secondary voltage is much lower than the primary the secondary tuning needs adjustment. When adjusting, if it still provides a low output and does not respond to the adjustment, T1 is defective and should be replaced with a good transformer. If either R1, R2, R3 are open, the series circuit will be interrupted and no AVC voltage will appear at points A or B. If R1 or R3 is shorted no AVC voltage will be developed, however, if R2 is shorted the circuit will still operate. With normal AVC voltage but no audio output, either volume control R3 is tuned down, R3 is defective, or coupling capacitor Cc may be open. A resistance check will determine if these parts are open or shorted. If C1 or C2 are shorted, no AVC voltage or detected output will be obtained. Use an ohmmeter to measure the resistance to ground, or an in-circuit capacitance checker C1 and C2. If the parts are satisfactory, diode V1 must be at fault; replace it with a known good tube. If previous operation indicated a general falling off in output, the diode could have been replaced immediately. The indiscriminate replacing of electron tubes at the first sign of trouble, without due cause, however, must be avoided.

Low Output. A weak input signal, or low emission in the detector diode are the prime cause of low output, as well as mistuning of T1. The effects of humidity can also cause circuit leakages which reduce the output. Although a slight change in parts values with age may cause a reduction of output, it most probably would go unnoticed, since turning up the volume slightly would restore the output to normal. If it becomes necessary to turn the volume control excessitively for a known signal, first check the preceding circuits to be certain that they are operating properly and are not at fault, before trouble-shooting the detector.

Distorted Output. If the values of C1 and C2 changed sufficiently to produce the wrong time constant, either too fast or too slow, distortion would occur. Likewise, if the emission of V1 is so low as not to supply the full peak current demand, distortion caused by clipping will also occur. Replace the diode with a known good tube and check the values of C1 and C2 with an in-circuit capacitance checker. A change in the values of R2 and C3 will change the attack time of the AVC loop but will not normally cause distortion. However, if C3 should short-circuit, the AVC voltage would be grounded out and the stages preceding the detector would operate at maximum sensitivity, and probably cause overloading with consequent distortion.

DIODE DETECTOR (WITH NOISE LIMITER).

APPLICATION.

The diode detector with noise limiter is usually used in radiotelephone reception to prevent noise pulses from interfering with, or garbling, voice transmissions.

CHARACTERISTICS.

Operates linearly over a large range of voltage.

Input impedance is relatively constant and independent of the input voltage.

Does not amplify the input signal.

Noise peaks are clipped without excessively increasing the distortion.

CIRCUIT ANALYSIS.

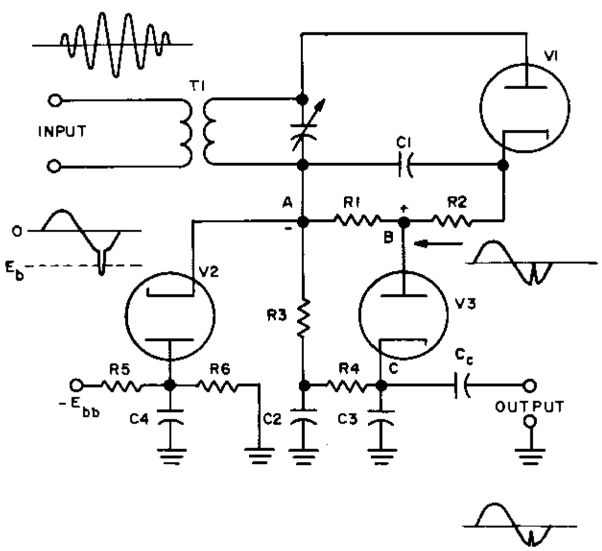
General. The diode detector with noise limiter is identical in operation with the Diode Detector described earlier in this section of the Handbook, except for the noise limiting circuitry. The reader should refer to the previous discussion for proper background before proceeding with this discussion.

Both shunt and series types of noise limiters are used. The series type continually conducts but stops conducting when a noise pulse arrives, and thus leaves a gap in the signal in place of the noise pulse. The shunt type noise limiter conducts only when the noise pulse exceeds a predetermined bias level, shorting the input to ground, and also leaves a void in the signal. Since these noise pulses and consequent signal holes are of short duration, the integrating effect of the ear on the sound minimizes this effect. In most practical noise limiters, the limiter becomes effective at around the 85 percent modulation level, so that subsequent peak flattening causes some distortion and a slight loss of audio volume. The voice, however, is understandable through heavy noise interference, which would otherwise completely mask or garble the intelligence being transmitted.

Circuit Operation. The schematic of a typical diode detector with noise limiters is shown in the accompanying illustration.

Diode V1 is the detector diode which rectifies the input signal from I-F transformer T1. Resistors R1 and R2 form a voltage divider load for diode detector V1, bypassed for RF by C1. The detector voltage appearing across R1 is applied to the anode of series noise limiter V3. Resistors R5and R6 form a bias voltage divider from a separate negative supply to ground, to supply a fixed negative cutoff bias to the anode of shunt diode limiter V2. Resistor R6 is bypassed by capacitor C4 so that any instantaneous voltage change appearing at the anode of V2 is bypassed to ground. Resistors R3 and R4 together with capacitors C2 and C3 form a low-pass filter and load circuit for series diode V2. Capacitor Cc is the detector output coupling capacitor.

When an unmodulated input signal is applied to the primary of IF transformer T1, the secondary voltage appears across diode V1 and V1 conducts for the duration of each positive r-f pulse, causing a flow of current from the



Diode Detector With Noise Limiters

cathode to plate, through T1 secondary, R1 and R2, back to the cathode and ground. A negative DC voltage thus exists at point A on the schematic and varies in amplitude directly with the r-f carrier amplitude. This is the AVC voltage discussed in the previous circuit for the Diode Detector (with AVC), in this section of the Handbook. When the input signal is modulated, the negative voltage at point A also varies slowly at audio frequencies in accordance with the modulation. At point B the detected voltage is identical with that at point A except that it is smaller than at point A because of the drop across resistor R1. The RC low-pass filter combination of R3 and C2 charges capacitor C2 relatively slowly so that audio frequency signals are effectively smoothed out. Low pass filter R4, C3 operates similarly except that the time constant is faster to ensure that no r-f component appears at point C to cause feedback. Thus both filters place the cathode of series diode V3 on a common negative bus, and the drop across R1 (between points A and B) appears as a forward bias on the anode of V3 (point A is more negative than point B). Thus diode V3 normally conducts, and the detected pulsating voltage at point B appears undistorted at point C, and is applied through coupling capacitor Cc as the audio output of the detector. Because R1 and R2 form a voltage divider, the detected voltage to ground which appears across R2 is considerably smaller than the developed AVC voltage. When a negative noise burst appears at point B, the anode of series limiter V3 is instantly driven highly negative, while the cathode voltage changes very slowly because of the slow filter time constants provided by R3, C2 and R4, C3. Thus for most of the noise burst, conduction of diode V3 is stopped and no output appears (a hole occurs in the output). Thus the noise spike is chopped off the detector waveform, and because it occurs for such a short time, the instantaneous loss of signal goes unnoticed. When the noise burst occurs for a long period of time or is a repetitive occurrence, the loss of signal may be noticed. For random short noise pulses this type of limiter is fairly effective.

Note also that when the negative noise bursts occur, the negative voltage at point A is increased, and if it is fed back as an AVC voltage change the overall sensitivity of the receiver will simultaneously decrease, just when a strong signal is needed to overcome the adverse signal to noise ratio. Therefore, shunt limiting diode V2 is connected from point A to ground. Normally, the negative plate voltage, which appears on V2 from voltage divider R5 and R6 connected across the separate negative bias supply, holds V2 in a nonconducting condition. When a negative noise burst appears and is of sufficient amplitude to drive the cathode of V2 more negative than the fixed biased anode, V2 conducts and the voltage at point A is temporarily shunted to ground via V2 and resistor R6. Capacitor C4 bypasses R6 and allows the instantaneous noise burst to be discharged to ground. Meanwhile, the relatively slowly moving d-c component produced by AVC action remains relatively unaffected. Consequently, the AVC voltage does not instantaneously increase (or decrease) and is effectively prevented from desensitizing the receiver during the noise burst. Thus conduction of diode V2 effectively removes the noise spike from the signal. Although the entire noise spike is not eliminated, the large peak amplitude above the fixed-bias level is removed so that the effect of the noise is considerably reduced by the shunt diode. In addition, the shunting effect of diode V2 on the detected audio temporarily reduces the signal supplied to the audio stage via series diode V3, and produces a noise silencing effect. The use of both a shunt and series diode although not absolutely necessary provides better overall noise limiting performance.

FAILURE ANALYSIS.

No Output. Any open circuited or short circuited condition as well as defective diodes can result in a loss of output. Lack of a negative voltage to ground at point A indicates a possible defective IF transformer T1, diode V1, or that R1 or R2 are open, or C1 is shorted. Use an oscilloscope with an r-f probe to determine if an input exists on the primary of T1. A large signal on the primary, but none at all or a very minute one on the secondary indicates that T1 is defective. With an input across the diode, check the resistance of R1 and R2 with an ohmmeter, and check C1 for a short. If an output can be observed at point C with the oscilloscope, but not on the other side of Cc, check coupling capacitor Cc with an in-circuit capacitance checker. If these parts are satisfactory diode V1 or V2 is at fault (an output at point C indicates that V1 is not at fault). Failure or defects of the remaining parts and diodes will not normally produce a no-output condition, but instead will produce a low output or ineffective noise elimination.

Low Output. A partial shunting of the detector output through diode V2 can occur if V2 is shorted, if the negative bias supply voltage fails, if R5 or R6 change in value, or if capacitors C2, C3, or C4 are either shorted or leaky. The capacitors may be checked for shorts with either an ohmmeter or an in-circuit capacitance checker, and the resistors can be checked with an ohmmeter. If diode V3 is defective, the output will probably be very low and distorted, depending upon the stray capacitance in the circuit.

Distorted Output. Since in normal operation the noise limiter effectively eliminates a noise signal, it is evident that the output waveform will always be different than the input waveform to a certain extent. Thus a slightly distorted output will practically always be obtained. The degree of the distortion depends upon the design of the circuit. Theoretically, the limiter should operate only on noise pulses which are larger in amplitude than the signal, however, most practical circuits start operating at about the 85 percent modulation level. Hence some peak clipping of the signal usually occurs and causes distortion on the modulation peaks. In normal operation, a slight amount of distortion will be noticed and the strength of the output signal will drop noticeably when the noise limiters are activated. Follow the signal through the circuit with an oscilloscope and notice where the distortion occurs. Further resistance checks of the associated parts with an ohmmeter will usually locate the defective part.

GRID-LEAK DETECTOR.

APPLICATION.

The grid-leak detector is used in simple two-or-three tube receivers, such as the regenerative type. Since this type of detector is particularly susceptible to overload and distortion at high levels of modulation, it is never used in modern high-gain superheterodyne receivers.

CHARACTERISTICS.

Is self-biased by a grid-leak.

Provides good sensitivity with increased signal gain.

Operates as a square-law detector for small signals and as a linear detector for large signals.

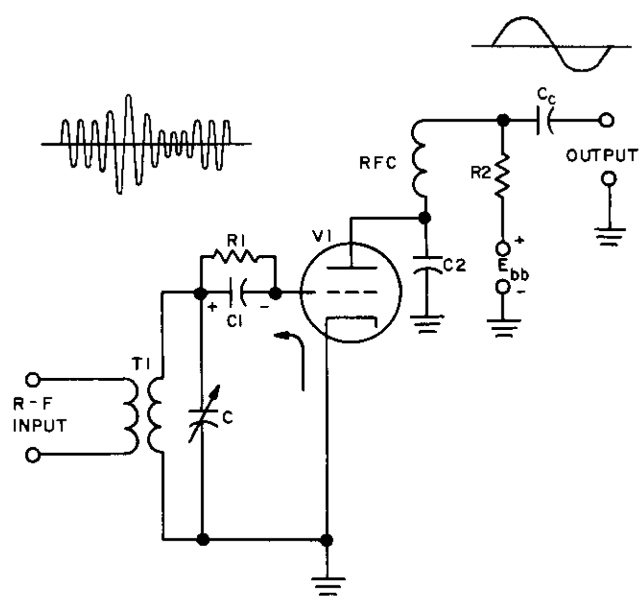
Is subject to overload and blocking effects on strong signals.

Although it produces a relatively larger output voltage than other comparable AM detectors, it is subject to more distortion.

CIRCUIT ANALYSIS.

General. The grid-leak detector, basically, uses a triode electron tube, and is considered to operate similarly to a diode detector with the added advantage of triode amplification. Although pentodes have been used to provide additional gain, the triode with a low plate voltage is usually preferred because of a reduction in tube noise and distortion. In operation, the grid and cathode of the triode operate similarly to the anode and cathode of the conventional diode detector (discussed previously in this section of the Handbook). The d-c bias produced by carrier rectification and the detected modulation appear across an RC network known as the grid-leak, and the modulation appears in amplified form in the plate of the triode. Since the detection occurs in the grid circuit it is known as grid detection. Because the developed grid bias is automatically controlled by the carrier amplitude, the grid-leak detector operates over a wide range of input voltage. On weak signals it operates near zero bias and uses the curved lower portion of the grid-current, grid-voltage characteristic to provide an output which varies as the square of the input signal, and is known as non-linear (square-law) operation. For large signals and large self-bias it operates over the linear portion of the characteristic curve. When overloaded by extremely strong signals, the bias reaches cutoff and conduction occurs for only part of the cycle, and the peaks are clipped, creating excessive distortion. The detailed operation of this detector under different conditions is discussed in the following paragraphs.

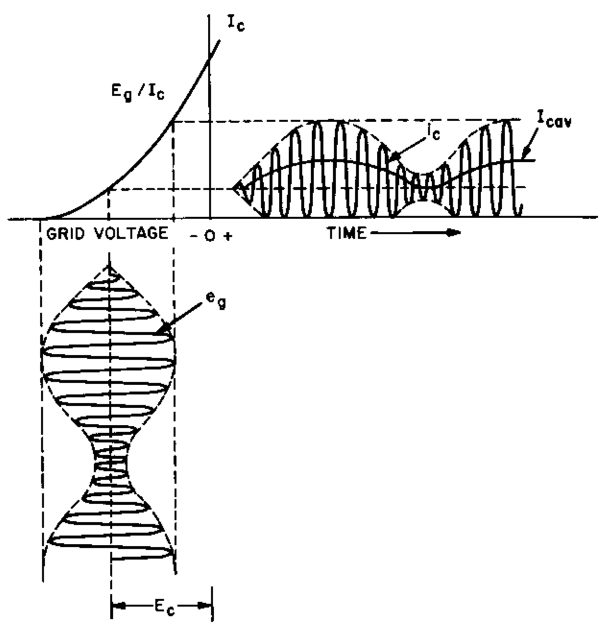
Circuit Operation. The schematic of a typical grid-leak detector is shown in the accompanying illustration.



Basic (Series) Grid-Leak Detector

The r-f input is applied through r-f transformer T1, and the grid-leak network consisting of R1 and C1 are connected in series with the grid of V1 and the output of T1 secondary, while the cathode is grounded. In the plate circuit, resistor R2 is the plate load, and is isolated from the plate r-f component by radio frequency choke RFC. The plate is also bypassed to ground by capacitor C2, which is small enough to act as a shunt for the r-f carrier voltage appearing in the plate circuit but not the modulation. Thus only the amplified modulation appears across load resistor R2 and is applied to the output through coupling and plate voltage blocking capacitor Cc.

In the absence of an input signal, V1 is contact-biased by grid-leak resistor R1, and operates near zero bias. In this condition, only a small potential is built up across R1 by grid current flow, biasing the grid slightly negative. Thus V1 is in a position to respond to both positive and negative signal variations for small signal detection. The accompanying waveform illustration demonstrates how the curvature of the grid current versus grid voltage characteristic of V1 distorts the basic signal and produces amplification with distortion.



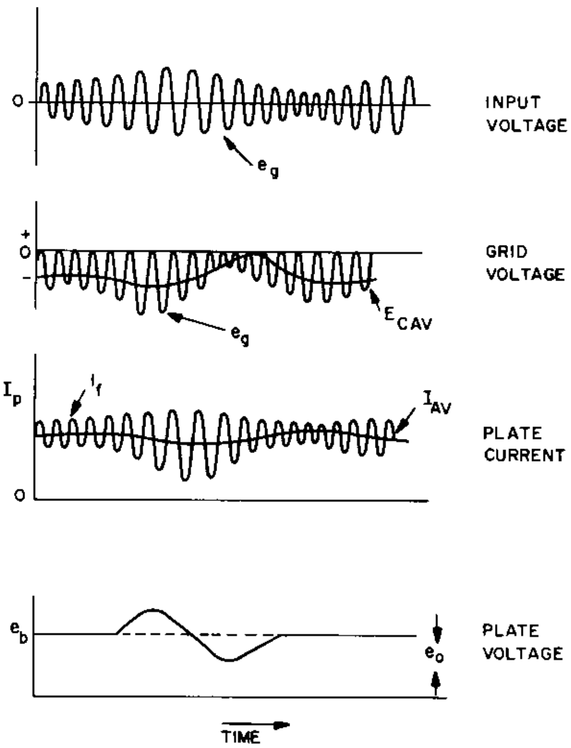
Small Signal Detection Characteristics

As shown in the illustration, when the input signal increases in amplitude grid current increases, flowing in the direction of the arrow on the schematic. Thus grid capacitor C1 is charged negatively during the positive grid swing. On the negative grid swing, grid current flow is reduced and the capacitor discharges slightly through the grid-to-cathode resistance which is lower than the high resistance grid-leak. Because of the curvature of the grid characteristic curve, the positive excursions are larger than the negative excursions. Therefore, a slowly increasing average grid current is developed as the signal modulation rises, and the average grid current falls when the signal modulation decreases, in synchronism with the modulation envelope. This develops a negative voltage across R1, which varies at the audio rate of the modulation around the negative bias level produced by the constant amplitude carrier pulses. Since the grid of V1 controls the operation and plate current of the triode, the change of grid voltage produced by the detected signal causes an identical but amplified plate current fluctuation. As this plate current varies in accordance with the modulation, a similar but amplified voltage is developed across plate load resistor R2. This is the audio output voltage which is coupled through Cc to the following audio amplifier stage. Because the r-f carrier voltage appears between the grid and the cathode of V1 it also appears in the plate circuit. Therefore, there is an r-f plate component of voltage which must be eliminated so that it can not cause spurious beats with the modulated signal, or unwanted oscillation by feedback within the tube. This is the function of RFC and C2. The r-f choke offers a high inductive impedance at the carrier frequency, while capacitor C2 offers a low impedance shunt path to ground. Hence, the r-f component is bypassed around the load resistor and power supply, and has no effect on circuit operation. Only the relatively slowly moving audio frequency current component flows through load resistor R2, to produce a corresponding audio frequency output voltage.

For large signals, the average carrier amplitude also rises, so that the grid is biased considerably negative, and only the positive excursions of r-f voltage on the input signal are effective in causing grid current flow. In this condition the detector operation is similar to a half-wave rectifier, and operates as a linear detector. The positive signal excursions produce a negative voltage across the grid leak by charging capacitor C1. During the negative signal excursions the charge on C1 keeps V1 inoperative so that the tube operates for a half cycle or less. Because maximum modulation peaks produce maximum negative grid voltage, the plate current of V1 is reduced during modulation. The reduction of plate current occurs at an audio rate and produces a corresponding audio output. As the current through detector output load resistor R2 reduces, the voltage across it and the output rises, as shown in the waveforms illustrated in the accompanying figure of large signal detection characteristics.

The linear grid detector is also known as a grid-leak power detector. In the small-signal or square-law grid-leak detector the output voltage although amplified is usually greatly distorted, therefore, large output voltages create greater overall distortion. In the power detector, the grid-leak values are reduced to prevent excessive distortion, and the input signal and the detector plate voltage are increased to provide a greater output. Thus the larger input signal produces operation over a larger output voltage swing, producing a greater output voltage with less overall distortion.

In operation, the major difference between the two types of detectors is obtained by making the large-signal, power-detector grid potential swing sufficiently negative that the flow of grid current is stopped for the major portion of the negative half cycle. During the positive half cycle

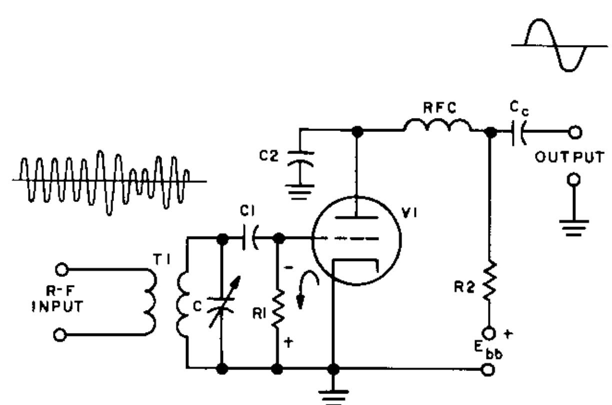


Large Signal Detection Characteristics

of carrier voltage, grid current flow charges the grid capacitor negatively. During the next negative half cycle, some of this accumulated charge leaks off through the grid-leak resistor (which is connected across C1), and is replenished during the next positive swing. Thus grid current can only flow for a small portion of the positive cycle. In the small-signal grid detector, however, grid current flows continuously, since the grid is never driven sufficiently negative to reduce grid current flow to zero. Under these conditions, the charge on the grid capacitor leaks off through the internal grid-to-cathode resistance, which is much lower than the high value of grid leak resistance used. In the large signal power detector the grid-to-cathode resistance is practically infinite during most of the cycle (because grid current is cut off). Operation of both detectors is essentially the same as shown in the waveform illustration for the small signal detector, except that the grid amplitude of the large signal detector is greater, and the grid current cut-off point corresponds to the value of bias developed by the carrier signal. Whereas in the small signal detector the grid bias is always less than grid-current cutoff.

As in all electron tube amplifiers, the plate-current, grid-voltage characteristic curve is linear up to the point where saturation begins. So that both the lower and upper regions of operation are curved. If the large signal power detector is driven sufficiently, the bend on the upper portion of the curve will also cause plate rectification to occur. Thus second and third harmonic distortion components will be produced and the overall detector distortion will increase. It is also necessary that the charge and discharge of the grid-leak follow the signal amplitude during large signal detection, otherwise, blocking and distortion will occur. With proper choice of grid-leak constants (which is inherent in good design) and an adequate plate voltage which does not exceed tube ratings, the distortion can be kept to low values almost equivalent to that of the diode detector. If the input signal is reduced to a very small value, the large signal power detector merely operates as a small-signal, square-law detector with a low output and the advantages of power detection are lost.

The schematic of a typical shunt grid-leak detector is shown in the accompanying illustration. Components are symbolized identical to, and operate exactly as explained for the series grid-leak detector discussed above. This circuit is generally used for the power type detector because slight advantages are claimed for avoiding blocking effects. The shunt grid resistor provides more loading on the tuned r-f input circuit, however, and produces a reduction in selectivity.



Shunt Grid-Leak Detector

FAILURE ANALYSIS.

No Output. An open or shorted grid or plate circuit, a defective tube, or an open coupling capacitor, Cc, can cause loss of output. Measure the plate supply and plate voltage with a high resistance voltmeter. Normal plate voltage indicates that load resistor R2 and the RFC are probably satisfactory and that C2 is not shorted. Apply a modulated signal from a signal generator to the input terminals of r-f transformer T1. Use a VTVM, electronic voltmeter or an oscilloscope (it must offer high impedance so as not to load or disturb the circuit operation) connected between grid and ground, to determine if the input signal produces a slight negative bias and if a signal is present. If no signal is present, T1 is defective. If the detected signal can be observed in the grid circuit but not in the plate circuit, V1 is defective. If the signal is present in both grid and plate circuits but no output exists, check coupling capacitor Cc for an open circuit. (Use an in-circuit capacitance checker).

Low Output. Low plate voltage, a defective tube or too weak an input will each cause a reduced output. The weak input signal may occur because r-f transformer T1 is not tuned to resonance. If T1 will not tune to resonance, either the signal frequency is out of range or T1 is defective. When in doubt, apply a modulated input from a local signal generator and note that the signal peaks in intensity as the resonance point of T1 is reached. If this occurs but the desired signal is still weak, additional r-f amplification or a better antenna are required. If the signal generator cannot produce a strong output, the detector is probably at fault. Check the plate voltage of V1; if the plate voltage is normal, either V1 is defective or output coupling capacitor Cc is leaky or partially open. If the plate voltage is not normal but is lower than usual, R2 may have changed value, the rfc may have developed a high resistance, or C2 may be leaky or shorted. Use an ohmmeter to check the resistance of R2 and the RFC, and check the resistance of C2 to ground. Replace any part which has a resistance higher or lower than that specified in the technical manual for the equipment. If the detector seems to be operable but the receiver output is low, it is possible that the audio stages following the detector are at fault, and not the detector circuits. To check the audio stages, use an audio signal generator and apply it to the output stage plate, then to the grid and note if the signal increases. Follow this procedure back to the detector to locate the defective audio stage.

Distorted Output. Excessive distortion can be produced by a change in the constants of the grid-leak network, by too high a plate voltage, or as a result of low emission from V1. If replacing the tube with a known good one does not eliminate the distortion, check the plate voltage with a high resistance voltmeter. If the plate voltage is normal, check the value of R1 and C1 with an ohmmeter and capacitance checker. If the grid-leak components are within tolerance value and distortion still occurs, it is possible that the input signal is too strong and overloading is causing the distortion. It is also possible that T1 is only tuned near resonance and the sidebands are being clipped. Tune T1 properly, and reduce the input signal, if possible.

PLATE DETECTOR.

APPLICATION.

The plate detector is used in small receivers as a power detector. It is usually used in tuned r-f receivers to supply a large audio output. While it can be used in the modern superheterodyne, it cannot be used to supply a simple AVC voltage. Thus, it is usually more economical and simpler to use a diode detector. The plate detector is, however, extensively used as the detector circuit in vacuum tube voltmeters and similar test equipment.

CHARACTERISTICS.

May use either self-or fixed-bias (self-bias is most prevalent).

Provides good sensitivity and increased signal gain.

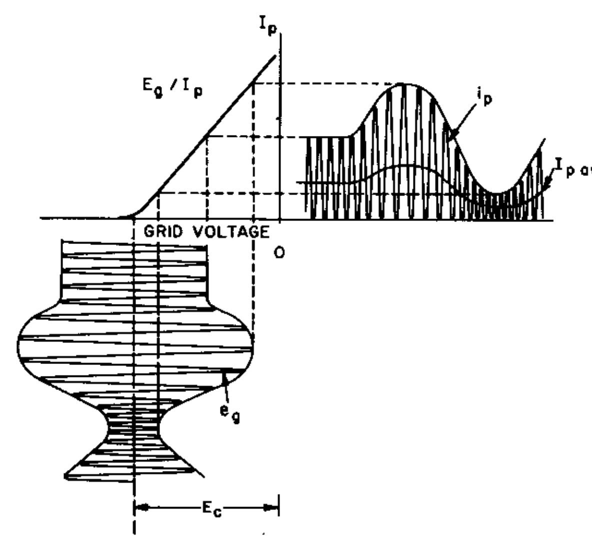
Operates as a linear detector for large signals.

Is normally operated with large input signals as a power detector.

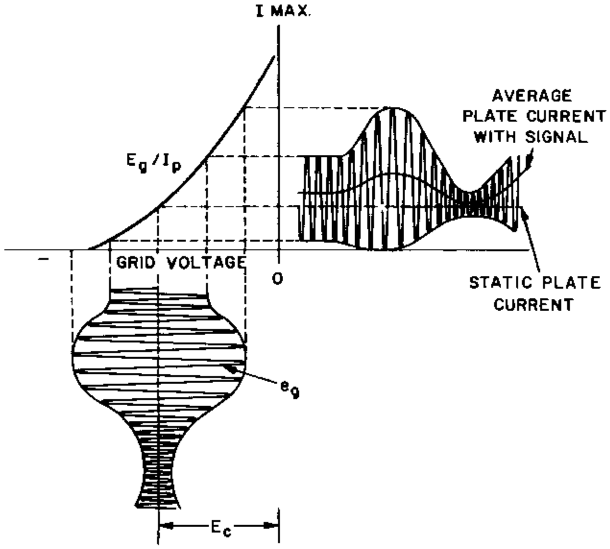
Distortion is considered to be slightly less than that of the grid-leak detector, and not better than the diode detector.

CIRCUIT ANALYSIS.

General. The plate detector usually operates class B, that is, it is biased to plate current cutoff, and for this condition it operates as a large signal linear detector. When used for small signals, or as the detector of a vacuum-tube voltmeter it operates on the lower curvature of a class A biased tube characteristic, and is a square law detector. In the plate detector there is no rectification of the signal in the grid circuit. The r-f input signal causes the a-c grid voltage to vary the tube plate current, producing both amplification and detection. Detection occurs in the linear plate detector because only one side of the signal (the positive portion) causes the tube to conduct, while the negative portion remains below cutoff and has no effect. Thus the plate output varies in accordance with the r-f envelope of the modulated carrier as shown in the accompanying waveform for linear detection. The square law detector operates over both the positive and negative variations of the input signal. Because of the curvature of the tube e_g/i_p characteristic for small input signals, an amplified but distorted plate output results. The large positive grid swing produces a greater plate current than the smaller negative swing. Thus the average output is greater during modulation than without modulation, as shown in the accompanying waveform illustration.



Linear Operation



Square Law Operation

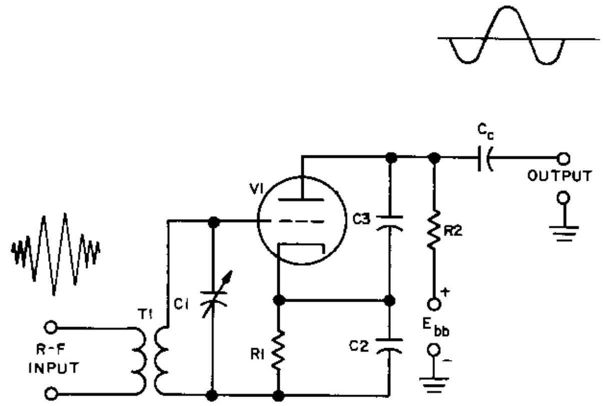


Plate Detector

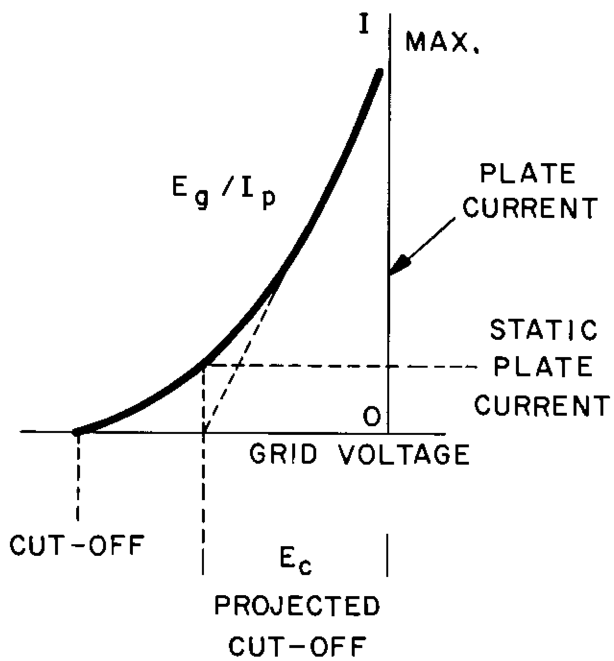
Since the output varies as the square of the input signal, at 100 percent modulation the maximum distortion can be as high as 25 percent. Operating as a linear detector the distortion is considerably less, as long as the signal is strong enough to keep it from operating in the lower curved portion of the tube characteristic, and not so large as to include operation over the upper curved portion. However, since the e_g/i_p characteristic curve of a triode is never perfectly straight but has a slightly bowed appearance, there is greater basic distortion than in the half-wave diode detector.

Circuit Operation. The schematic of a typical plate detector is shown in the accompanying illustration.

Transformer T1 is the r-f input transformer, with the transformer secondary tuned by C1. Cathode bias is obtained from R1 and C2. The plate load R2, is bypassed for r-f by C3. The output is capacitively coupled through Cc.

With no signal applied, the average bias produced by cathode current flow through R1 holds the grid to plate current cut off. Although spoken of as cutoff bias, the tube is actually biased to projected cutoff, as shown in the accompanying illustration. (See section 2, paragraph 2.2.1 in this handbook for a detailed explanation of cathode bias.) Therefore, negative input signal excursions occur over the curved portion and produce some slight distortion. For full linear operation a separate and higher fixed bias is always applied and the complete negative excursion of the input signal is eliminated with a consequent reduction of overall distortion.

When an input signal is applied, the positive portion of the signal increases the grid voltage, and the plate current of V1 follows, likewise. Thus the plate waveform of V1 consists of pulses of current at the input frequency, whose peak values trace out a curve which varies exactly as the



Detector Operation Characteristic

modulated r-f. Thus the audio frequency component of plate current develops a similar plate voltage output waveform across the plate load resistor R2 of opposite polarity or phase. Thus at the peak of current, the plate and output voltage is a minimum, while at the minimum value of plate current the output voltage is maximum. Capacitor C3 bypasses any r-f which might appear on the plate of V1 after rectification, to avoid feedback through the plate to grid capacity causing oscillation or unwanted beats. In some instances, C3 may be bypassed to ground instead of to the cathode, this is usually done in receivers operating at the higher radio frequencies.

Normally, no grid current is drawn and the plate detector offers an extremely high input impedance with practically no input loading. Since the input circuit is not loaded down, a slight improvement in selectivity is usually observed over that of the grid-leak detector. If, however, the input is large enough to draw grid current (signal exceeds the bias), additional plate distortion is obtained by curvature of the upper portion of the tube characteristic, and the lowered grid input impedance also reduces the selectivity, so that the overall performance is lower than for the grid-leak detector.

FAILURE ANALYSIS.

No Output. An open input or output circuit, or a defective tube, as well as lack of plate voltage, will cause a no-output condition. Check the plate supply and plate voltage with a high resistance voltmeter. No output with a normal supply voltage, but with no plate voltage indicates that plate load resistor R2 may be open, or that bypass capacitor C3 is shorted. Check the resistance of R2 with the plate voltage off, and check C3 with an in-circuit capacitance checker. If plate voltage is normal but no output is obtained, use an oscilloscope and r-f probe to observe that an input signal exists on the grid of V1. If it does and no output exists, either cathode resistor R1 is open or V1 is defective. Check the bias voltage across R1 with a voltmeter. Since bias bypass capacitor C2 may be shorted, it is usually simpler to measure the resistance of R1. If the resistance across R1 is zero, then C2 is shorted. If R1 is infinite it is open. Also, do not neglect the possibility of a shorted secondary winding or tuning capacitor C1.

Low Output. A low plate voltage, a defective tube, or a small input signal will produce a low output. Check the supply voltage with a voltmeter. If normal, check the plate voltage of V1; lower than normal voltage on the plate indicates that R2 has increased in value, or that an abnormal plate current exists. Check the voltage between cathode and ground, if it is normal or slightly low check R2 for the proper resistance value (with plate voltage off). If T1 is defective, or if C1 is not tuned to resonance a low output can also occur. If T1 primary is open, a weak output signal may still be obtained if there is sufficient capacitive coupling between primary and secondary, or to V1 grid. In this case, while C1 will tune through resonance there will not be the normal large build up of output signal as the resonant point is passed. If T1 is defective, a resistance analysis can be made with an ohmmeter to verify if the windings are open, but there is also the possibility of a short circuit or leakage across one of these windings. To determine if T1 is at fault, temporarily disconnect it from V1 grid and connect the input signal through an isolating capacitor direct to V1 grid. A large increase in signal indicates that T1 must be defective. The output of a modulated signal generator tuned to the input frequency can be used to supply an input directly to the grid of V1, if a known strong local signal is not available. If the output signal obtained in this case still is weak, but increases considerably when the generator output is applied to the plate circuit, tube V1 is at fault. Where all signals fade in and out and the output is low, V1 is usually at fault because of low emission.

Distortion. Since there is normally some distortion from the linear detector, particularly on strong signals at high percentages of modulation, there may be some doubt as to whether or not the distortion is normal or excessive. When distortion is suspected, check the plate voltage and cathode bias with a voltmeter. Abnormal voltages indicate that the detector is probably at fault. If, however, it is found that tuning C1 eliminates the distortion, or that it only exists on extremely strong signals, the detector is most likely performing normally. When the distortion continuously occurs with either weak or strong signals the detector is definitely at fault. Note, however, that when strong fading exists it is possible that selective fading is phasing out some of the sideband frequencies and causing the distortion. Such distortion will not appear on signals having a steady amplitude.

INFINITE IMPEDANCE DETECTOR.

APPLICATION.

The infinite impedance detector is used in tuned radio frequency receivers where less distortion than that supplied by the conventional plate detector is required, and no gain through the detector stage can be tolerated. Its light loading effects improve sensitivity and selectivity.

CHARACTERISTICS.

Uses self-bias, but can be fixed-biased, if desired.

Provides good sensitivity, with reduced distortion.

Operates as a linear detector for large signals.

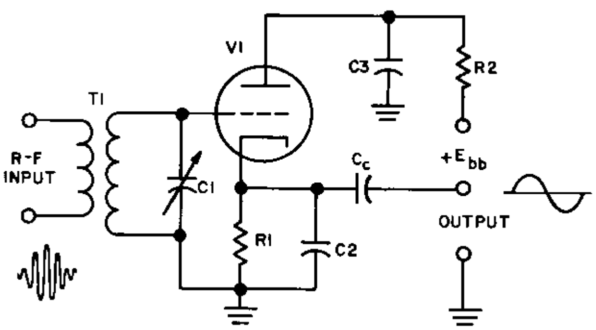
Is normally operated as a modified power detector. The cathode output connection prevents any large increase of gain.

Presents a very high or infinite impedance to the input signal.

CIRCUIT ANALYSIS.

General. The infinite impedance detector is also known in other texts as a **reflex** detector because of the large value of degenerative feedback provided in this arrangement. However, this nomenclature is misleading since it also applies to reflex circuits where detection and amplification through positive feedback occur in the same stage, and these circuits are not infinite impedance detectors. The basic infinite impedance detector used a bypassed plate load to achieve more than unity gain. In effect, it combined the advantages of plate detection with the equivalent of diode detection which offered no load to the source. The circuit is always easily recognized because of the cathode output connection, large cathode resistance, and relatively small r-f bypass (about 250 picofarads), plus the fact that when the plate resistor is used the plate bypass is sufficiently large enough for both RF and audio bypassing (about 0.1 microfarad). Because of the infinite impedance offered this circuit does not load the input. Consequently, greater sensitivity and selectivity is obtained than with conventional plate detectors. On the other hand, it is not as sensitive as the grid-leak detector, but the output is practically distortionless and much lower than is normally obtained by either the plate or grid types of detectors previously discussed. If not better, it is at least as good as the conventional diode detector. The two major disadvantages which restrict its use, is that it cannot supply a simple source of AVC, and the negative feedback through cathode degeneration produces less than unity gain.

Circuit Operation. The schematic of a typical infinite impedance detector is shown in the accompanying illustration.



Infinite Impedance Detector

Transformer T1 is the r-f input transformer, and is tuned by C1 (in superheterodyne receivers T1 represents the i-f input transformer). Cathode bias is supplied by R1 which is only bypassed for RF by C2 so that it is degenerative at audio frequencies. The output is taken from across R1 through coupling capacitor Cc. Resistor R2 and capacitor C3 form a plate filter and voltage dropping network, which reduces the plate voltage and bypasses to ground any rf or audio currents in the plate circuit. In some circuits R2 is not used, while in other circuits both R2 and C3 are eliminated. In either event, there is no change in circuit operation.

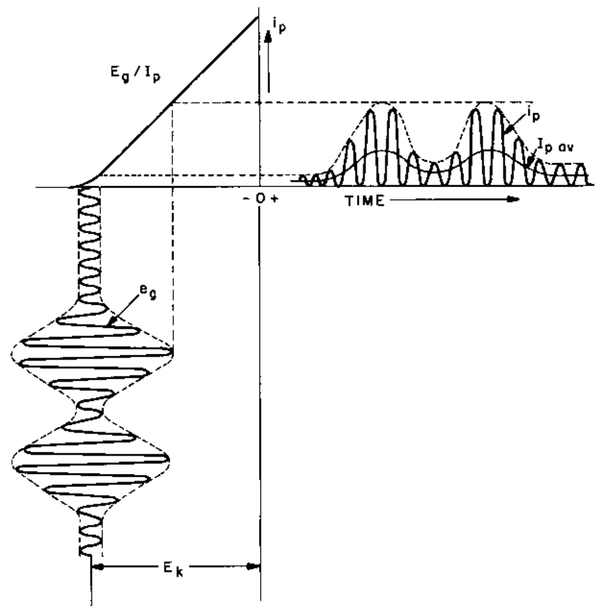
By using a large value of resistance for R1, the average plate current flow through this resistor develops a high bias. Thus, in the absence of an input signal only a small plate current flows because of the cathode bias is almost at plate current cutoff value. Since current flow through the tube is from cathode to plate, any increase in cathode current develops a positive voltage at the cathode with respect to ground and increases the instantaneous bias. However, R1 is bypassed by C2, which is chosen to offer a low impedance to ground for radio frequencies, but not for audio frequencies. Consequently, the r-f signal does not pass through the load (cathode resistor R1) but the audio frequency variations of the modulation on the detected signal do. Thus a degenerative voltage is developed on the cathode, which makes the output signal amplitude always less than the input signal which produces it. This is a form of negative feedback which places the output signal in series with the grid-cathode circuit. Since the output signal appears in opposite polarity to the input it helps cancel a portion of the input signal, elimiantes distortion, and improves linearity. (See Section 6 of this Handbook covering Feedback Amplifiers for a complete discussion of inverse or degenerative feedback.) Because of the degenerative feedback inherent in a cathode output connection, the output signal amplitude can never exceed the input signal, and the gain is always less than unity.

Another result of the feedback action is to prevent the flow of grid current. The increase of bias with increase of signal ensures that the input signal never exceeds the bias, hence grid current will never flow. Thus the infinite impedance detector always presents a very high (infinite) impedance between grid and cathode, and produces no load on the input circuit. Consequently, there is no shunt load across the secondary of T1 and C1, and the selectivity of the tuned input circuit depends only on the Q of the tank circuit. Thus better selectivity is obtained. When the input signal reduces in amplitude, the decreased grid voltage produces a reduction of plate and cathode current, accordingly. Since cathode resistor R1 is not bypassed for audio frequencies, the instantaneous audio current variations through R1 develop an output voltage which varies with a modulation envelope of the received signal. The process is practically identical to that of the diode detector discussed previously in this section of the Handbook, since only the positive portion of the input is effective as shown in the accompanying illustration, (the negative portion is biased off).

With a large input signal the circuit always operates over the straight (linear) portion of the plate current-grid voltage characteristic. Since plate load resistor R2 is bypassed by C3, any instantaneous r-f or audio current variations are bypassed to ground, and the plate voltage remains constant regardless of cathode current fluctuations.

FAILURE ANALYSIS.

No Output. An open or shorted input or output circuit, lack of plate voltage, or a defective tube can create a no-output condition. Check the supply voltage with a high resistance voltmeter to determine that the fault is not in the power supply, and then check the plate voltage. No plate voltage indicates possibility of R2 being open or C3 being shorted. Check R3 for proper resistance with an ohmmeter, and C3 for a low resistance to ground. Check the cathode bias voltage developed across R1. If no bias exists, either V1 is defective, R1 is open, or C2 is shorted. Check R1 and C2 with an ohmmeter. If normal



Detection Characteristics

plate and cathode voltages exist use a VTVM to check the grid input voltage. If no grid signal voltage is found, make certain that C1 is set to the proper frequency for the desired input signal, and if still no input exists, check T1 for continuity with an ohmmeter. If an input signal exists on the grid of V1, check coupling capacitor Cc to make certain it is not open (use an in-circuit capacitance checker).

Low Output. A weak input signal can cause a low output. A low emission tube usually causes erratic fading on all signals and a low output. Low plate voltage will also cause a reduced output. Check the plate and cathode bias voltages. If the plate voltage is low with a normal supply voltage, check R2 for an increased resistance value and C3 for a partially shorted or leaky condition. If the cathode bias is low, R1 may have changed value, C2 may be leaking and shunting R1 with a low value of resistance, or V1 plate current may be weak because of low emission. Check R1 with an ohmmeter and C2 for leakage. A weak input signal can also be caused by defective r-f transformer, T1, or by a defective or mistuned tank tuning capacitor, C1. If there is any change in signal as C1 is tuned, the tuning capacitor is probably satisfactory and the primary of T1 is probably open. Check T1 for continuity with an ohmmeter. If the transformer continuity is complete and weak signals still occur on a known local signal, there is still the remaining possibility that T1 is shorted.

Distortion. Since the infinite impedance detector is noted for its fidelity and lack of distortion, it is evident that noticeable distortion indicates improper performance. Check the bias with a voltmeter. Low bias will place the operating point on the bend of the E_g/I_p curve, and square law detection with its high distortion products will result instead of linear detection. Distortion accompanied with a low output can also be caused by a defective tube.

REGENERATIVE DETECTOR.

APPLICATION.

The regenerative detector is used in simple one or two tube receivers, particularly in the high frequency regions where normal r-f amplifiers do not provide much gain. It is mostly used for CW and voice reception.

CHARACTERISTICS.

Uses a grid-leak detector with regenerative feedback from plate to grid.

Has better sensitivity than any non-regenerative detector.

Has better selectivity than any non-regenerative detector.

Has poor fidelity with relatively high distortion for music and, therefore, is mostly used for voice and CW (code) reception.

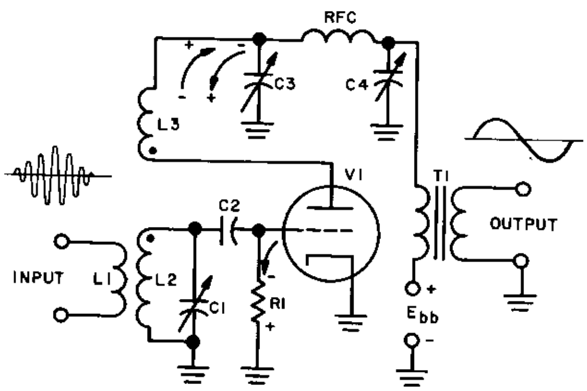
CIRCUIT ANALYSIS.

General. The regenerative detector utilizes the high sensitivity of a grid-leak detector, together with the increased amplification afforded by regenerative feedback to provide a unique detector with extreme sensitivity and high gain. Since grid-leak detection is used, the distortion level is high, and because regeneration increases the selectivity of the tuned input circuit, a narrow band-width is obtained. Thus, the high frequency components of a modulated signal are effectively eliminated by circuit selectivity of the order of 2-to-3 kc. Hence, this circuit is restricted in use mainly to communications applications involving only voice and code reception.

There are a number of circuit variations, most of which involve the method of controlling the regenerative feedback. Because feedback varies with the frequency range covered, fixed forms of feedback are suitable only over a very narrow range of operation. With smooth control of feedback, it is possible to increase the regeneration until the feedback reaches the critical point where any further regeneration will cause continuous oscillation of the circuit. Voice reception is amplified the greatest just below this point. For code reception, the amount of regeneration is increased until the circuit just oscillates, and the desired signal is tuned in by adjusting the tuning capacitor slightly off resonance until an audible note is produced. This type of reception is known as **autodyne** reception, which uses a single tube to perform detection and oscillation simultaneously; as contrasted with **heterodyne** reception, which uses a separate oscillator to produce a heterodyne signal.

Circuit Operation. The schematic of a typical regenerative detector is shown in the accompanying illustration.

The r-f input signal is applied to L1, the primary winding of the r-f input transformer, of which L2 is the secondary, tuned by capacitor C1. Feedback winding L3 is in-



Regenerative Detector Circuit

ductively coupled to L2, and consists of a few turns wound in the same direction as those of the secondary coil and located at the ground end of the secondary coil (L3 is called the "tickler" coil). Variable capacitor C3 is connected in series between ground and tickler coil winding to control the amount of regenerative feedback. The radio frequency choke, RFC, and capacitor C4, form a low-pass filter which bypasses any r-f component in the plate circuit to ground. Capacitor C2 and resistor R1 form a conventional parallel grid-leak arrangement. The audio output is applied to the primary of transformer T1, used to provide a step-up in output voltage between primary and secondary. Although any other method of audio coupling may be used, the transformer is usually used because of the large output it produces in comparison with other types of coupling.

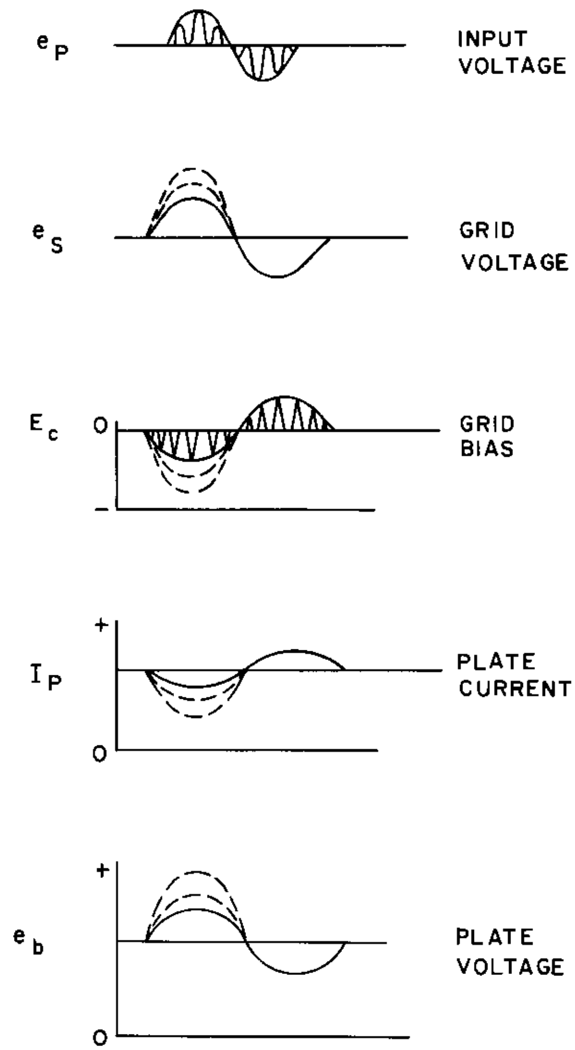
Initially, the circuit rests in its quiescent condition with no signal applied, and draws heavy plate current because only contact bias is supplied by R1 (see Section 2 paragraph 2.2 in this Handbook for a complete explanation of contact bias). We shall also assume that feedback capacitor C3 is set to the middle of its range and offers a low capacitive reactance to ground. Tickler coil L3 is fixed-coupled to L2, and wound so that both grid and plate ends of the winding are of additive polarity.

When an input signal is applied to L1 it is inductively coupled into the resonant tank consisting of L2 and C1. The low reactance of the grid-leak capacitor, in turn, allows the tank signal to appear at the grid of V1, across R1. On the positive half cycle grid current flow is increased, and capacitor C2 is charged negatively as shown by the polarities and current flow arrow on the schematic. Thus as the signal rises in a positive direction the negative grid bias on V1 increases. This negative grid bias increment decreases plate current flow because of control grid action within the tube. In the quiescent condition, plate current flows through the tickler coil winding in such a direction as to produce a polarity similar to that of L2 across L3. Thus the plate end of the tickler is negative when the grid is positive. Since, in the absence of an input signal there is a steady unchanging flow of plate current, the field built up around L3 remains steady and constant so that no feedback voltage is induced into L2. When the input signal is applied, however, the reduction of plate current with the increase of grid-leak bias produces a change in the lines of magnetic flux cutting the two coils, and a feedback voltage is induced in L2 by the current change in L3. The reduction of plate current causes the field around L3 to collapse and induce a voltage of opposite polarity to that normally produced in the increasing current direction. Hence a positive voltage is fed back to further activate the grid of V1. Since the input signal and the feedback voltage are of the same polarity they add, and produce a still greater negative grid bias. The increased bias, in turn, causes a further reduction of plate current, and a larger feedback voltage. This cycle of signal build-up by regenerative feedback continues until the input signal amplitude changes. As the amplitude changes, the feedback action follows. That is, as the signal increases the feedback increases, and as the signal decreases the feedback, likewise, decreases. With feedback, the combined signal value is always greater than without feedback. Thus, weak signals are greatly enhanced and the sensitivity of this type of detector is greater than for non-regenerative types.

On the negative half-cycle of input signal, the flow of grid current is reduced, and a small amount of the charge on capacitor C2 leaks off to ground through grid-leak R1. Therefore, the grid bias on V1 is reduced and an increased plate current flows. The increased current flow is in the direction of original (quiescent) current flow and produces a feedback voltage of negative polarity, which adds to the negative signal voltage on the grid. This regenerative build up in the opposite direction during the negative half-cycle of operation is limited to a value less than zero bias, since the tube is operating on the lower bend of the characteristic transfer curve. Hence the positive and negative swings developed across the primary of audio output transformer T1 are unequal and distortion is produced.

The accompanying waveform illustration shows the relationships between the grid and plate voltages and currents. The dotted lines in the waveforms indicate the build up of signal by regenerative action during the positive half-cycle. When the input voltage increases, the secondary voltages increases and is further enhanced by feedback, while the detected signal produces a grid bias which increases and is further enhanced by the feedback. The plate current, in turn, is progressively reduced, while the plate voltage increases. The changes of plate current occuring at audio frequencies in the primary of T1 induces a similar output voltage in the secondary.

When the capacitance of feedback capacitor C3 is increased, the reactance to ground is reduced and a greater r-f current flows through tickler coil L3, and produces a larger feedback voltage. As long as the feedback is kept below the point of oscillation, maximum amplification is obtained. Once the feedback becomes great enough to drive the grid to cut-off and beyond, the tube conducts only during the peak of the signal and for less than a half cycle



Grid and Plate Voltage Waveforms

(class C operation). During the cutoff period the tank circuit supplies the missing portion of the signal and continuous amplitude sine-wave oscillations occur.

Although the r-f component in the plate circuit is effectively bypassed to ground by regeneration capacitor C3, radio frequency choke RFC, is placed in series with the plate lead to offer a high r-f resistance (impedance) and prevent the possibility of r-f feedback through the load consisting of audio output transformer T1 and the power supply. To ensure that no RF remains to cause a fringe howl and deteriorate detector performance, capacitor C4 is also used to bypass the primary of T1. Thus, any remaining RF which might exist at the load end of the RFC is bypassed to ground by C4, so that only the slow current variations caused by modulation and occurring at audio frequencies appear in the transformer primary, and induce an output voltage in the secondary.

When voltage is fed back from the plate to the grid circuit, the result is to effectively reduce the losses in the grid circuit. Since the Q of an inductance is the ratio of the reactance to the resistance in the circuit. It is evident that when the r-f resistance in the circuit is decreased and the same reactance exists, a higher Q results. Thus, with a higher Q tank circuit resulting from feedback, a greater selectivity exists. This improved selectivity makes for sharper tuning, and will cut off the higher modulation frequencies in wide-band transmission such as is used for music at broadcast frequencies. At high frequencies, however, the side bands are a much smaller percentage of the signal so that not as much sideband clipping occurs and usable voice reception is possible without excessive distortion. Since code transmissions occupy a very narrow frequency spectrum of one thousand cycles or less the increased selectivity of the tuned circuit during feedback is not sufficient to affect code reception. One of the major disadvantages of this circuit for Military use is that, when oscillating it reradiates and produces a low powered CW output; which, besides interferring with nearby receivers tuned to the same frequency, offers a convenient means for the enemy to locate the source with direction finders. This radiation can be eliminated by use of an r-f stage between the detector and antenna, which acts as a buffer stage when properly neutralized.

FAILURE ANALYSIS.

No Output. Lack of an input signal, loss of plate voltage, an open or shorted input or output circuit, or a defective tube can result in a loss of output. First measure the supply voltage with a high resistance voltmeter to make certain that the supply or a blown supply fuse is not at fault. Then measure the plate voltage to ground. If the plate voltage is normal, plate circuit components C3, C4, RFC and the primary of T1 are not at fault. If removing and replacing the tube produces a click in the output device it indicates that the secondary of T1 is not open or shorted, and that the trouble is most probably located in the grid circuit. Turn regeneration control C3 past the point where oscillation usually begins and touch the grid of V1 with your finger. A click in the output indicates the circuit is oscillating and that the tube and feedback portion of the circuit are operating. If there still is no output, the input coil is probably open or shorted. Use an ohmmeter to check the input coil for continuity. If the coil is not open, the possibility of a grid to ground short or an open grid capacitor, C2, still exists. Therefore, it is usually easier to connect the antenna or the output of a signal generator direct to the grid of V1. If the input or tuning portion of the circuit is at fault and C2 is not open, a weak signal will usually be heard. Also rotate tuning capacitor C1, and listen for a noise indicating shorted tuning capacitor plates.

If no plate voltage is obtained, either T1 or the RFC is open, or capacitors C3 or C4 are shorted, or tube V1 is defective. An infinite resistance when measuring across T1, RFC, or L3, indicates an open circuit.

Low Output. Low plate voltage, a defective tube, or partially shorted or open parts can cause a reduced output. If the plate voltage is low, check T1 primary, the RFC, and coil L3 for high resistance soldered joints and partially open windings, as indicated by a high resistance reading on an ohmmeter. Also check C3 and C4 for leakage to ground with an in-circuit capacitance checker. If the plate voltage is normal but the output is low, check the secondary of T1 for continuity with an ohmmeter (if sufficient stray capacitance coupling between primary and secondary windings exists weak signals may be heard even though the secondary is open). Rotate tuning capacitor C1 to determine if it is tuning. If it tunes the signal, check input coil L1 for high resistance or an open, since a small, stray capacitive coupling from primary L1 to secondary L2 will produce an output signal even if L1 is open, especially at the higher radio frequencies. Where a stong local signal exists, touching the input winding (or V1 grid) with the finger will increase the signal if the antenna is defective or too small (this type of indicator may not be too effective below decks or in a well-shielded compartment).

Distorted Output. Since grid-leak detection is used there will normally be noticeable distortion, particularly on strong, heavily modulated signals. A continuous tone beat-note heard with the modulation indicates the detector is oscillating and that a readjustment of the regeneration control is necessary to prevent self-oscillation. A high-pitched audio squeal which occurs when the audio gain is increased is known as fringe howl, and occurs only if the RFC and capacitor C4 are not operating properly to bypass the excess r-f plate component to ground. This could occur if the RFC were shorted or C4 were open. First substitute a good RFC, then if the squeal persists shunt C4 with a capacitor of similar value. If V1 is low in emission, there will usually be distorted signals coupled with continuous fading and a weak output. Should the values of the grid-leak resistor or capacitor change noticeably, both blocking and excessive distortion may occur.

SUPER-REGENERATIVE DETECTOR.

APPLICATION.

The super-regenerative detector is used in cheap, one or two tube receivers for the VHF and UHF regions where RF amplification does not provide much gain, and good selectivity is not required. It is is particularly popular in portable-mobile transceivers and walkie-talkies, where small size and low power consumption is important.

CHARACTERISTICS.

May be separately quenched or self-quenched.

Uses a low quenching frequency to obtain high gain.

Selectivity is much less than for any other form of detector.

Has an inherent noise reducing and limiting action.

Responds almost equally as well to strong signals as to weak signals.

Provides high sensitivity and gain in a single tube.

CIRCUIT ANALYSIS.

General. The super-regenerative detector uses a low frequency (from 15 kc to 100 kc) as a **quench** oscillator, generated either internally or separately, to control the regeneration applied to a grid-leak detector, and thus supply an extremely high gain from a single tube. The use of a quenching frequency effectively broadens the selectivity of the tuned input circuit to the point where it acts almost as if it were not tuned. Hence, a major disadvantage is that any strong signal within a few hundred kilocycles of the desired frequency will override it and blank out the desired signal. It also responds somewhat logarithmically to input signal strength so that an amplitude limiting and AVC action is obtained. Thus, extremely weak signals below the threshold level are not detected, and both weak and strong signals above the threshold appear at the output with nearly the same intensity. In addition, high amplitude noise interference, such as produced by spark ignition systems is minimized without the necessity of adding a limiter stage. Signals with low levels of modulation (less than 50 to 60 percent) produce only a weak or garbled output, whereas signals with high percentages of modulation produce a loud output, accompanied by high distortion. In most instances, the interruptions of the quenching oscillator produce an audio output in the form of a high-pitched hiss caused by noise, which appears between stations, and disappears as the signal is tuned in (on extremely weak signals the hiss will mask out the signal). Since the super-regenerator is oscillating, except during the quench period, it is usually necessary to use an r-f amplifier as a buffer to prevent reradiation and interference with other reception. This is also a major disadvantage when used in Military equipment, since interception by enemy direction finders is still possible even with an r-f stage if it is not perfectly neutralized.

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

Transformer T1 is an r-f input transformer, with primary L1 (antenna winding) untuned, and secondary L2 tuned by C1. The tuned secondary tank is connected between the grid and plate of triode V1 as a conventional ultraudion oscillator. Grid-leak bias and low frequency quenching is provided by R1 and C2. The audio output is taken through r-f isolating choke RFC and applied to the primary of audio output transformer T2. The plate voltage is varied to control regeneration by potentiometer R2, and the primary of T2 is bypassed by C3 to prevent r-f feedback.

In the absence of an input signal, the grid-leak produces contact bias (see paragraph 2.2.2. in Section 2 of this Handbook for a detailed explanation of grid-leak bias action), and a steady plate current flows. When an unmodulated carrier signal is applied to the input, the grid is driven positive on the positive peaks, and grid current