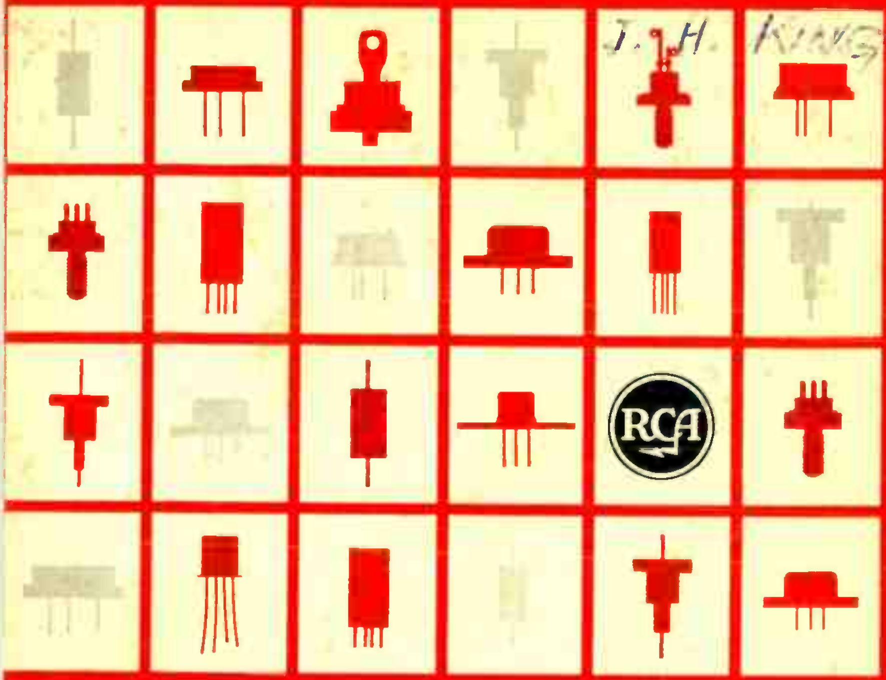
Suggested Price $1.50

J. H. King



RCA transistor manual

RADIO CORPORATION OF AMERICA
Electronic Components and Devices   Harrison, N.J.

Technical Series SC-12

CONTENTS

RCA
Transistor Manual

This manual, like its preceding edition, has been prepared to assist those who work or experiment with semiconductor devices and circuits. It will be useful to engineers, educators, students, radio amateurs, hobbyists, and others technically interested in transistors, silicon rectifiers, silicon controlled rectifiers, varactor diodes, and tunnel diodes.

This edition has been thoroughly revised to cover the latest changes in semiconductor-device technology and applications. The TECHNICAL DATA Section, as well as the text material, has been greatly expanded and brought up to date. Of particular interest to the hobbyist and experimenter are the many practical and timely additions to the CIRCUITS Section.

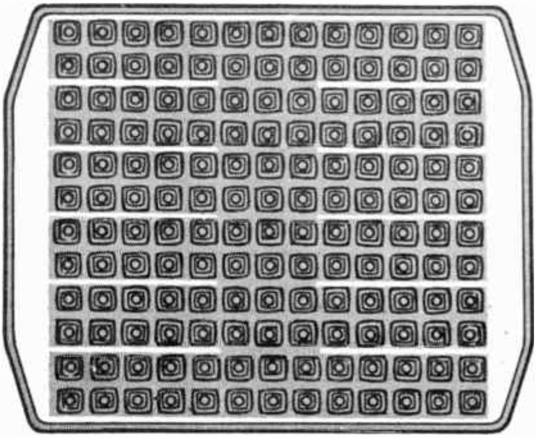
RADIO CORPORATION OF AMERICA

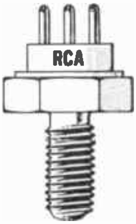
Electronic Components and Devices
Harrison, New Jersey

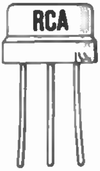
3-66
Printed in U.S.A.

Electrode Configurations Used in RCA MOS Field-Effect Transistors and RCA Overlay Transistors

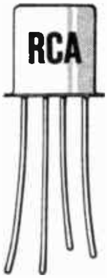
OVERLAY TRANSISTORS







MOS FIELD-EFFECT TRANSISTORS



Materials, Junctions, and Devices

SEMICONDUCTOR devices are small but versatile units that can perform an amazing variety of control functions in electronic equipment. Like other electron devices, they have the ability to control almost instantly the movement of charges of electricity. They are used as rectifiers, detectors, amplifiers, oscillators, electronic switches, mixers, and modulators.

In addition, semiconductor devices have many important advantages over other types of electron devices. They are very small and light in weight (some are less than an inch long and weigh just a fraction of an ounce). They have no filaments or heaters, and therefore require no heating power or warm-up time. They consume very little power. They are solid in construction, extremely rugged, free from microphonics, and can be made impervious to many severe environmental conditions. The circuits required for their operation are usually simple.

SEMICONDUCTOR MATERIALS

Unlike other electron devices, which depend for their functioning on the flow of electric charges through a vacuum or a gas, semiconductor devices make use of the flow of current in a solid. In general, all materials may be classified in three major categories—conductors, semiconductors, and insulators—depending upon their ability to conduct an electric current. As the name indicates, a semiconductor material has poorer conductivity than a conductor, but better conductivity than an insulator.

The materials most often used in semiconductor devices are germanium and silicon. Germanium has higher electrical conductivity (less resistance to current flow) than silicon, and is used in most low- and medium-power diodes and transistors. Silicon is more suitable for high-power devices than germanium. One reason is that it can be used at much higher temperatures. A relatively new material which combines the principal desirable features of both germanium and silicon is gallium arsenide. When further experience with this material has been obtained, it is expected to find much wider use in semiconductor devices.

Resistivity

The ability of a material to conduct current (conductivity) is directly proportional to the number of free (loosely held) electrons in the material. Good conductors, such as silver, copper, and aluminum, have large numbers of free electrons; their resistivities are of the order of a few millionths of an ohm-centimeter. Insulators such as glass, rubber, and mica, which have very few loosely held electrons, have resistivities as high as several million ohm-centimeters.

Semiconductor materials lie in the range between these two extremes, as shown in Fig. 1. Pure germanium has a resistivity of 60 ohm-centimeters. Pure silicon has a considerably higher resistivity, in the order of 60,000 ohm-centimeters. As used in semiconductor devices, however, these materials contain carefully controlled amounts of certain impurities which reduce their resistivity to about 2 ohm-centimeters at room temperature (this resistivity decreases rapidly as the temperature rises).

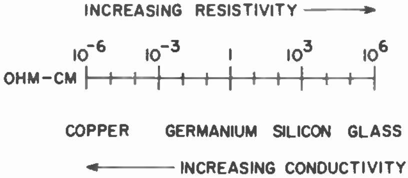


Figure 1. Resistivity of typical conductor, semiconductors, and insulator.

Impurities

Carefully prepared semiconductor materials have a crystal structure. In this type of structure, which is called a lattice, the outer or valence electrons of individual atoms are tightly bound to the electrons of adjacent atoms in electron-pair bonds, as shown in Fig. 2. Because such a structure has no loosely held electrons, semiconductor materials are poor conductors under normal conditions. In order to separate the electron-pair bonds and provide free electrons for electrical conduction, it would be necessary to apply high temperatures or strong electric fields.

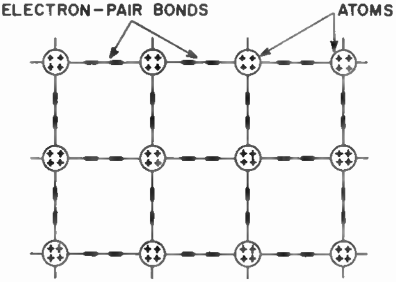


Figure 2. Crystal lattice structure.

Another way to alter the lattice structure and thereby obtain free electrons, however, is to add small amounts of other elements having a different atomic structure. By the addition of almost infinitesimal amounts of such other elements, called "impurities", the basic electrical properties of pure semiconductor materials can be modified and controlled. The ratio of impurity to the semiconductor material is usually extremely small, in the order of one part in ten million.

When the impurity elements are added to the semiconductor material, impurity atoms take the place of semiconductor atoms in the lattice structure. If the impurity atoms added have the same number of valence electrons as the atoms of the original semiconductor material, they fit neatly into the lattice, forming the required number of electron-pair bonds with semiconductor atoms. In this case, the electrical properties of the material are essentially unchanged.

When the impurity atom has one more valence electron than the semiconductor atom, however, this extra electron cannot form an electron-pair bond because no adjacent valence electron is available. The excess electron is then held very loosely by the atom, as shown in Fig. 3, and

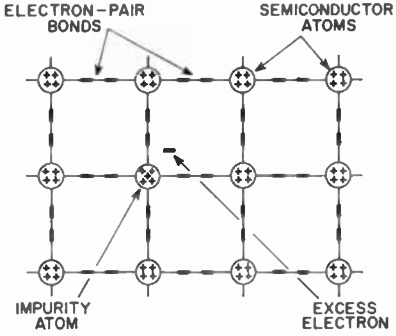


Figure 3. Lattice structure of n-type material.

requires only slight excitation to break away. Consequently, the presence of such excess electrons makes the material a better conductor, i.e., its resistance to current flow is reduced.

Impurity elements which are added to germanium and silicon crystals to provide excess electrons include arsenic and antimony. When these elements are introduced, the resulting material is called **n-type** because the excess free electrons have a negative charge. (It should be noted, however, that the negative charge of the electrons is balanced by an equivalent positive charge in the center of the impurity atoms. Therefore, the net electrical charge of the semiconductor material is not changed.)

A different effect is produced when an impurity atom having one less valence electron than the semiconductor atom is substituted in the lattice structure. Although all the valence electrons of the impurity atom form electron-pair bonds with electrons of neighboring semiconductor atoms, one of the bonds in the lattice structure cannot be completed because the impurity atom lacks the final valence electron. As a result, a vacancy or "hole" exists in the lattice, as shown in Fig. 4. An electron from an adjacent electron-pair bond may then absorb enough energy to break its bond and move through the lattice to fill the hole. As in the case of excess electrons, the presence of "holes" encourages the flow of electrons in the semiconductor material; consequently, the conductivity is increased and the resistivity is reduced.

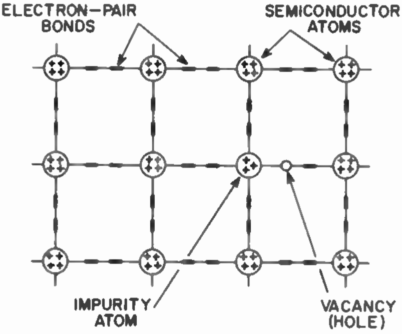


Figure 4. Lattice structure of p-type material.

The vacancy or hole in the crystal structure is considered to have a positive electrical charge because it represents the absence of an electron. (Again, however, the net charge of the crystal is unchanged.) Semiconductor material which contains these "holes" or positive charges is called **p-type** material. P-type materials are formed by the addition of aluminum, gallium, or indium.

Although the difference in the chemical composition of n-type and p-type materials is slight, the differences in the electrical characteristics of the two types are substantial, and are very important in the operation of semiconductor devices.

P-N JUNCTIONS

When n-type and p-type materials are joined together, as shown in Fig. 5, an unusual but very important phenomenon occurs at the interface where the two materials meet (called the **p-n junction**). An interaction takes place between the two types of material at the junction as a result of the holes in one material and the excess electrons in the other.

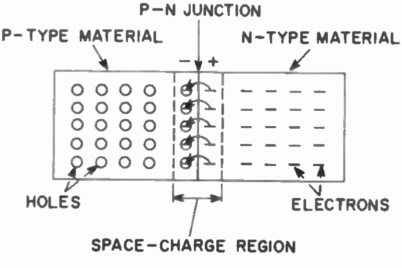


Figure 5. Interaction of holes and electrons at p-n junction.

When a p-n junction is formed, some of the free electrons from the n-type material diffuse across the junction and recombine with holes in the lattice structure of the p-type material; similarly, some of the holes in the p-type material diffuse across the junction and recombine with free electrons in the lattice structure of the n-type material. This interaction or diffusion is brought into equilibrium by a small space-charge region (sometimes called the **transition region** or **depletion layer**). The p-type material thus acquires a slight negative charge and the n-type material acquires a slight positive charge.

The potential gradient established across the space-charge region by the diffusion process is represented in Fig. 6 by an imaginary battery connected across the junction. (The battery symbol is shown only to represent the internal effects; the potential is not directly measurable.) In the absence of external circuits or voltages, this potential gradient discourages further diffusion across the p-n junction because electrons from the n-type material are repelled by the slight negative charge induced in the p-type material and holes from the p-type material are repelled by the slight positive charge induced in the n-type material. In effect, therefore, the potential gradient (or energy **barrier**, as it is sometimes called) prevents total interaction between the two types of material, and thus preserves the differences in their characteristics.

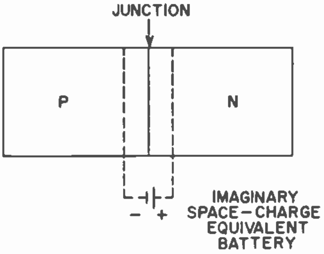
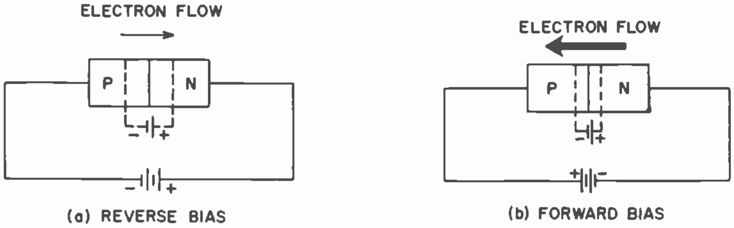


Figure 6. Potential gradient across space-charge region.

CURRENT FLOW

When an external battery is connected across a p-n junction, the amount of current flow is determined by the polarity of the applied voltage and its effect on the space-charge region. In Fig. 7a, the positive terminal of the battery is connected to the n-type material and the negative terminal to the p-type material. In this arrangement, the free electrons in the n-type material are attracted toward the positive terminal of the battery and away from the junction. At the same time, holes from the p-type material are attracted toward the negative terminal of the battery and away from the junction. As a result, the space-charge region at the junction becomes effectively wider, and the potential gradient increases until it approaches the potential of the external battery. Current flow is then extremely small because no voltage difference (electric field) exists across either the p-type or the n-type region. Under these conditions, the p-n junction is said to be **reverse-biased.**

In Fig. 7b, the positive terminal of the external battery is connected to the p-type material and the negative terminal to the n-type material. In this arrangement, electrons in the p-type material near the positive ter-



(a) REVERSE BIAS

(b) FORWARD BIAS

Figure 7. Electron current flow in biased p-n junctions.

minal of the battery break their electron-pair bonds and enter the battery, creating new holes. At the same time, electrons from the negative terminal of the battery enter the n-type material and diffuse toward the junction. As a result, the space-charge region becomes effectively narrower, and the energy barrier decreases to an insignificant value. Excess electrons from the n-type material can then penetrate the space-charge region, flow across the junction, and move by way of the holes in the p-type material toward the positive terminal of the battery. This electron flow continues as long as the external voltage is applied. Under these conditions, the junction is said to be forward-biased.

The generalized voltage-current characteristic for a p-n junction in Fig. 8 shows both the reverse-bias and forward-bias regions. In the forward-bias region, current rises rapidly as the voltage is increased and is quite high. Current in the reverse-bias region is usually much lower. Excessive voltage (bias) in either direction should be avoided in normal applications because excessive currents and the resulting high temperatures may permanently damage the semiconductor device.

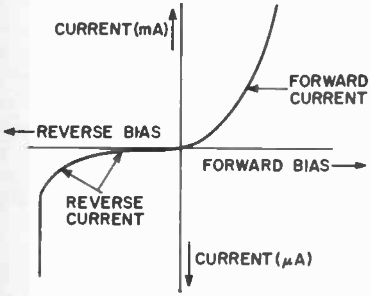


Figure 8. Voltage-current characteristic for a p-n junction.

N-P-N AND P-N-P STRUCTURES

Fig. 7 shows that a p-n junction biased in the reverse direction is equivalent to a high-resistance element (low current for a given applied voltage), while a junction biased in the forward direction is equivalent to a low-resistance element (high current for a given applied voltage). Because the power developed by a given current is greater in a high-resistance element than in a low-resistance element ($P = I^2R$), power gain can be obtained in a structure containing two such resistance elements if the current flow is not materially reduced. A device containing two p-n junctions biased in opposite directions can operate in this fashion.

Such a two-junction device is shown in Fig. 9. The thick end layers are made of the same type of material (n-type in this case), and are separated by a very thin layer of the opposite type of material (p-type in the device shown). By means of the external batteries, the left-hand (n-p) junction is biased in the forward direction to provide a low-resistance input circuit, and the right-hand (p-n) junction is biased in the reverse direction to provide a high-resistance output circuit.

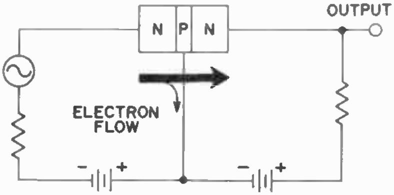


Figure 9. N-P-N structure biased for power gain.

Electrons flow easily from the left-hand n-type region to the center p-type region as a result of the forward biasing. Most of these electrons diffuse through the thin p-type region, however, and are attracted by the positive potential of the external battery across the right-hand junction. In practical devices, approximately 95 to 99.5 per cent of the electron current reaches the right-hand n-type region. This high percentage of current penetration provides power gain in the high-resistance output circuit and is the basis for transistor amplification capability.

The operation of p-n-p devices is similar to that shown for the n-p-n device, except that the bias-voltage polarities are reversed, and electron-current flow is in the opposite direction. (Many discussions of semiconductor theory assume that the "holes" in semiconductor material constitute the charge carriers in p-n-p devices, and discuss "hole currents" for these devices and "electron currents" for n-p-n devices. Other texts discuss neither hole current nor electron current, but rather "conventional current flow", which is assumed to travel through a circuit in a direction from the positive terminal of the external battery back to its negative terminal. For the sake of simplicity, this discussion will be restricted to the concept of electron current flow, which travels from a negative to a positive terminal.)

TYPES OF DEVICES

The simplest type of semiconductor device is the **diode**, which is represented by the symbol shown in Fig. 10. Structurally, the diode is basically a p-n junction similar to those shown in Fig. 7. The n-type material which serves as the negative electrode is referred to as the **cathode**, and the p-type material which serves as the positive electrode is referred to as the **anode**. The arrow symbol used for the anode represents the direction of "conventional current flow" mentioned above; electron current flows in a direction opposite to the arrow.

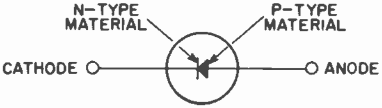


Figure 10. Schematic symbol for a semiconductor diode.

Because the junction diode conducts current more easily in one direction than in the other, it is an effective rectifying device. If an ac signal is applied, as shown in Fig. 11, electron current flows freely during the positive half cycle, but little or no current flows during the negative half cycle.

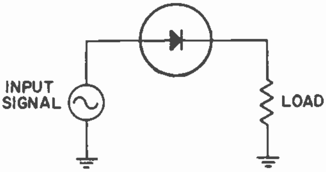


Figure 11. Simple diode rectifying circuit.

One of the most widely used types of semiconductor diode is the silicon rectifier. These devices are available in a wide range of current capabilities, ranging from tenths of an ampere to 40 amperes or more, and are capable of operation at voltages as high as 800 volts or more. Parallel and series arrangements of silicon rectifiers permit even further extension of current and voltage limits. Characteristics and applications of these devices are discussed in detail in the section on **Silicon Rectifiers.**

If two p-type and n-type semiconductor materials are arranged alternately in series, a device is produced which behaves as a conventional rectifier in the reverse direction and as a series combination of an electronic switch and a rectifier in the forward direction. Conduction in the forward direction can then be controlled or "gated" by operation of the electronic switch. Such devices are discussed in the section on **Silicon Controlled Rectifiers.**

Several variations of the basic junction diode structure have been developed for use in special applications. One of the most important of these developments is the **tunnel diode**, which is used for amplification, switching, and pulse generation. This special diode is described in the section on **Tunnel Diodes and Other Semiconductor Diodes.**

When a second junction is added to a semiconductor diode to provide power or voltage amplification (as shown in Fig. 9), the resulting device is called a **transistor.** The three regions of the device are called the **emitter,** the **base,** and the **collector,** as shown in Fig. 12. In normal operation, the emitter-to-base junction is biased in the forward direction, and the collector-to-base junction in the reverse direction.

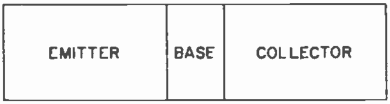


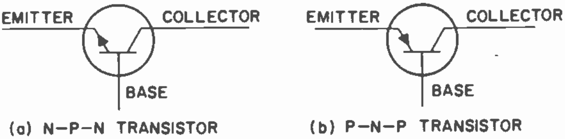
Figure 12. Functional diagram of transistor structure.

Different symbols are used for n-p-n and p-n-p transistors to show the difference in the direction of current flow in the two types of devices. In the n-p-n transistor shown in Fig. 13a, electrons flow from the emitter to the collector. In the p-n-p transistor shown in Fig. 13b, electrons flow from the collector to the emitter. In other words, the direction of dc electron current is always opposite to that of the arrow on the emitter lead. (As in the case of semiconductor diodes, the arrow indicates the direction of "conventional current flow" in the circuit.)

The first two letters of the n-p-n and p-n-p designations indicate the respective polarities of the voltages applied to the emitter and the collector in normal operation. In an n-p-n transistor, the emitter is made negative with respect to both the collector and the base, and the collector is made positive with respect to both the emitter and the base. In a p-n-p transistor, the emitter is made positive with respect to both the collector and the base, and the collector is made negative with respect to both the emitter and the base.

The transistor, which is a three-element device, can be used for a wide variety of control functions, including amplification, oscillation, and frequency conversion. Transistor characteristics and applications are discussed in detail in the following sections.

A relatively new type of transistor, the **MOS field-effect transistor,** utilizes a metal control electrode to modulate the conductivity of the semiconductor material. Because of their very high input impedance and square-law transfer characteristics, MOS transistors are especially suitable for use as voltage amplifiers. Characteristics and applications of these devices are described in the section on **MOS Field-Effect Transistors.**



(a) N–P–N TRANSISTOR (b) P–N–P TRANSISTOR

Figure 13. Schematic symbols for transistors.

Transistor Designs and Circuit Configurations

THE performance of transistors in electronic equipment depends on many factors besides the basic characteristics of the semiconductor material. The two most important factors are the design and fabrication of the transistor structure and the general circuit configuration used.

DESIGN AND FABRICATION

The ultimate aim of all transistor fabrication techniques is the construction of two parallel p-n junctions with controlled spacing between the junctions and controlled impurity levels on both sides of each junction. A variety of structures has been developed in the course of transistor evolution.

The earliest transistors made were of the point-contact type. In this type of structure, two pointed wires were placed next to each other on an n-type block of semiconductor material. The p-n junctions were formed by electrical pulsing of the wires. This type has been superseded by junction transistors, which are fabricated by the various alloy, diffusion, and crystal-growth techniques described below.

In grown-junction transistors, the impurity content of the semiconductor material is changed during the growth of the original crystal ingot to provide the p-n-p or n-p-n regions. The grown crystal is then sliced into a large number of small-area devices, and contacts are made to each region of the devices. The finished transistor is encased in plastic or a hermetically sealed enclosure.

In alloy-junction transistors, two small "dots" of a p-type or n-type impurity element are placed on opposite sides of a thin wafer of n-type or p-type semiconductor material, respectively, as shown in Fig. 14. After proper heating, the impurity "dots" alloy with the semiconductor material to form the regions for the emitter and collector junctions. The base connection in this structure is made to the original semiconductor wafer.

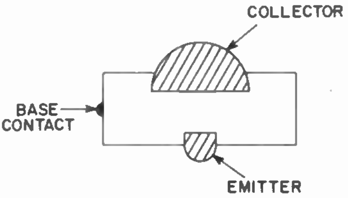


Figure 14. Structure of alloy-junction transistor.

The drift-field transistor is a modified alloy-junction device in which the impurity concentration in the base wafer is diffused or graded, as shown in Fig. 15. Two advantages are derived from this structure: (a) the resultant built-in voltage or "drift field" speeds current flow, and (b) the ability to use a heavy impurity concentration in the vicinity of the emitter and a light concentration in the vicinity of the collector makes it possible to minimize capacitive charging times. Both these advantages lead to a substantial extension of the frequency performance over the alloy-junction device.

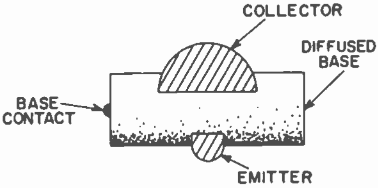


Figure 15. Structure of drift-field transistor.

Mesa and planar transistors use newer construction techniques which are better suited to many applications than the grown-junction or alloy methods. These transistors involve two basic processes: (1) the use of diffusion masking materials and photolithographic techniques to obtain a planar structure in which all the p-n junctions are buried under a protective passivating layer, and (2) the use of a separate collector-contact diffusion or an epitaxial growth to reduce the electrical series resistance in the collector. In these types, the original semiconductor wafer serves as the collector. The base region is diffused into the wafer, and the emitter "dot" or region is then alloyed or diffused into the base region. A "mesa" or flat-topped peak may then be etched to reduce the collector area at the base-collector junction. The mesa structure is inherently rugged, has large power-dissipation capability, and can operate at very high frequencies.

Fig. 16 shows the structure of double-diffused epitaxial mesa and planar structures in production today. The grading of the impurity concentration in the base region results in a drift field and in reduced base-lead resistance. The use of a diffused emitter region permits tight geometry control. The use of a relatively light impurity concentration in the collector region results in high collector-breakdown voltages and low collector-junction capacitance.

A new emitter electrode structure called an "overlay" is used in some power transistors to improve high-frequency capability. In this overlay structure (shown in the frontispiece on page 2), a large number of separate emitters are tied together by diffused and metalized regions. This approach increases the emitter edge-to-area ratio and reduces the input time constant of the transistor. The desired overlay structure is fabricated by carefully controlled diffusion and precise photographic processes.

BASIC CIRCUITS

There are three basic ways of connecting transistors in a circuit: common-base, common-emitter, and common-collector. In the **common-base** (or grounded-base) connection shown in Fig. 17, the signal is introduced into the emitter-base circuit and extracted from the collector-base circuit. (Thus the base element of the transistor is common to both the in-

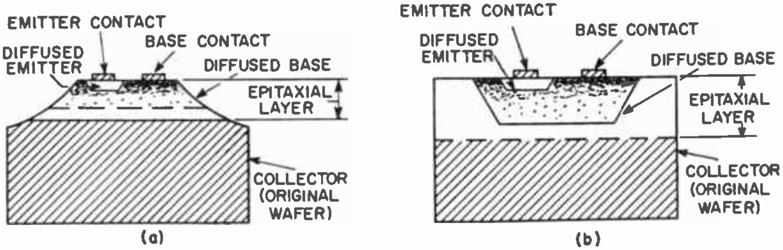


Figure 16. Structure of (a) double-diffused epitaxial mesa transistor and (b) double-diffused epitaxial planar transistor.

put and output circuits.) Because the input or emitter-base circuit has a low impedance (resistance plus reactance) in the order of 0.5 to 50 ohms, and the output or collector-base circuit has a high impedance in the order of 1000 ohms to one megohm, the voltage or power gain in this type of configuration may be in the order of 1500.

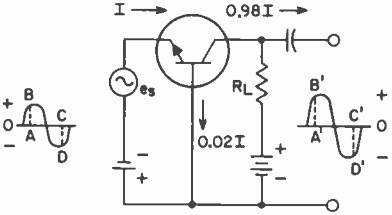


Figure 17. Common-base circuit configuration.

The direction of the arrows in Fig. 17 indicates electron current flow. As stated previously, most of the current from the emitter flows to the collector; the remainder flows through the base. In practical transistors, from 95 to 99.5 per cent of the emitter current reaches the collector. The current gain of this configuration, therefore, is always less than unity, usually in the order of 0.95 to 0.995.

The waveforms in Fig. 17 represent the input voltage produced by the signal generator e_s and the output voltage developed across the load resistor R_L. When the input voltage is positive, as shown at AB, it opposes the forward bias produced by the base-emitter battery, and thus reduces current flow through the n-p-n transistor. The reduced electron current flow through R_L then causes the top point of the resistor to become less negative (or more positive) with respect to the lower point, as shown at A'B' on the output waveform. Conversely, when the input signal is negative, as at CD, the output signal is also negative, as at C'D'. Thus, the phase of the signal remains unchanged in this circuit, i.e., there is no voltage phase reversal between the input and the output of a common-base amplifier.

In the common-emitter (or grounded-emitter) connection shown in Fig. 18, the signal is introduced into the base-emitter circuit and extracted from the collector-emitter circuit. This configuration has more moderate input and output impedances than the common-base circuit. The input (base-emitter) impedance is in the range of 20 to 5000 ohms, and the output (collector-emittter) impedance is about 50 to 50,000 ohms. Power gains in the order of 10,000 (or approximately 40 dB) can be realized with this circuit because it provides both current gain and voltage gain.

Current gain in the common-emitter configuration is measured between the base and the collector, rather than between the emitter and the collector as in the common-base circuit. Because a very small change in base current produces a relatively large change in collector current, the current gain is always greater than unity in a common-emitter circuit; a typical value is about 50.

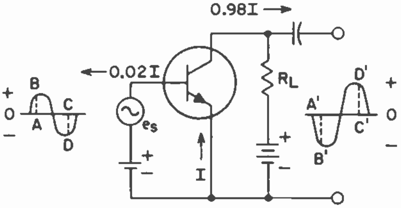


Figure 18. Common-emitter circuit configuration.

The input signal voltage undergoes a phase reversal of 180 degrees in a common-emitter amplifier, as shown by the waveforms in Fig. 18. When the input voltage is positive, as shown at AB, it increases the forward bias across the base-emitter junction, and thus increases the total current flow through the transistor. The increased electron flow through R_L then causes the output voltage to become negative, as shown at A′B′. During the second half-cycle of the waveform, the process is reversed, i.e., when the input signal is negative, the output signal is positive (as shown at CD and C′D′.)

The third type of connection, shown in Fig. 19, is the **common-collector** (or grounded-collector) circuit. In this configuration, the signal is introduced into the base-collector circuit and extracted from the emitter-collector circuit. Because the input impedance of the transistor is high and the output impedance low in this connection, the voltage gain is less than unity and the power gain is usually lower than that obtained in either a common-base or a common-emitter circuit. The common-collector circuit is used primarily as an impedance-matching device. As in the case of the common-base circuit, there is no phase reversal of the signal between the input and the output.

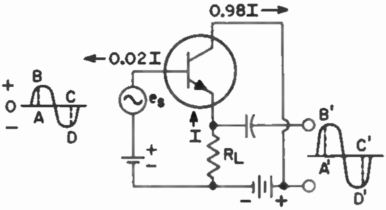


Figure 19. Common-collector circuit configuration.

The circuits shown in Figs. 17 through 19 are biased for n-p-n transistors. When p-n-p transistors are used, the polarities of the batteries must be reversed. The voltage phase relationships, however, remain the same.

Transistor Characteristics

THE term "characteristic" is used to identify the distinguishing electrical features and values of a transistor. These values may be shown in curve form or they may be tabulated. When the characteristics values are given in curve form, the curves may be used for the determination of transistor performance and the calculation of additional transistor parameters.

Characteristics values are obtained from electrical measurements of transistors in various circuits under certain definite conditions of current and voltage. Static characteristics are obtained with dc potentials applied to the transistor electrodes. Dynamic characteristics are obtained with an ac voltage on one electrode under various conditions of dc potentials on all the electrodes. The dynamic characteristics, therefore, are indicative of the performance capabilities of the transistor under actual working conditions.

Published data for transistors include both electrode characteristic curves and transfer characteristic curves. These curves present the same information, but in two different forms to provide more useful data. Because transistors are used most often in the common-emitter configuration, characteristic curves are usually shown for the collector or output electrode. The collector-characteristic curve is obtained by varying collector-to-emitter voltage and measuring collector current for different values of base current. The transfer-characteristic curve is obtained by varying the base-to-emitter (bias) voltage or current at a specified or constant collector voltage, and measuring collector current. A collector-characteristic family of curves is shown in Fig. 20. Fig. 21 shows transfer-characteristic curves for the same transistor.

One of the most important characteristics of a transistor is its

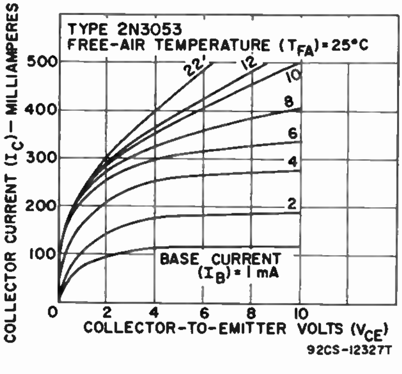


Figure 20. Collector-characteristic curves.

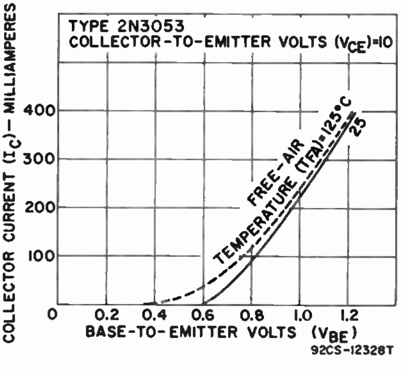


Figure 21. Transfer-characteristic curves.

forward current-transfer ratio, i.e., the ratio of the current in the output electrode to the current in the input electrode. Because of the different ways in which transistors may be connected in circuits, the forward current-transfer ratio is specified for a particular circuit configuration. The common-base forward current-transfer ratio is often called **alpha** (or α), and the common-emitter forward current-transfer ratio is often called **beta** (or β).

In the common-base circuit shown in Fig. 17, the emitter is the input electrode and the collector is the output electrode. The dc alpha, therefore, is the ratio of the dc collector current I_C to the dc emitter current I_E:

$$\alpha = \frac{I_C}{I_E} = \frac{0.98\ I}{I} = 0.98$$

In the common-emitter circuit shown in Fig. 18, the base is the input electrode and the collector is the output electrode. The dc beta, therefore, is the ratio of the dc collector current I_C to the dc base current I_B:

$$\beta = \frac{I_C}{I_B} = \frac{0.98\ I}{0.02\ I} = 49$$

Because the ratios given above are based on dc currents, they are properly called dc alpha and dc beta. It is more common, however, for the current-transfer ratio to be given in terms of the ratio of signal currents in the input and output electrodes, or the ratio of a change in the output current to the input signal current which causes the change. Fig. 22 shows typical electrode currents in a common-emitter circuit under no-signal conditions and with a one-microampere signal applied to the base. The signal current of one microampere in the base causes a change of 49 microamperes (147-98) in the collector current. Thus the ac beta for the transistor is 49.

The **frequency cutoff** of a transistor is defined as the frequency at which the value of alpha (for a common-base circuit) or beta (for a common-emitter circuit) drops to 0.707 times its one-kilocycle value. The **gain-bandwidth product** is the frequency at which the common-emitter forward current-transfer ratio (beta) is equal to unity. These characteristics provide an approximate indication of the useful frequency range of the device, and help to determine the most suitable circuit configuration for a particular application. Fig. 23 shows typical curves of alpha and beta as functions of frequency.

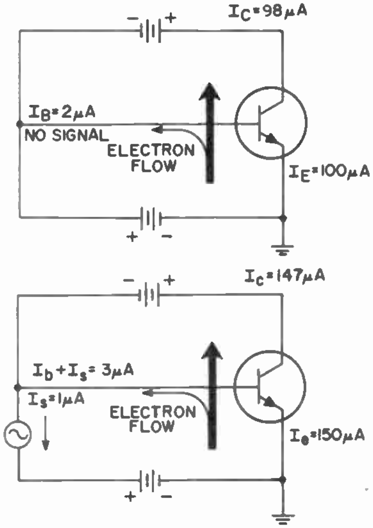


Figure 22. Electrode currents under no-signal and signal conditions.

Extrinsic transconductance may be defined as the quotient of a small change in collector current divided by the small change in emitter-to-base voltage producing it, under the condition that other voltages remain unchanged. Thus, if an emitter-to-base voltage change of 0.1 volt causes a collector-current change of 3 milliamperes (0.003 ampere) with other voltages constant, the transconductance is 0.003 divided by 0.1, or 0.03 mho. (A "mho" is the unit of conductance, and was named by spelling

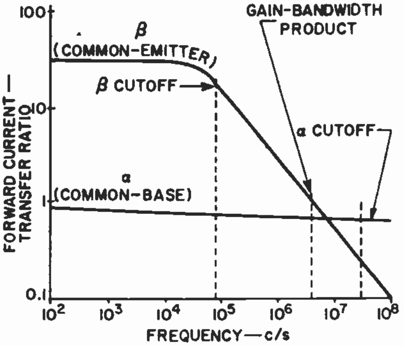


Figure 23. Forward current-transfer ratio as a function of frequency.

"ohm" backward.) For convenience, a millionth of a mho, or a micromho (μmho), is used to express transconductance. Thus, in the example, 0.03 mho is 30,000 micromhos.

Cutoff currents are small dc reverse currents which flow when a transistor is biased into non-conduction. They consist of **leakage currents**, which are related to the surface characteristics of the semiconductor material, and **saturation currents**, which are related to the impurity concentration in the material and which increase with increasing temperatures. Collector-cutoff current is the dc current which flows in the reverse-biased collector-to-base circuit when the emitter-to-base circuit is open. Emitter-cutoff current is the current which flows in the reverse-biased emitter-to-base circuit when the collector-to-base circuit is open.

Transistor **breakdown voltages** define the voltage values between two specified electrodes at which the crystal structure changes and current begins to rise rapidly. The voltage then remains relatively constant over a wide range of electrode currents. Breakdown voltages may be measured with the third electrode open, shorted, or biased in either the forward or the reverse direction. For example, Fig. 24 shows a series of collector-characteristic curves for different base-bias conditions. It can be seen that the collector-to-emitter breakdown voltage increases as the base-to-emitter bias decreases from the normal forward values through zero to reverse values. The symbols shown on the abscissa are sometimes used to designate collector-to-emitter breakdown voltages with the base open (BV_{CEO}), with external base-to-emitter resistance (BV_{CER}), with the base shorted to the emitter (BV_{CES}), and with a reverse base-to-emitter voltage (BV_{CEV}).

As the resistance in the base-to-emitter circuit decreases, the collector characteristic develops two breakdown points, as shown in Fig. 24. After the initial breakdown, the collector-to-emitter voltage decreases with increasing collector current until another breakdown occurs at a lower voltage. This minimum collector-to-emitter breakdown voltage is called the **sustaining voltage.**

In large-area power transistors, there is a limiting mechanism referred to as "**second breakdown**". This condition is not a voltage breakdown, but rather an electrically and thermally regenerative process in which current is focused in a very small area of the order of the diameter of a human hair. The very high current, together with the voltage across the transistor, causes a localized heating that may melt a minute hole from the collector to the emitter of the transistor and thus cause a short circuit. This regenerative process is not initiated unless certain high voltages and currents are coincident for certain finite lengths of time.

In conventional transistor structures, the limiting effects of second breakdown vary directly with the amplitude of the applied voltage and inversely with the width of the base region. These effects are most severe in power transistors in which narrow base structures are used to achieve good high-frequency response. In RCA "overlay" power transistors, a special emitter configuration is used to provide greater

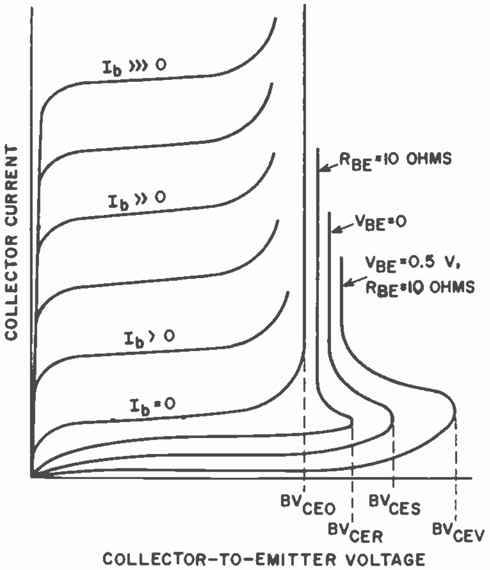


Figure 24. Typical collector-characteristic curves showing location of various breakdown voltages.

current-handling capability and minimize the possibility of "hot spots" occurring at the emitter-base junction. This new design extends the range of power and frequency over which transistors can be operated before second breakdown begins to limit performance.

The curves at the left of Fig. 24 show typical collector characteristics under normal forward-bias conditions. For a given base input current, the collector-to-emitter saturation voltage is the minimum voltage required to maintain the transistor in full conduction (i.e., in the saturation region). Under saturation conditions, a further increase in forward bias produces no corresponding increase in collector current. Saturation voltages are very important in switching applications, and are usually specified for several conditions of electrode currents and ambient temperatures.

Reach-through (or punch-through) voltage defines the voltage value at which the depletion region in the collector region passes completely through the base region and makes contact at some point with the emitter region. This "reach-through" phenomenon results in a relatively low-resistance path between the emitter and the collector, and causes a sharp increase in current. Punch-through voltage does not result in permanent damage to a transistor, provided there is sufficient impedance in the power-supply source to limit transistor dissipation to safe values.

Stored base charge is a measure of the amount of charge which exists in the base region of the transistor at the time that forward bias is removed. This stored charge supports an undiminished collector current in the saturation region for some finite time before complete switching is effected. This delay interval, called the "storage time", depends on the degree of saturation into which the transistor is driven. (This effect is discussed in more detail under "Switching" in the section on **Transistor Applications**.

Transistor Applications

The diversified applications of transistors are treated in this section under the major functional classifications of Detection, Amplification, TV Sync and Deflection, Oscillation, Frequency Conversion, and Switching. The following general descriptions of basic radio, television, communications, and computer systems indicate the types of circuits used to perform the various specialized functions in these systems, and serve as a guide to the specific applications material in this section. Because various coupling and biasing methods are used in transistor circuits, bias and coupling arrangements are discussed separately before specific applications are considered. Bias stability requirements for transistor circuits are also described.

GENERAL SYSTEM FUNCTIONS

When speech, music, or video information is transmitted from a radio or television station, the station radiates a modulated radio-frequency (rf) carrier. The function of a radio or television receiver is simply to reproduce the modulating wave from the modulated carrier.

As shown in Fig. 25, a superheterodyne radio receiver picks up the transmitted modulated rf signal, amplifies it and converts it to a modulated intermediate-frequency (if) signal, amplifies the modulated if signal, separates the modulating signal from the basic carrier wave, and amplifies the resulting audio signal to a level sufficient to produce the desired volume in a speaker. In addition, the receiver usually includes some means of producing automatic gain control (agc) of the modulated signal before the audio information is separated from the carrier.

The transmitted rf signal picked up by the radio receiver may contain either amplitude modulation (AM) or frequency modulation (FM). (These modulation techniques are described later in the section on Detection.) In either case, amplification prior to the detector stage is performed by tuned amplifier circuits designed for the proper frequency and bandwidth. Frequency conversion is performed by mixer and oscillator circuits or by a single converter stage

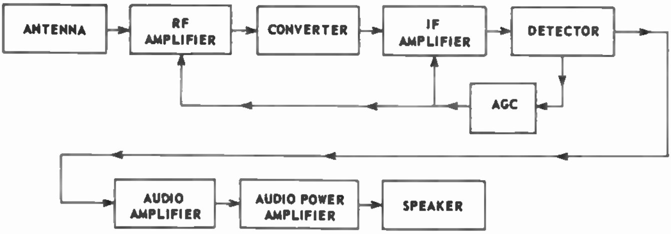


Figure 25. Simplified block diagram for a broadcast-band receiver.

which performs both mixer and oscillator functions. Separation of the modulating signal is normally accomplished by one or more diodes in a detector or discriminator circuit. Amplification of the audio signal is then performed by one or more audio amplifier stages.

Audio-amplifier systems for phonograph or tape recordings are similar to the stages after detection in a radio receiver. The input to the amplifier is a low-power-level audio signal from the phonograph or magnetic-tape pickup head. This signal is usually amplified through a preamplifier stage, one or more low-level (pre-driver or driver) audio stages, and an audio power amplifier. The system may also include frequency-selective circuits which act as equalization networks and/or tone controls.

The operation of a television receiver is more complex than that of a radio receiver, as shown by the simplified block diagram in Fig. 26. The tuner section of the receiver selects the proper rf signals for the desired channel frequency, amplifies them, and converts them to a lower intermediate frequency. As in a radio, these functions are accomplished in rf-amplifier, mixer, and local-oscillator stages. The if signal is then amplified in if-amplifier stages which provide the additional gain required to bring the signal level to an amplitude suitable for detection.

After if amplification, the detected signal is separated into sound and picture information. The sound signal is amplified and processed to provide an audio signal which is fed to an audio amplifier system similar to those described above. The picture (video) signal is passed through a video amplifier stage which conveys beam-intensity information to the television picture tube and thus controls instantaneous "spot" brightness. At the same time, deflection circuits cause the electron beam of the picture tube to move the "spot" across the faceplate horizontally and vertically. Special "sync" signals derived from the video signal assure that the horizontal and vertical scanning are timed so that the picture produced on the receiver exactly duplicates the picture being viewed by the camera or pickup tube.

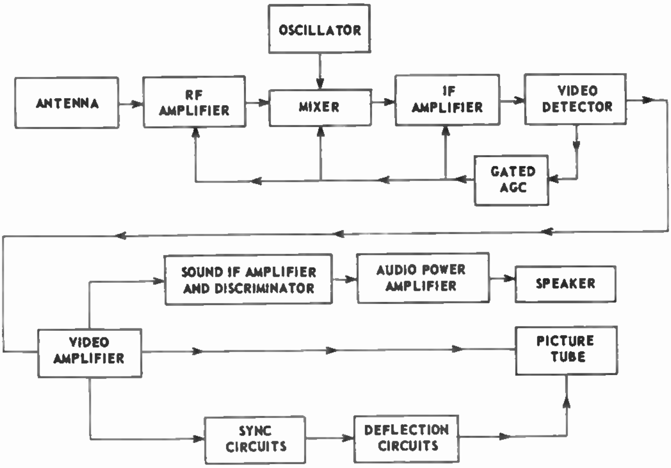


Figure 26. Simplified block diagram for a television receiver.

A communications transceiver contains transmitting circuits, as well as receiving circuits similar to those of a radio receiver. The transmitter portion of such a system consists of two sections. In one section, the desired intelligence (voice, code, or the like) is picked up and amplified through one or more amplifier stages (which are usually common to the receiver portion) to a high-level stage called a modulator. In the other section, an rf signal of the desired frequency is developed in an oscillator stage and amplified in one or more rf-amplifier stages. The audio-frequency (af) modulating signal is impressed on the rf carrier in the final rf-power-amplifier stage (high-level modulation), in the rf low-level stage (low-level modulation), or in both. Fig. 27 shows a simplified block diagram of the transmitter portion of a citizens-band transceiver that operates at a frequency of 27 megacycles per second. The transmitting section of a communications system may also include frequency-multiplier circuits which raise the frequency of the developed rf signal as required.

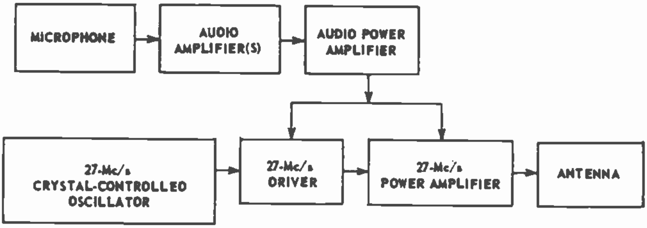


Figure 27. Simplified block diagram for the transmitter portion of a 27-Mc/s communications transceiver.

Basically, a computer system is designed to evaluate information supplied to it in such a way that a predetermined output is obtained for prescribed input conditions. This evaluation is performed by switching circuits (also called logic circuits or "gates") which provide a binary output ("1" or "0"). Various types of logic circuits can be combined in large quantity to perform complicated analytical functions at very high speed.

BIASING

For most non-switching applications, the operating point for a particular transistor is established by the quiescent (dc, no-signal) values of collector voltage and emitter current. In general, a transistor may be considered as a current-operated device, i.e., the current flowing in the emitter-base circuit controls the current flowing in the collector circuit. The voltage and current values selected, as well as the particular biasing arrangement used, depend upon both the transistor characteristics and the specific requirements of the application.

As mentioned previously, biasing of a transistor for most applications consists of forward bias across the emitter-base junction and reverse bias across the collector-base junction. In Figs. 17, 18, and 19, two batteries were used to establish bias of the correct polarity for an n-p-n transistor in the common-base, common-emitter, and common-collector circuits, respectively. Many variations of these basic circuits can also be used. (In these simplified dc circuits, inductors and transformers are represented only by their series resistance.)

A simplified biasing arrangement for the common-base circuit is shown in Fig. 28. Bias for both the collector-base junction and the emitter-base

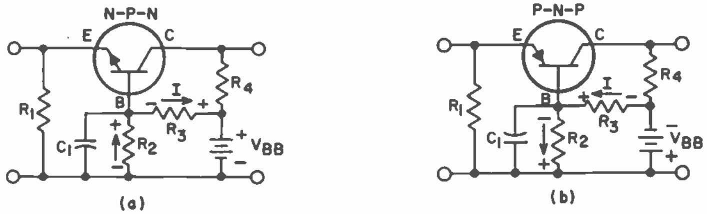


Figure 28. Biasing network for common-base circuit for (a) n-p-n and (b) p-n-p transistors.

junction is obtained from the single battery through the voltage-divider network consisting of resistors R_2 and R_3. (For the n-p-n transistor shown in Fig. 28a, the emitter-base junction is forward-biased because the emitter is negative with respect to the base, and the collector-base junction is reverse-biased because the collector is positive with respect to the base, as shown. For the p-n-p transistor shown in Fig. 28b, the polarity of the battery and of the electrolytic bypass capacitor C_1 is reversed.) The electron current I from the battery and through the voltage divider causes a voltage drop across resistor R_2 which biases the base. The proper amount of current then flows through R_1 so that the correct emitter potential is established to provide forward bias relative to the base. This emitter current establishes the amount of collector current which, in turn, causes a voltage drop across R_4. Simply stated, the voltage divider consisting of R_2 and R_3 establishes the base potential; the base potential essentially establishes the emitter potential; the emitter potential and resistor R_1 establish the emitter current; the emitter current establishes the collector current; and the collector current and R_4 establish the collector potential. R_2 is bypassed with capacitor C_1 so that the base is effectively grounded for ac signals.

A single battery can also be used to bias the common-emitter circuit. The simplified arrangement shown in Fig. 29 is commonly called "fixed bias". In this case, both the base and the collector are made positive with respect to the emitter by means of the battery. The base resistance R_B is then selected to provide the desired base current I_B for the transistor (which, in turn, establishes the desired emitter current I_E), by means of the following expression:

$$R_B = \frac{V_{BB} - V_{BE}}{I_B}$$

where V_{BB} is the battery supply voltage and V_{BE} is the base-to-emitter voltage of the transistor.

In the circuit shown, for example, the battery voltage is six volts. The value of R_B was selected to provide a base current of 27 microamperes, as follows:

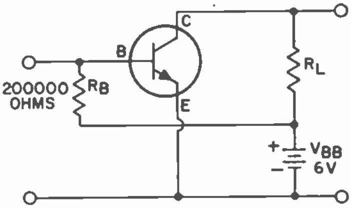


Figure 29. "Fixed-bias" arrangement for common-emitter circuit.

$$R_B = \frac{6 - 0.6}{27 \times 10^{-6}} = 200{,}000 \text{ ohms}$$

The fixed-bias arrangement shown in Fig. 29, however, is not a satisfactory method of biasing the base in a common-emitter circuit. The critical base current in this type of circuit is very difficult to maintain under fixed-bias conditions because of variations between transistors and the sensitivity of these devices to temperature changes. This problem is partially overcome in the "self-bias" arrangement shown in Fig. 30.

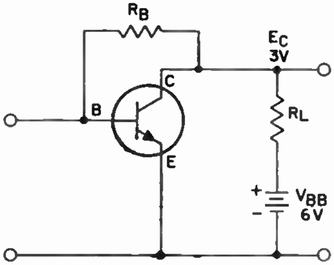


Figure 30. "Self-bias" arrangement for common-emitter circuit.

In this circuit, the base resistor is tied directly to the collector. This connection helps to stabilize the operating point because an increase or decrease in collector current produces a corresponding decrease or increase in base bias. The value of R_B is then determined as described above, except that the collector voltage V_{CE} is used in place of the supply voltage V_{BB}:

$$R_B = \frac{V_{CE} - V_{BE}}{I_B}$$

$$= \frac{3 - 0.6}{27 \times 10^{-6}} = 90,000 \text{ ohms}$$

The arrangement shown in Fig. 30 overcomes many of the disadvantages of fixed bias, although it reduces the effective gain of the circuit.

In the bias method shown in Fig. 31, the voltage-divider network composed of R_1 and R_2 provides the required forward bias across the base-emitter junction. The value of the base bias voltage is determined by the current through the voltage divider. This type of circuit provides less gain than the circuit of Fig. 30, but is commonly used because of its inherent stability.

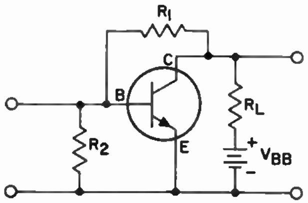


Figure 31. Bias network using voltage-divider arrangement for increased stability.

The common-emitter circuits shown in Figs. 32 and 33 may be used to provide stability and yet minimize loss of gain. In Fig. 32, a resistor R_E is added to the emitter circuit, and the base resistor R_2 is returned to the positive terminal of the battery instead of to the collector. The emitter resistor R_E provides additional stability. It is bypassed with capacitor C_E. The value of C_E depends on the lowest frequency to be amplified.

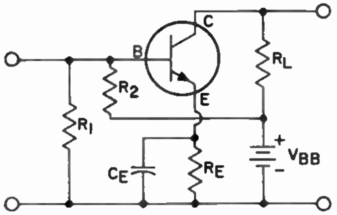


Figure 32. Bias network using emitter stabilizing resistor.

In Fig. 33, the R_2R_3 voltage-divider network is split, and all ac feedback currents through R_3 are shunted to ground (bypassed) by capacitor C_1.

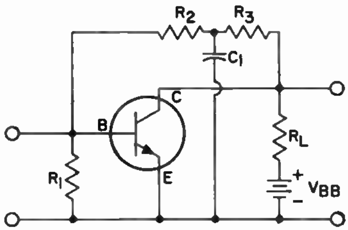


Figure 33. Bias network using split voltage-divider network.

The value of R_3 is usually larger than the value of R_2. The total resistance of R_2 and R_3 should equal the resistance of R_1 in Fig. 31.

In practical circuit applications,

any combination of the arrangements shown in Figs. 30, 31, 32, and 33 may be used. However, the stability of Figs. 30, 31, and 33 may be poor unless the voltage drop across the load resistor R_L is at least one-third the value of the supply voltage. The determining factors in the selection of the biasing circuit are usually gain and bias stability (which is discussed later).

In many cases, the bias network may include special elements to compensate for the effects of variations in ambient temperature or in supply voltage. For example, the thermistor (temperature-sensitive resistor) shown in Fig. 34a is used to compensate for the rapid increase of collector current with increasing temperature. Because the thermistor resistance decreases as the temperature increases, the emitter-to-base bias voltage is reduced and the collector current tends to remain constant. The addition of the shunt and series resistances provides most effective compensation over a desired temperature range.

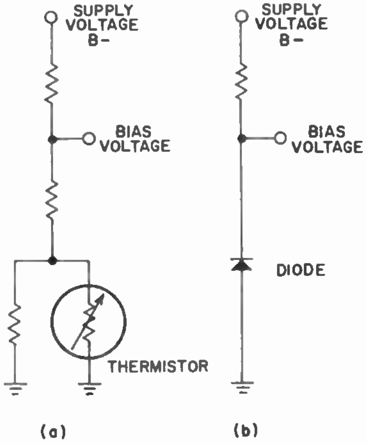


Figure 34. Bias networks including (a) a thermistor and (b) a temperature- and voltage-compensating diode.

The diode biasing network shown in Fig. 34b stabilizes collector current for variations in both temperature and supply voltage. The forward-biased diode current determines a bias voltage which establishes the transistor idling current (collector current under no-signal conditions). As the temperature increases, this bias voltage decreases. Because the transistor characteristic also shifts in the same direction and magnitude, however, the idling current remains essentially independent of temperature. Temperature stabilization with a properly designed diode network is substantially better than that provided by most thermistor bias networks. Any temperature-stabilizing element should be thermally close to the transistor being stabilized.

In addition, the diode bias current varies in direct proportion with changes in supply voltage. The resultant change in bias voltage is small, however, so that the idling current also changes in direct proportion to the supply voltage. Supply-voltage stabilization with a diode biasing network reduces current variation to about one-fifth that obtained when resistor or thermistor bias is used for a germanium transistor and one-fifteenth for a silicon transistor.

The bias networks of Figs. 29 through 33 are generally used in class A circuits. Class B circuits normally employ the bias networks shown in Fig. 34. The bias resistor values for class B circuits are generally much lower than those for class A circuits.

BIAS STABILITY

Because transistor currents tend to increase with temperature, it is necessary in the design of transistor circuits to include a "stability factor" to keep the collector-current variation within tolerable values under the expected high-temperature operating conditions. The bias stability factor SF is expressed as the ratio between a change in dc collector current and the corresponding change in dc collector-cutoff current.

For a given set of operating voltages, the stability factor can be calculated for a maximum permissible rise in dc collector current from the room-temperature value, as follows:

$$SF = \frac{I_{Cmax} - I_{C1}}{I_{CBO2} - I_{CBO1}}$$

where I_{C1} and I_{CBO1} are measured at 25 degrees centigrade, I_{CBO2} is measured at the maximum expected ambient (or junction) temperature, and I_{Cmax} is the maximum permissible collector current for the specified collector-to-emitter voltage at the maximum expected ambient (or junction) temperature (to keep transistor dissipation within ratings).

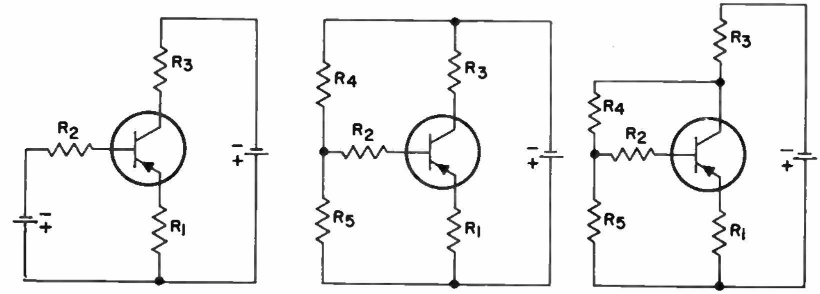
The calculated values of SF can then be used, together with the appropriate values of beta and $r_{b'}$ base-connection resistance), to determine suitable resistance values for the transistor circuit. Fig. 35 shows equations for SF in terms of resistance values for three typical circuit configurations. The maximum value which SF can assume is the value of beta. Although this analysis was originally made for germanium transistors, in which the collector saturation current I_{Co} is relatively large, the same type of analysis may be applied to interchangeability with beta for silicon transistors.

COUPLING

Three basic methods are used to couple transistor stages: transformer, resistance-capacitance, and direct coupling.

The major advantage of transformer coupling is that it permits power to be transferred from one impedance level to another. A transformer-coupled common-emitter n-p-n stage is shown in Fig. 36. The voltage step-down transformer T_1 couples the signal from the collector of the preceding stage to the base of the common-emitter stage. The voltage loss inherent in this transformer is not significant in transistor circuits because, as mentioned previously, the transistor is a current-operated device. Although the voltage is stepped down, the available current is stepped up. The change in base current resulting from the presence of the signal causes an ac collector current to flow in the primary winding of transformer T_2, and a power gain is obtained between T_1 and T_2.

This use of a voltage step-down



$$SF = \frac{\beta(R_1 + R_2')}{R_2' + \beta R_1}$$

$$R_2' = R_2 + r_b'$$

$$SF = \frac{\beta(R_1 + Req)}{Req + \beta R_1}$$

$$Req = R_2' + \frac{R_4 R_5}{R_4 + R_5}$$

$$R_2' = R_2 + r_b'$$

$$SF = \frac{\beta(P + Q)}{Q + \beta P}$$

$$Q = R_2'(R_3 + R_4 + R_5) + R_4 R_5$$

$$P = R_1 (R_3 + R_4 + R_5) + R_3 R_5$$

$$R_2' = R_2 + r_b'$$

Figure 35. Bias-stability-factor equations for three typical circuit configurations.

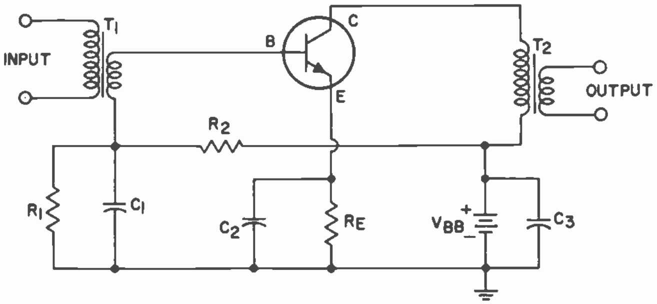


Figure 36. Transformer-coupled common-emitter stage.

transformer is similar to that in the output stage of an audio amplifier, where a step-down transformer is normally used to drive the loudspeaker, which is also a current-operated device.

The voltage-divider network consisting of resistors R_1 and R_2 in Fig. 36 provides bias for the transistor. The voltage divider is bypassed by capacitor C_1 to avoid signal attenuation. The stabilizing emitter resistor R_E permits normal variations of the transistor and circuit elements to be compensated for automatically without adverse effects. This resistor R_E is bypassed by capacitor C_2. The voltage supply V_{BB} is also bypassed, by capacitor C_3, to prevent feedback in the event that ac signal voltages are developed across the power supply. Capacitor C_1 and C_2 may normally be replaced by a single capacitor connected between the emitter and the bottom of the secondary winding of transformer T_1 with little change in performance.

The use of resistance-capacitance coupling usually permits some economy of circuit costs and reduction of size, with some accompanying sacrifice of gain. This method of coupling is particularly desirable in low-level, low-noise audio amplifier stages to minimize hum pickup from stray magnetic fields. Use of resistance-capacitance (RC) coupling in battery-operated equipment is usually limited to low-power operation. The frequency response of an RC-coupled stage is normally better than that of a transformer-coupled stage.

Fig. 37a shows a two-stage RC-coupled circuit using n-p-n transistors in the common-emitter configuration. The method of bias is similar to that used in the transformer-coupled circuit of Fig. 36. The major additional components are the collector load resistances R_{L1} and R_{L2} and the coupling capacitor C_c. The value of C_c must be made fairly large, in the order of 2 to 10 microfarads, because of the small input and load resistances involved. (It should be noted that electrolytic capacitors are normally used for coupling in transistor audio circuits. Polarity must be observed, therefore, to obtain proper circuit operation. Occasionally, excessive leakage current through an electrolytic coupling capacitor may adversely affect transistor operating currents.)

Impedance coupling is a modified form of resistance-capacitance coupling in which inductances are used to replace the load resistors. This type of coupling is rarely used except in special applications where supply voltages are low and cost is not a significant factor.

Direct coupling is used primarily when cost is an important factor. (It should be noted that direct-coupled amplifiers are not inherently dc amplifiers, i.e., that they cannot always amplify dc signals. Low-frequency response is usually limited by other factors than the coupling

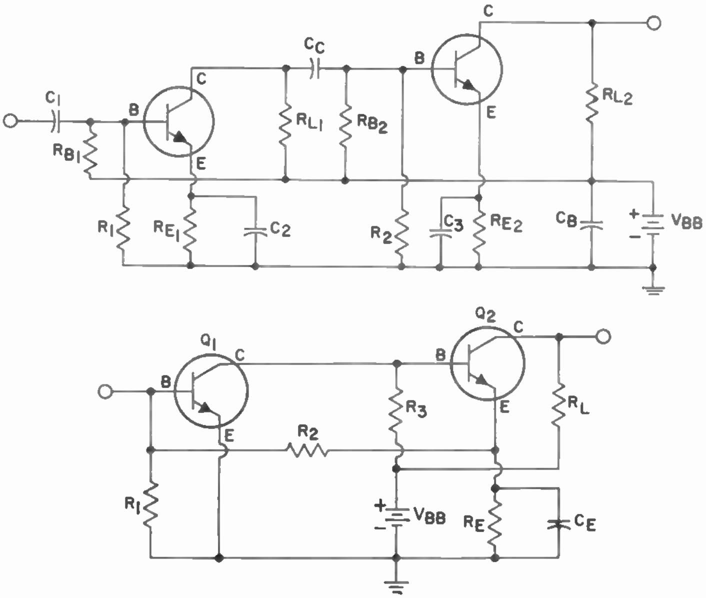


Figure 37. (a) Two-stage resistance-capacitance-coupled circuit and (b) two-stage direct-coupled circuit.

network.) In the direct-coupled amplifier shown in Fig. 37b, resistor R_3 serves as both the collector load resistor for the first stage and the bias resistor for the second stage. Resistors R_1 and R_2 provide circuit stability similar to that of Fig. 31 because the emitter voltage of transistor Q_2 and the collector voltage of transistor Q_1 are within a few tenths of a volt of each other.

Because so few circuit parts are required in the direct-coupled amplifier, maximum economy can be achieved. However, the number of stages which can be directly coupled is limited. Temperature variation of the bias current in one stage may be amplified by all the stages, and severe temperature instability may result.

DETECTION

The circuit of a radio, television, or communications receiver in which the modulation is separated from the carrier is called the demodulator or detector stage. Transmitted rf signals may be modulated in either of two ways. If the frequency of the carrier remains constant and its amplitude is varied, the carrier is called an amplitude-modulated (AM) signal. If the amplitude remains essentially constant and the frequency is varied, the carrier is called a frequency-modulated (FM) signal.

The effect of **amplitude modulation (AM)** on the waveform of an rf signal is shown in Fig. 38. The audio-

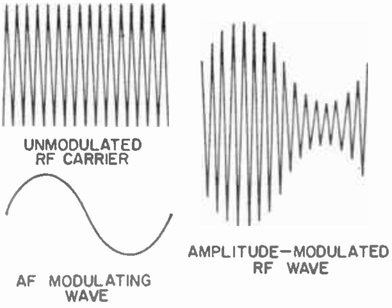


Figure 38. Waveforms showing effect of amplitude modulation on an rf wave.

frequency (af) modulation can be extracted from the amplitude-modulated carrier by means of a simple **diode detector** circuit such as that shown in Fig. 39. This circuit eliminates alternate half-cycles of the waveform, and detects the peaks of the remaining half-cycles to produce the output voltage shown in Fig. 40. In this figure, the rf voltage applied to the circuit is shown in light line; the output voltage across the capacitor C is shown in heavy line.

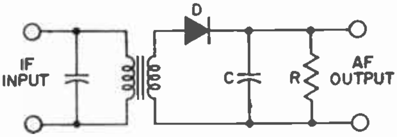


Figure 39. Basic diode detector circuit.

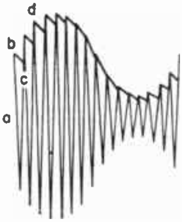


Figure 40. Waveform showing modulated rf input (light line) and output voltage (heavy line) of diode-detector circuit of Figure 39.

Between points (a) and (b) of Fig. 40, capacitor C charges up to the peak value of the rf voltage. Then, as the applied rf voltage falls away from its peak value, the capacitor holds the cathode of the diode at a potential more positive than the voltage applied to the anode. The capacitor thus temporarily cuts off current through the diode. While the diode current is cut off, the capacitor discharges from (b) to (c) through the diode load resistor R.

When the rf voltage on the anode rises high enough to exceed the potential at which the capacitor holds the cathode, current flows again and the capacitor charges up to the peak value of the second positive half-cycle at (d). In this way, the voltage across the capacitor follows the peak value of the applied rf voltage and reproduces the af modulating signal. The jaggedness of the curve in Fig. 40, which represents an rf component in the voltage across the capacitor, is exaggerated in the drawing. In an actual circuit, the rf component of the voltage across the capacitor is small. When the voltage across the capacitor is amplified, the output of the amplifier reproduces the speech or music that originated at the transmitting station.

Another way to describe the action of a diode detector is to consider the circuit as a half-wave rectifier. When the signal on the anode swings positive, the diode conducts and the rectified current flows. The dc voltage across the capacitor C varies in accordance with the rectified amplitude of the carrier and thus reproduces the af signal. Capacitor C should be large enough to smooth out rf or if variations, but should not be so large as to affect the audio variations. (Although two diodes can be connected in a circuit similar to a full-wave rectifier to produce full-wave detection, in practice the advantages of this connection generally do not justify the extra circuit cost and complication.)

In the circuit shown in Fig. 39, it is often desirable to forward-bias the diode almost to the point of conduction to improve performance for weak signal levels. It is also desirable that the resistance of the ac load which follows the detector be considerably larger than the diode load resistor to avoid severe distortion of the audio waveform at high modulation levels.

The effect of **frequency modulation** (FM) on the waveform of an rf signal is shown in Fig. 41. In this type of transmission, the frequency of the rf carrier deviates from the mean value at a rate proportional to the audio-frequency modulation and by an amount (determined in the transmitter) proportional to the ampli-

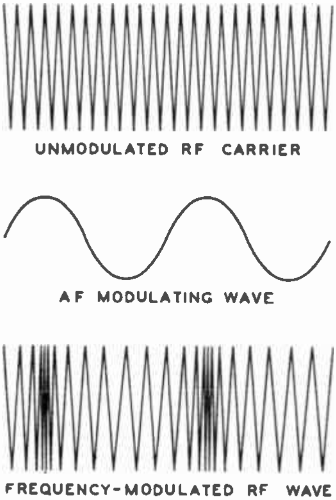


Figure 41. Waveforms showing effect of frequency modulation on an rf wave.

tude of the af modulating signal. That is, the number of times the carrier frequency deviates above and below the center frequency is a measure of the frequency of the modulating signal; the amount of frequency deviation from the center frequency is a measure of the loudness of the modulating signal. For this type of modulation, a detector is required to discriminate between deviations above and below the center frequency and to translate these deviations into a voltage having an amplitude that varies at audio frequencies.

The FM detector shown in Fig. 42 is called a **balanced phase-shift discriminator**. In this detector, the mutually coupled tuned circuits in the primary and secondary windings of the transformer T are tuned to the center frequency. A characteristic of a double-tuned transformer is that the voltages in the primary and secondary windings are 90 degrees out of phase at resonance, and that the phase shift changes as the frequency changes from resonance. Therefore, the signal applied to the diodes and the RC combinations for peak detection also changes with frequency.

Because the secondary winding of the transformer T is center-tapped, the applied primary voltage E_p is added to one-half the secondary voltage E_s through the capacitor C_1. The addition of these voltages at resonance can be represented by the diagram in Fig. 43; the resultant voltage E_1 is the signal applied to one peak-detector network consisting of one diode and its RC load. When the signal frequency decreases (from resonance), the phase shift of $E_s/2$ becomes greater than 90 degrees, as shown at (a) in Fig. 44, and E_1 becomes smaller. When the signal frequency increases (above resonance), the phase shift of $E_s/2$ is less than 90 degrees, as shown at (b), and E_1 becomes larger. The curve

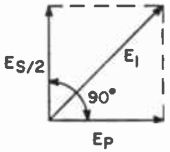


Figure 43. Diagram illustrating phase shift in double-tuned transformer at resonance.

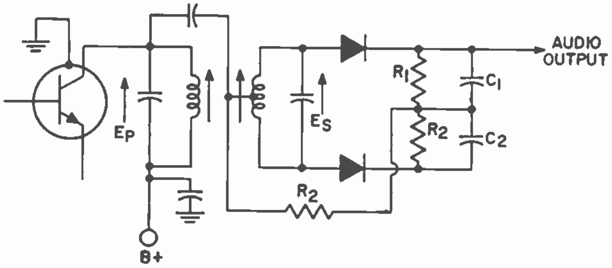


Figure 42. Balanced phase-shift discriminator circuit.

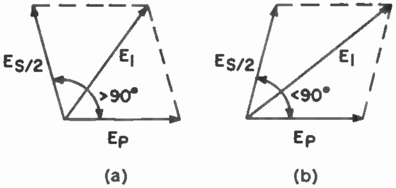


Figure 44. Diagrams illustrating phase shift in double-tuned transformer (a) below resonance and (b) above resonance.

of E_1 as a function of frequency in Fig. 45 is readily identified as the response curve of an FM detector.

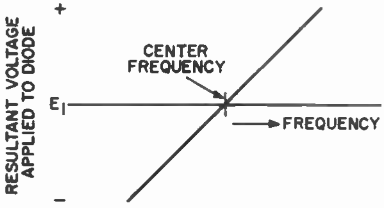


Figure 45. Diagram showing resultant voltage E_1 in Figure 43 as a function of frequency.

Because the discriminator circuit shown in Fig. 42 uses a push-pull configuration, the diodes conduct on alternate half-cycles of the signal frequency and produce a plus-and-minus output with respect to zero rather than with respect to E_1. The primary advantage of this arrangement is that there is no output at resonance. When an FM signal is applied to the input, the audio output voltage varies above and below zero as the instantaneous frequency varies above and below resonance. The frequency of this audio voltage is determined by the modulation frequency of the FM signal, and the amplitude of the voltage is proportional to the frequency excursion from resonance. (The resistor R_2 in the circuit provides a dc return for the diodes, and also maintains a load impedance across the primary winding of the transformer.)

One disadvantage of the balanced phase-shift discriminator shown in Fig. 42 is that it detects audio modulation (AM) as well as frequency modulation (FM) in the if signal because the circuit is balanced only at the center frequency. At frequencies off resonance, any variation in amplitude of the if signal is reproduced to some extent in the audio output.

The ratio-detector circuit shown in Fig. 46 is a discriminator circuit which has the advantage of being relatively insensitive to amplitude variations in the FM signal. In this circuit, E_p is added to $E_s/2$ through the mutual coupling M_2 (this voltage addition may be made by either mutual or capacitive coupling). Because of the phase-shift relationship of these voltages, the resultant detected signals vary with frequency variations in the same manner as described for the phase-shift discriminator circuit shown in Fig. 42. However, the diodes in the ratio detector are placed "back-to-back" (in series, rather than in push-pull) so

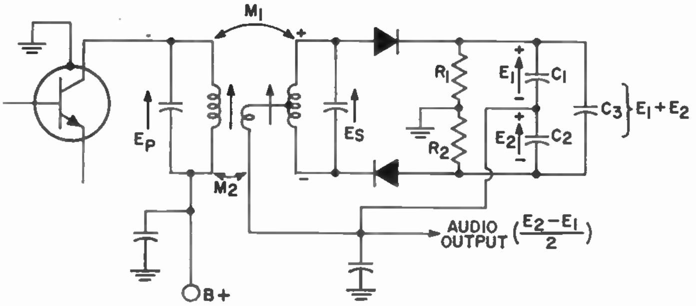


Figure 46. Ratio-detector circuit.

that both halves of the circuit operate simultaneously during one-half of the signal frequency cycle (and are cut off on the other half-cycle). As a result, the detected voltages E_1 and E_2 are in series, as shown for the instantaneous polarities that occur during the conduction half-cycle. When the audio output is taken between the equal capacitors C_1 and C_2, therefore, the output voltage is equal to $(E_2 - E_1)/2$ (for equal resistors R_1 and R_2).

The dc circuit of the ratio detector consists of a path through the secondary winding of the transformer, both diodes (which are in series), and resistors R_1 and R_2. The value of the electrolytic capacitor C_3 is selected so that the time constant of R_1, R_2, and C_3 is very long compared to the detected audio signal. As a result, the sum of the detected voltages $(E_1 + E_2)$ is a constant and the AM components on the signal frequency are suppressed. This feature of the ratio detector provides improved AM rejection as compared to the phase-shift discriminator circuit shown in Fig. 42.

AMPLIFICATION

The amplifying action of a transistor can be used in various ways in electronic circuits, depending on the results desired. The four recognized classes of amplifier service can be defined for transistor circuits as follows:

A class A **amplifier** is an amplifier in which the base bias and alternating signal are such that collector current in a transistor flows continuously during the complete electrical cycle of the signal, and even when no signal is present.

A class AB **amplifier** is an amplifier in which the base bias and alternating signal are such that collector current in a transistor flows for appreciably more than half but less than the entire electrical cycle.

A class B **amplifier** is an amplifier in which the base is biased to approximately collector-current cutoff, so that collector current is approximately zero when no signal is applied, and so that collector current in a transistor flows for approximately one-half of each cycle when an alternating signal is applied.

A class C **amplifier** is an amplifier in which the base is biased to such a degree that the collector current in a transistor is zero when no signal is applied, and so that collector current in a transistor flows for appreciably less than one-half of each cycle when an alternating signal is applied.

For radio-frequency (rf) amplifiers which operate into selective tuned circuits, or for other amplifiers in which distortion is not a prime factor, any of the above classes of amplification may be used with either a single transistor or a push-pull stage. For audio-frequency (af) amplifiers in which distortion is an important factor, single transistors can be used only in class A amplifiers. For class AB or class B audio-amplifier service, a balanced amplifier stage using two transistors is required. A push-pull stage can also be used in class A audio amplifiers to obtain reduced distortion and greater power output. Class C amplifiers cannot be used for audio or AM applications.

Audio Amplifiers

Audio amplifier circuits are used in radio and television receivers, public address systems, sound recorders and reproducers, and similar applications to amplify signals in the frequency range from 20 to 20,000 cycles per second. Each transistor in an audio amplifier can be considered as either a current amplifier or a power amplifier.

Simple class A amplifier circuits are normally used in low-level audio stages such as **preamplifiers** and drivers. Preamplifiers usually follow

low-level output transducers such as microphones, hearing-aid and phonograph pickup devices, and recorder-reproducer heads.

One of the important characteristics of a low-level amplifier circuit is its **signal-to-noise ratio,** or **noise figure.** The input circuit of an amplifier inherently contains some thermal noise contributed by the resistive elements in the input device. All resistors generate a predictable quantity of noise power as a result of thermal activity. This power is about 160 dB below one watt for a bandwidth of 10 kilocycles per second.

When an input signal is amplified, therefore, the thermal noise generated in the input circuit is also amplified. If the ratio of signal power to noise power (S/N) is the same in the output circuit as in the input circuit, the amplifier is considered to be "noiseless" and is said to have a noise figure of unity, or zero dB.

In practical circuits, however, the ratio of signal power to noise power is inevitably impaired during amplification as a result of the generation of additional noise in the circuit elements. A measure of the degree of impairment is called the noise figure (NF) of the amplifier, and is expressed as the ratio of signal power to noise power at the input (S_i/N_i) divided by the ratio of signal power to noise power at the output (S_o/N_o), as follows:

$$NF = \frac{S_i/N_i}{S_o/N_o}$$

The noise figure in dB is equal to ten times the logarithm of this power ratio. For example, an amplifier with a one-dB noise figure decreases the signal-to-noise ratio by a factor of 1.26, a 3-dB noise figure by a factor of 2, a 10-dB noise figure by a factor of 10, and a 20-dB noise figure by a factor of 100.

In audio amplifiers, it is desirable that the noise figure be kept low. In general, the lowest value of NF is obtained by use of an emitter current of less than one milliampere and a collector voltage of less than two volts for a signal-source resistance between 300 and 3000 ohms. If the input impedance of the transistor is matched to the impedance of the signal source, the lowest value of NF that can be attained is 3 dB. Generally, the best noise figure is obtained by use of a transistor input impedance approximately 1.5 times the source impedance. However, this condition is often not realizable in practice because many transducers are reactive rather than resistive. In addition, other requirements such as circuit gain, signal-handling capability, and reliability may not permit optimization for noise.

In the simple low-level amplifier stage shown in Fig. 47, resistor R_1 determines the base bias for the transistor. The output signal is developed across the load resistor R_2. The collector voltage and the emitter current are kept relatively low to reduce the noise figure. If the load impedance across the capacitor C_2 is low compared to R_2, very little voltage swing results on the collector. Therefore, ac feedback through R_1 does not cause much reducton of gain.

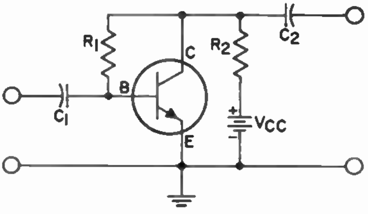


Figure 47. Simple low-level class A amplifier.

In many cases, low-level amplifier stages used as preamplifiers include some type of **frequency-compensation network** to enhance either the low-frequency or the high-frequency components of the input signal. The frequency range and dynamic range* which can be recorded on a phonograph record or on magnetic tape depend on several factors, including the composition, mechanical characteristics, and speed of the record or tape, and the electrical and mechanical characteristics of the recording equipment. To achieve wide frequency and dynamic range, manufacturers of commercial recordings use equipment which introduces a nonuniform relationship between amplitude and frequency. This relationship is known as a "recording characteristic". To assure proper reproduction of a high-fidelity recording, therefore, some part of the reproducing system must have a frequency-response characteristic which is the inverse of the recording characteristic. Most manufacturers of high-fidelity recordings use the RCA "New Orthophonic" (RIAA) characteristic for discs and the NARTB characteristic for magnetic tape.

The simplest type of equalization network is shown in Fig. 48. Because the capacitor C is effectively an open circuit at low frequencies, the low frequencies must be passed through the resistor R and are attenuated. The capacitor has a lower reactance at high frequencies, however, and bypasses high-frequency components around R so that they receive negligible attenuation. Thus the network effectively "boosts" the high frequencies. This type of equalization is called "attenuative".

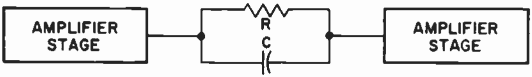


Figure 48. Simple RC frequency-compensation network.

Some typical preamplifier stages are shown in the Circuits section. The location of the frequency-compensation network or "equalizer" in the reproducing system depends on the types of recordings which are to be reproduced and on the pickup devices used. All commercial pickup devices provide very low power levels to a transistor preamplifier stage (transistors amplify current, not voltage).

A ceramic high-fidelity phonograph pickup is usually designed to provide proper compensation for the RIAA recording characteristic when the pickup is operated into the load resistance specified by its manufacturer. Usually, a "matching" resistor is inserted in series with the input of the preamplifier transistor. However, this arrangement produces a fairly small signal current which must then be amplified. If the matching resistor is not used, equalization is required, but some improvement can be obtained in dynamic range and gain.

A magnetic high-fidelity phonograph pickup, on the other hand, usually has an essentially flat frequency-response characteristic. Because a pickup of this type merely reproduces the recording characteristic, it must be followed by an equalizer network, as well as by a preamplifier having sufficient gain to satisfy the input requirements of the tone-control amplifier and/or power amplifier. Many designs include both the equalizing and amplifying circuits in a single unit.

A high-fidelity magnetic-tape pickup head, like a magnetic phonograph pickup, reproduces the recording characteristic. This type of pickup device, therefore, must also be followed by an equalizing network and preamplifier to provide equalization for the NARTB characteristic.

---

* The dynamic range of an amplifier is a measure of its signal-handling capability. The dynamic range expresses in dB the ratio of the maximum usable output signal (generally for a distortion of about 10 per cent) to the minimum usable output signal (generally for a signal-to-noise ratio of about 20 dB). A dynamic range of 40 dB is usually acceptable; a value of 70 dB is exceptional for any audio system.

Feedback networks may also be used for frequency compensation and for reduction of distortion. Basically, a feedback network returns a portion of the output signal to the input circuit of an amplifier. The feedback signal may be returned in phase with the input signal (positive or regenerative feedback) or 180 degrees out of phase with the input signal (negative, inverse, or degenerative feedback). In either case, the feedback can be made proportional to either the output voltage or the output current, and can be applied to either the input voltage or the input current. A negative feedback signal proportional to the output current raises the output impedance of the amplifier; negative feedback proportional to the output voltage reduces the output impedance. A negative feedback signal applied to the input current decreases the input impedance; negative feedback applied to the input voltage increases the input impedance. Opposite effects are produced by positive feedback.

A simple negative or inverse feedback network which provides high-frequency boost is shown in Fig. 49. This network provides equalization comparable to that obtained with Fig. 48, but is more suitable for low-level amplifier stages because it does not require the first amplifier stage to provide high-level low frequencies. In addition, the inverse feedback improves the distortion characteristics of the amplifier.

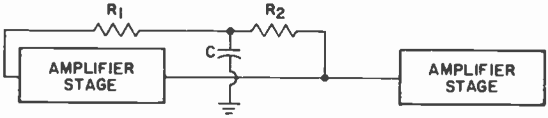


Figure 49. Negative-feedback frequency-compensation network.

As mentioned previously, it is undesirable to use a high-resistance signal source for a transistor audio amplifier because the extreme impedance mismatch results in high noise figure. High source resistance cannot be avoided, however, if an input device such as a ceramic pickup is used. In such cases, the use of negative feedback to raise the input impedance of the amplifier circuit (to avoid mismatch loss) is no solution because feedback cannot improve the signal-to-noise ratio of the amplifier. A more practical method is to increase the input impedance somewhat by operating the transistor at the lowest practical current level and by using a transistor which has a high forward current-transfer ratio.

Some preamplifier or low-level audio amplifier circuits include variable resistors or potentiometers which function as **volume** or **tone controls.** Such circuits should be designed to minimize the flow of dc currents through these controls so that little or no noise will be developed by the movable contact during the life of the circuit. Volume controls and their associated circuits should permit variation of gain from zero to maximum, and should attenuate all frequencies equally for all positions of the variable arm of the control. Several examples of volume controls and tone controls are shown in the Circuits section.

A tone control is a variable filter (or one in which at least one element is adjustable) by means of which the user may vary the frequency response of an amplifier to suit his own taste. In radio receivers and home amplifiers, the tone control usually consists of a resistance-capacitance network in which the resistance is the variable element.

The simplest form of tone control is a fixed tone-compensating or "equalizing" network such as that shown in Fig. 50. At high frequencies, the capacitor C_2 serves as a bypass for the resistor R_1, and the combined impedance of the resistor-capacitor network is reduced. Thus, the output of the network is greater at high frequencies than at low frequencies, and the frequency response is reasonably flat over a wide frequency range. The response curve can be "flattened" still more by use of a lower value for resistor R_1.

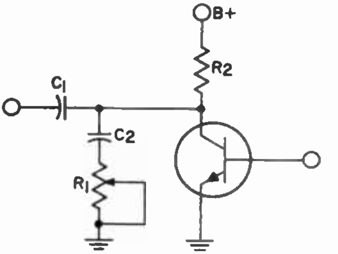


Figure 50. Simple tone-control network for fixed tone compensation or equalization.

The tone-control network shown in Fig. 51 has two stages with completely separate bass and treble controls. Fig. 52 shows simplified representations of the bass control when the potentiometer is turned to its extreme variations (labeled BOOST and CUT). At very high frequencies, C_1 and C_2 are effectively short circuits and the network becomes the simple voltage divider R_1 and R_2. In the bass-boost position, R_3 is inserted in series with R_2 so that there is less attenuation to very low frequencies than to very high frequencies. Therefore, the bass is said to be "boosted". In the bass-cut position, R_3 is inserted in series with R_1 so that there is more attenuation to very low frequencies.

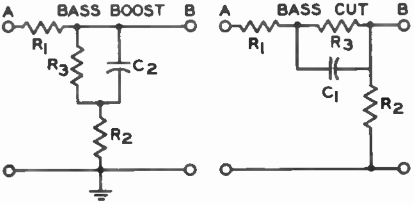


Figure 52. Simplified representations of bass-control circuit at extreme ends of potentiometer.

Fig. 53 shows extreme positions of the treble control. R_6 is generally much larger than R_4 or R_5 and may be treated as an open circuit in the extreme positions. In both the boost and cut positions, very low frequencies are controlled by the voltage divider R_4 and R_5. In the boost position, R_4 is bypassed by the high frequencies and the voltage-divider point D is placed closer to C. In the cut posi-

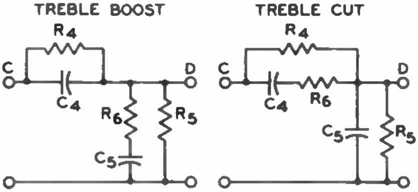


Figure 53. Simplified representations of treble-control circuit at extreme ends of potentiometer.

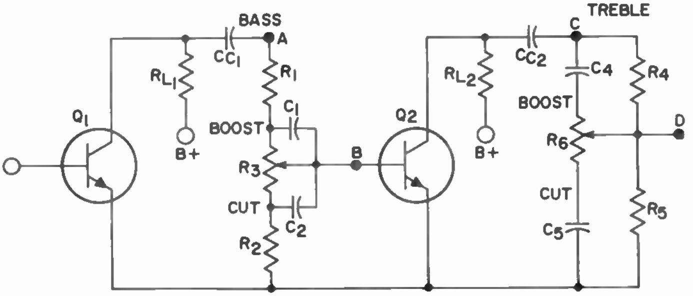


Figure 51. Two-stage tone-control circuit incorporating separate bass and treble controls.

tion, R_5 is bypassed and there is greater attenuation of the high frequencies.

The frequencies at which boost and cut occur in the circuit of Fig. 51 are controlled by the values of C_1, C_2, C_4, and C_5. Both the output impedance of the driving stage (generally R_{L1}) and the loading of the driven stage affect the response curves and must be considered. This tone-control circuit, like the one in Fig. 50, is attenuative. Feedback tone controls may also be employed.

The location of a tone-control network is of considerable importance. In a typical preamplifier, it may be in the collector circuit of the final low-level stage or in the input circuit of the first stage. If the amplifier incorporates negative feedback, the tone control must be inserted in a part of the amplifier which is external to the feedback loop, or must be made a part of the feedback network. The over-all gain of a well designed tone-control network should be approximately unity. The system dynamic range should be adequate for all frequencies anticipated with the tone controls in any position. The high-frequency gain should not be materially affected as the bass control is varied, nor should the low-frequency gain be sensitive to the treble control.

Driver stages in audio amplifiers are located immediately before the power-output stage. When a single-ended class A output stage is used, the driver stage is similar to a preamplifier stage. When a push-pull output stage is used, however, the audio driver must provide two output signals, each 180 degrees out of phase with the other. This phase requirement can be met by use of a tapped-secondary transformer between a single-ended driver stage and the output stage, as shown in Fig. 54. The transformer T_1 provides the required out-of-phase input signals for the two transistors Q_1 and Q_2 in the push-pull output stage.

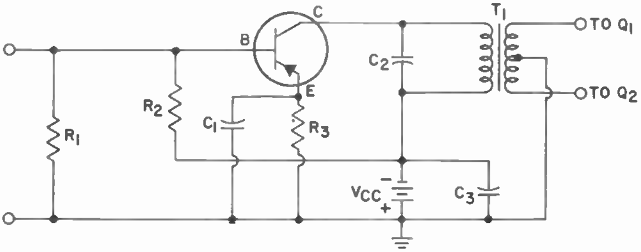


Figure 54. Driver stage for push-pull output circuit.

Transistor audio **power amplifiers** may be class A single-ended stages, or class A, class AB, or class B push-pull stages. A simple class A single-ended power amplifier is shown in Fig. 55. Component values which will provide the desired power output can be calculated from the transistor characteristics and the supply voltage. For example, an output of four watts may be desired from a circuit operating with a supply voltage of 14.5 volts (this voltage is normally available in automobiles which have a 12-volt ignition system). If losses are assumed to be negligible, the power output (PO) is equal to the peak collector volt-

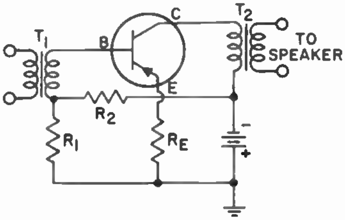


Figure 55. Class A power-amplifier circuit.

age (e_c) times the peak collector current (i_c), each divided by the square root of two to obtain rms values. The peak collector current can then be determined as follows:

$$PO = \frac{e_c}{\sqrt{2}} \times \frac{i_c}{\sqrt{2}}$$

$$i_c = PO(\sqrt{2}) \times \frac{\sqrt{2}}{e_c}$$

$$= 4\sqrt{2} \times \frac{\sqrt{2}}{14.5}$$

$$= 0.55, \text{ or approximately } 0.6 \text{ ampere.}$$

In class A service, the dc collector current and the peak collector swing are about the same. Thus, the collector voltage and current are 14.5 volts and 0.6 ampere, respectively.

The voltage drop across the resistor R_E in Fig. 55 usually ranges from 0.3 to 1 volt; a typical value of 0.6 volt can be assumed. The value of R_E must equal the 0.6-volt drop divided by the 0.6-ampere emitter current, or one ohm. (The emitter current is assumed to be nearly equal to the 0.6-ampere collector current.)

The current through resistor R_2 should be about 10 to 20 per cent of the collector current; a typical value is 15 per cent of 0.6, or 90 milliamperes.

The voltage from base to ground is equal to the base-to-emitter voltage (determined from the transistor transfer-characteristics curves for the desired collector or emitter current; normally about 0.4 volt for a germanium power transistor operating at an emitter current of 600 milliamperes) plus the emitter-to-ground voltage (0.6 volt as described above), or one volt. The voltage across R_2, therefore, is 14.5 minus 1, or 13.5 volts. The value of R_2 must equal 13.5 divided by 90, or about 150 ohms.

Because the voltage drop across the secondary winding of the driver transformer T_1 is negligible, the voltage drop across R_1 is one volt. The current through R_1 equals the current through R_2 (90 milliamperes) minus the base current. If the dc forward current-transfer ratio (beta) of the transistor selected has a typical value of 60, the base current equals the collector current of 600 milliamperes divided by 60, or 10 milliamperes. The current through R_1 is then 90 minus 10, or 80 milliamperes, and the value of R_1 is 1 divided by 80, or about 12 ohms.

The transformer requirements are determined from the ac voltages and currents in the circuit. The peak collector voltage swing that can be used before distortion occurs as a result of clipping of the output voltage is about 13 volts. The peak collector current swing available before current cutoff occurs is the dc current of 600 milliamperes. Therefore, the collector load impedance should be 13 volts divided by 600 milliamperes, or about 20 ohms, and the output transformer T_2 should be designed to match a 20-ohm primary impedance to the desired speaker impedance. If a 3.2-ohm speaker is used, for example, the impedance values for T_2 should be 20 ohms to 3.2 ohms.

The total input power to the circuit of Fig. 55 is equal to the voltage required across the secondary winding of the driver transformer T_1 times the current. The driver signal current is equal to the base current (10 milliamperes peak, or 7 milliamperes rms). The peak ac signal voltage is nearly equal to the sum of the base-to-emitter voltage across the transistor (0.4 volt as determined above), plus the voltage across R_E (0.6 volt), plus the peak ac signal voltage across R_1 (10 milliamperes times 12 ohms, or 0.12 volt). The input voltage, therefore, is about one volt peak, or 0.7 volt rms. Thus, the total ac input power required to produce an output of 4 watts is 0.7 volt times 7 milliamperes, or 5 milliwatts, and the input impedance is 0.7 volt divided by 7 milliamperes, or 100 ohms.

Higher power output can be achieved with less distortion in class A service by the use of a **push-pull** circuit arrangement. One of the disadvantages of a transistor class A amplifier (single-ended or push-pull), however, is that collector current flows at all times. As a result, transistor dissipation is highest when no ac signal is present. This dissipation can be greatly reduced by use of class B push-pull operation. When two transistors are connected in class B push-pull, one transistor amplifies half of the signal, and the other transistor amplifies the other half. These half-signals are then combined in the output circuit to restore the original waveform in an amplified state.

Ideally, transistors used in class B service should be biased to collector cutoff so that no power is dissipated under zero-signal conditions. At low signal inputs, however, the resulting signal would be distorted, as shown in Fig. 56, because of the low forward current-transfer ratio of the transistor at very low currents. This type of distortion, called **cross-over distortion**, can be suppressed by the use of a bias voltage which permits a small collector current flow at zero signal level. Any residual distortion can be further reduced by the use of negative feedback.

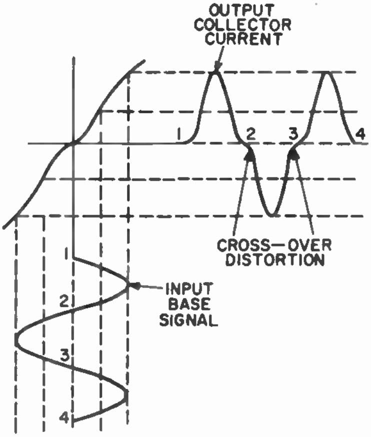


Figure 56. Waveforms showing cause of cross-over distortion.

A typical class B push-pull audio amplifier is shown in Fig. 57. Resistors R_{E1} and R_{E2} are the emitter stabilizing resistors. Resistors R_1 and R_2 form a voltage-divider network which provides the bias for the transistors. The base-emitter circuit is biased near collector cutoff so that very little collector power is dissipated under no-signal conditions. The characteristics of the bias network must be very carefully chosen so that the bias voltage will be just sufficient to minimize cross-over distortion at low signal levels. Because

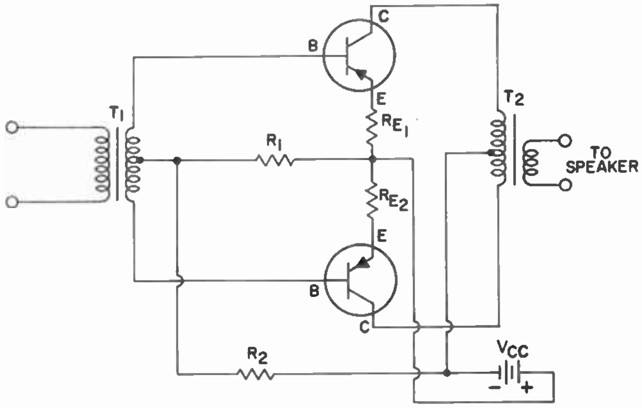


Figure 57. Class B push-pull audio-amplifier circuit.

the collector current, collector dissipation, and dc operating point of a transistor vary with ambient temperature, a temperature-sensitive resistor (such as a thermistor) or a bias-compensating diode may be used in the biasing network to minimize the effect of temperature variations.

The advantages of class B operation can be obtained without the need for an output transformer by use of a single-ended class B circuit such as that shown in Fig. 58. In this circuit, the secondary windings of the driver transformer T_1 are phased so that a negative signal from base to emitter of one transistor is accompanied by a positive signal from base to emitter of the other transistor. When a negative signal is applied to the base of transistor Q_1, for example, Q_1 draws current. This current must flow through the load because the accompanying positive signal on the base of transistor Q_2 cuts Q_2 off. When the signal polarity reverses, transistor Q_1 is cut off, while Q_2 conducts current. The resistive dividers R_1R_2 and R_3R_4 provide a dc bias which keeps the transistors slightly above cutoff under no-signal conditions and thus minimizes cross-over distortion. The emitter resistors R_{E1} and R_{E2} help to compensate for differences between transistors and for the effects of ambient-temperature variations.

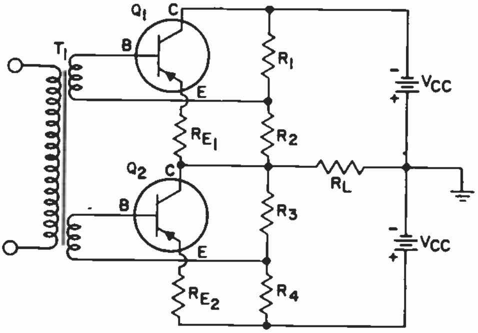


Figure 58. Single-ended class B circuit.

The secondary windings of any class B driver transformer should be bifilar-wound (i.e., wound together) to obtain tighter coupling and thereby minimize leakage inductance. Otherwise, "ringing" may occur in the cross-over region as a result of the energy stored in the leakage inductance.

Because junction transistors can be made in both p-n-p and n-p-n types, they can be used in **complementary-symmetry** circuits to obtain all the advantages of conventional push-pull amplifiers plus direct coupling. The arrows in Fig. 59 indicate the direction of electron current flow in the terminal leads of p-n-p and n-p-n transistors. When these two transistors are connected in a single stage, as shown in Fig. 60, the dc electron current path in the output circuit is completed through the collector-emitter circuits of the transistors. In the circuits of Figs. 58 and 60, essentially no dc current flows through the load resistor R_L.

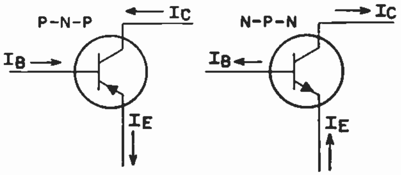


Figure 59. Electron-current flow in p-n-p and n-p-n transistors.

Therefore, the voice coil of a loudspeaker can be connected directly in place of R_L without excessive speaker cone distortion.

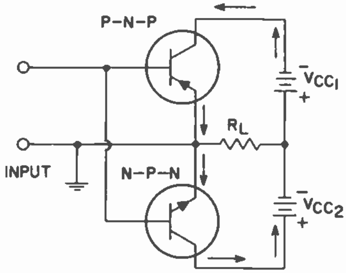


Figure 60. Basic complementary-symmetry circuit.

Several high-fidelity amplifiers are shown in the Circuits section. The performance capabilities of such amplifiers are usually given in terms of frequency response, total harmonic distortion, maximum power output, and noise level. To provide high-fidelity reproduction of audio program material, an amplifier should have a frequency response which does not vary more than 1 dB over the entire audio spectrum. General practice is to design the amplifier so that its frequency response is flat within 1 dB from a frequency well below the lowest to be reproduced to one well above the upper limit of the audible region.

Harmonic distortion and intermodulation distortion produce changes in program material which may have adverse effects on the quality of the reproduced sound. Harmonic distortion causes a change in the character of an individual tone by the introduction of harmonics which were not originally present in the program material. For high-fidelity reproduction, total harmonic distortion (expressed as a percentage of the output power) should not be greater than about 0.5 per cent at the desired listening level.

Intermodulation distortion is a change in the waveform of an individual tone as a result of interaction with another tone present at the same time in the program material. This type of distortion not only alters the character of the modulated tone, but may also result in the generation of spurious signals at frequencies equal to the sum and difference of the interacting frequencies. Intermodulation distortion should be less than 2 per cent at the desired listening level. In general, any amplifier which has low intermodulation distortion will have very low harmonic distortion.

The maximum power output which a high-fidelity amplifier should deliver depends upon a complex relation of several factors, including the size and acoustical characteristics of the listening area, the desired listening level, and the efficiency of the loudspeaker system. Practically, however, it is possible to determine amplifier requirements in terms of room size and loudspeaker efficiency.

The acoustic power required to reproduce the loudest passages of orchestral music at concert-hall level in the average-size living room is about 0.4 watt. Because high-fidelity loudspeakers of the type generally available for home use have an efficiency of only about 5 per cent, the output stage of the amplifier should therefore be able to deliver a power output of at least 8 watts. Because many wide-range loudspeaker systems, particularly those using crossover networks, have efficiencies of less than 5 per cent, output stages used with such systems must have correspondingly larger power outputs.

The noise level of a high-fidelity amplifier determines the range of volume the amplifier is able to reproduce, i.e., the difference (usually expressed in dB) between the loudest and softest sounds in program material. Because the greatest volume range utilized in electrical program material at the present time is about 60 dB, the noise level of a high-fidelity amplifier should be at least 60 dB below the signal level at the desired listening level.

The design of audio equipment for

direct operation from the ac power line normally requires the use of either a power transformer or a large voltage-dropping resistor to reduce the 120-volt ac line voltage to a level that is appropriate for transistors. Both of these techniques have disadvantages. The use of a transformer adds cost to the system. The use of a dropping resistor places restrictions on the final packaging of the instrument because the resistor must dissipate power. In addition, low-voltage supplies are usually more expensive to filter than high-voltage supplies.

The use of high-voltage silicon transistors eliminates the need for either a power transformer or a high-power voltage-dropping resistor, and permits the use of economical circuits and components in **line-operated audio equipment**. Several ac/dc circuits using these high-voltage transistors are shown in the Circuits section. The basic class A audio output stage shown in Fig. 61 is essentially of the same design as the class A amplifier discussed previously. Because the supply voltage is much higher, however, the currents are about one-tenth as high and the impedances about 100 times as high.

The use of a voltage-dependent resistor (VDR) as a damping resistor across the primary winding of the output transformer in Fig. 61 protects the output circuit against the destructive effects of transient voltages that can occur under abnormal conditions. If the VDR were not used, the peak collector voltage under transient conditions could be as high as five to ten times the supply voltage, or far in excess of the breakdown-voltage rating for the transistor. Because the resistance of the VDR varies directly with voltage, its use limits the transient voltage to safe levels but does not degrade overall circuit performance.

Fig. 62 shows another effective method for protection against transient voltages. In this arrangement, the output transformer is replaced by a center-tapped transformer and a silicon rectifier that has a peak-reverse-voltage rating of 300 to 400 volts. The peak voltage across the output is thus limited to a value which does not exceed twice the magnitude of the supply voltage. As the collector voltage approaches a value equal to twice the supply voltage, the voltage at the diode end of the transformer becomes sufficiently negative to forward-bias the diode and thus

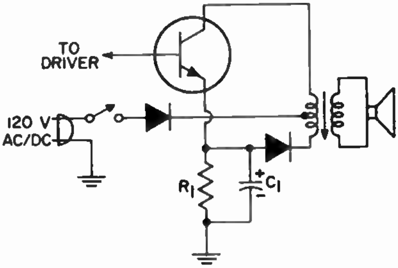


Figure 62. Alternate method for protection against transient voltages.

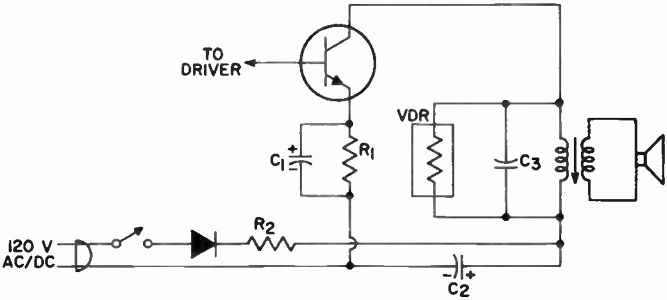


Figure 61. Basic audio output stage for line-operated equipment.

clamp the collector voltage. The required transformer primary impedance is generally about 10,000 ohms center-tapped; in addition, it is recommended that a bifilar winding be used to minimize leakage inductance. Because the arrangement shown in Fig. 62 provides more reliable protection against transients than that of Fig. 61, a higher supply voltage and a higher transformer impedance can be used.

It should be noted that special precautions are required in the construction of circuits for line-voltage operation. Because these circuits operate at high ac and dc voltages, special care must be exercised to assure that no metallic part of the chassis or output transformer is exposed to touch, accidental or otherwise. The circuits should be installed in non-metallic cabinets, or should be properly insulated from metallic cabinets. Insulated knobs should be used for potentiometer shafts and switches.

A **phase inverter** is a type of class A amplifier used when two out-of-phase outputs are required. In the split-load phase-inverter stage shown in Fig. 63, the output current of transistor Q_1 flows through both the collector load resistor R_4 and the emitter load resistor R_3. When the input signal is negative, the increased output current causes the collector side of resistor R_4 to become more positive and the emitter side of resistor R_3 to become more negative with respect to ground. When the input signal is positive, the output current decreases and opposite voltage polarities are established across resistors R_3 and R_4. Thus, two output signals are produced which are 180 degrees out of phase with each other. This circuit provides the 180-degree phase relationship only when each load is resistive and constant throughout the entire signal swing. It is not suitable as a driver stage for a class B output stage.

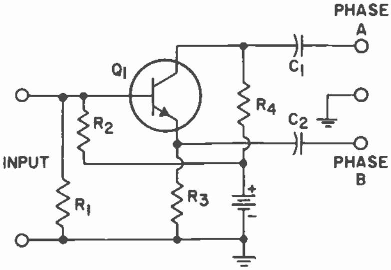


Figure 63. Split-load phase inverter stage.

Direct-Current Amplifiers

Direct-current amplifiers are normally used in transistor circuits to amplify small dc or very-low-frequency ac signals. Typical applications of such amplifiers include the output stages of series-type and shunt-type regulating circuits, chopper-type circuits, differential amplifiers, and pulse amplifiers.

In **series regulator circuits** such as that shown in Fig. 64, direct-coupled amplifiers are used to amplify an error or difference signal obtained from a comparison between a portion of the output voltage and a reference source. The reference-voltage source V_R is placed in the emitter circuit of the amplifier transistor Q_1 so that the error or differ-

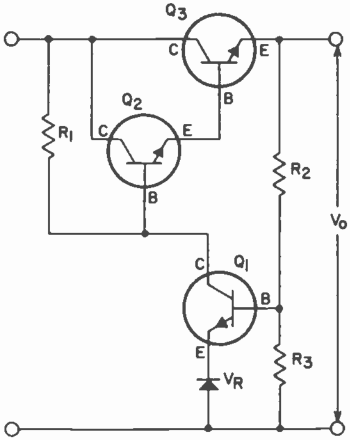


Figure 64. Typical series regulator circuit.

ence signal between V_R and some portion of the output voltage V_O is developed and amplified. The amplified error signal forms the input to the regulating element consisting of transistors Q_2 and Q_3, and the output from the regulating element develops a controlling voltage across the resistor R_1.

Shunt regulator circuits are not as efficient as series regulator circuits for most applications, but they have the advantage of greater simplicity. In the shunt voltage regulator circuit shown in Fig. 65, the current through the shunt element consisting of transistors Q_1 and Q_2 varies with changes in the load current or the input voltage. This current variation is reflected across the resistance R_1 in series with the load so that the output voltage V_O is maintained nearly constant.

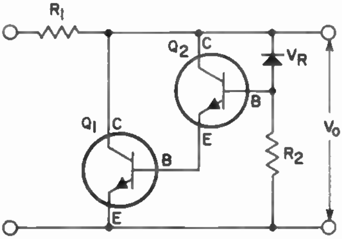


Figure 65. Typical shunt regulator circuit.

Direct-coupled amplifiers are also used in **chopper-type** circuits to amplify low-level dc signals, as illustrated by the block diagram in Fig. 66. The dc signal modulates an ac carrier wave, usually a square wave, and the modulated wave is then amplified to a convenient level. The series of amplified pulses can then be detected and integrated into the desired dc output signal.

Differential amplifiers can be used to provide voltage regulation, as described above, or to compensate for fluctuations in current due to signal, component, or temperature variations. Typical differential amplifier elements such as those shown in Fig. 67 include an output stage which supplies current to the load resistor R, and the necessary number of direct-coupled cascaded stages

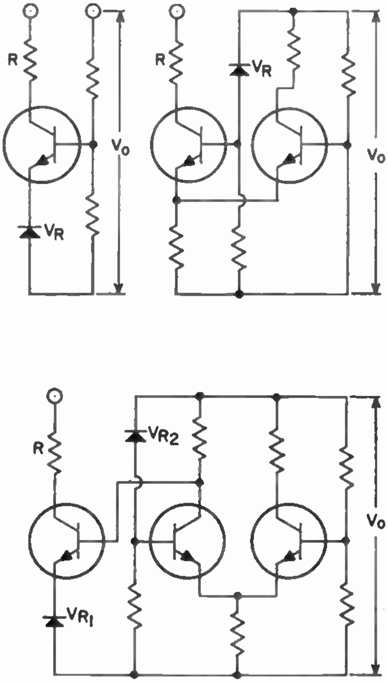


Figure 67. Typical differential amplifier circuits.

to provide the required amount of gain for a given condition of line-voltage or load-current regulation. The reference-voltage source V_R is

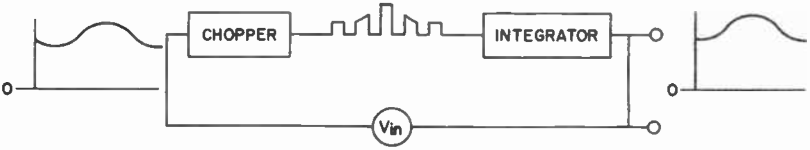


Figure 66. Block diagram showing action of "chopper" circuit.

placed in one of the cascaded stages in such a manner that an error or difference signal between V_R and some portion of the output voltage V_O is developed and amplified. Some form of temperature compensation is usually included to insure stability of the direct-coupled amplifier.

Tuned Amplifiers

In transistor radio-frequency (rf) and intermediate-frequency (if) amplifiers, the bandwidth of frequencies to be amplified is usually only a small percentage of the center frequency. Tuned amplifiers are used in these applications to select the desired bandwidth of frequencies and to suppress unwanted frequencies. The selectivity of the amplifier is obtained by means of tuned interstage coupling networks.

The properties of tuned amplifiers depend upon the characteristics of **resonant circuits.** A simple parallel resonant circuit (sometimes called a "tank" because it stores energy) is shown in Fig. 68. For practical purposes, the resonant frequency of such a circuit may be considered independent of the resistance R, provided R is small compared to the inductive reactance X_L. The resonant frequency f_r is then given by

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

For any given resonant frequency, the product of L and C is a constant; at low frequencies LC is large; at high frequencies it is small.

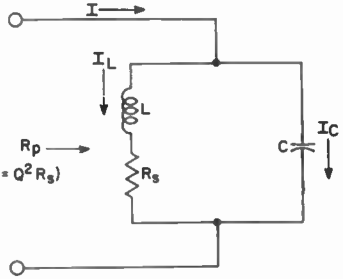


Figure 68. Simple parallel resonant circuit.

The Q (selectivity) of a parallel resonant circuit alone is the ratio of the current in the tank (I_L or I_C) to the current in the line (I). This unloaded Q, or Q_o, may be expressed in various ways, for example:

$$Q_L = \frac{I_C}{I} = \frac{X_L}{R} = \frac{R_p}{X_C}$$

where X_L is the inductive reactance ($= 2\pi fL$), X_c is the capacitive reactance ($= 1/[2\pi fC]$), and R_p is the total impedance of the parallel resonant circuit (tank) at resonance. The Q varies inversely with the resistance of the inductor. The lower the resistance, the higher the Q and the greater the difference between the tank impedance at frequencies off resonance compared to the tank impedance at the resonant frequency.

The Q of a tuned interstage coupling network also depends upon the impedances of the preceding and following stages. The output impedance of a transistor can be considered as consisting of a resistance R_o in parallel with a capacitance C_o, as shown in Fig. 69. Similarly, the input impedance can be considered as consisting of a resistance R_i in parallel with a capacitance C_i. Because the

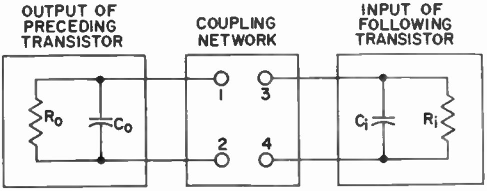


Figure 69. Equivalent output and input circuits of transistors connected by a coupling network.

tuned circuit is shunted by both the output impedance of the preceding transistor and the input impedance of the following transistor, the effective selectivity of the circuit is the loaded Q (or Q_L) based upon the total impedance of the coupled network, as follows:

$$Q_L = \frac{\left\{\begin{matrix}\text{total loading on}\\ \text{coil at resonance}\end{matrix}\right\}}{X_L \text{ or } X_C}$$

The capacitances C_o and C_i in Fig. 69 are usually considered as part of the coupling network. For example, if the required capacitance between terminals 1 and 2 of the coupling network is calculated to be 500 picofarads and the value of C_o is 10 picofarads, a capacitor of 490 picofarads is used between terminals 1 and 2 so that the total capacitance is 500 picofarads. The same method is used to allow for the capacitance C_i at terminals 3 and 4.

When a tuned resonant circuit in the primary winding of a transformer is coupled to the nonresonant secondary winding of the transformer, as shown in Fig. 70a, the effect of the input impedance of the following stage on the Q of the tuned circuit can be determined by considering the values reflected (or referred) to the primary circuit by transformer action. The reflected resistance r_i is equal to the resistance R_i in the secondary circuit times the square of the effective turns ratio between the primary and secondary windings of the transformer T:

$$r_i = R_i\,(N_1/N_2)^2$$

where N_1/N_2 represents the electrical turns ratio between the primary winding and the secondary winding of T. If there is capacitance in the secondary circuit (C_s), it is reflected to the primary circuit as a capacitance C_{sp}, and is given by

$$C_{sp} = C_p \div (N_1/N_2)^2$$

The loaded Q, or Q_L, is then calculated on the basis of the inductance L_p, the total shunt resistance (R_o pedance $Z_t = Q_oX_c = Q_oX_L$), and plus r_i plus the tuned-circuit im- the total capacitance ($C_p + C_{sp}$) in the tuned circuit.

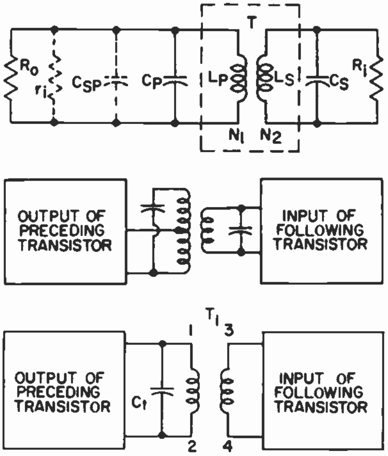


Figure 70. Equivalent circuits for transformer-coupling networks: (a) having tuned primary winding; (b) using inductive coupling; (c) using tap on primary winding.

Fig. 70b shows a coupling network which consists of a single-tuned circuit using mutual inductive coupling. The capacitance C_t includes the effects of both the output capacitance of the preceding transistor and the input capacitance of the following transistor (referred to the primary of transformer T_1). The bandwidth of a single-tuned transformer is determined by the half-power points on the resonance curve (—3 dB or 0.707 down from the maximum). Under these conditions, the band pass Δf is equal to the ratio of the center or resonant frequency f_r divided by the loaded (effective) Q of the circuit, as follows:

$$\Delta f = f_r/Q_L$$

The inherent internal feedback in transistors can cause instability and oscillation as the gain of an amplifier stage is increased (i.e., as the load and source impedances are increased from zero to matched conditions). At low radio frequencies, therefore, where the potential gain of transistors is high, it is often desirable to keep the transistor load impedance low. Relatively high capacitance values in the tuned collector circuit can then be avoided by use of a tap on the primary winding of the coupling transformer, as shown in Fig. 70c. At higher frequencies, the gain potential of the transistor decreases, and impedance matching is permissible. However, lead inductance becomes significant at higher frequencies, particularly in the emitter circuit. All lead lengths should be kept short, therefore, and especially the emitter lead, which not only degrades performance but is also a mutual coupling to the output circuit.

External feedback circuits are often used in tuned coupling networks to counteract the effects of the internal transistor feedback and thus provide more gain or more stable performance. If the external feedback circuit cancels the effects of both the resistive and the reactive internal feedback, the amplifier is considered to be **unilateralized.** If the external circuit cancels the effect of only the reactive internal feedback, the amplifier is considered to be **neutralized.**

In the design of low-level tuned rf amplifiers, careful consideration must be given to the transistor and circuit parameters which control circuit stability, as well as those which maintain adequate power gain. In addition, if the signals to be amplified are relatively weak, it is important that the transistor and its associated circuit provide low noise figure at the operating frequency.

The relative power-gain capabilities of transistors at high frequencies are indicated by their theoretical maximum frequency of oscillation f_{max}. At this frequency, the unilateralized matched power gain, or **maximum available gain MAG,** is zero dB. As shown in Fig. 71, the curve of MAG as a function of frequency for a typical rf transistor rises approximately 6 dB per octave above f_{max}.

Because most practical rf amplifiers are not individually unilateralized, the power gain that can be obtained is somewhat less than the MAG because of internal feedback in the circuit. This feedback is greater in unneutralized circuits than in neutralized circuits, and therefore gain is lower when neutralization is not used. From a practical consideration, the feedback capacitance which must be considered is the total feedback capacitance between collector and base, including both stray and socket capacitances. In neutralized circuits, stray capacitances, socket capacitance, and the typical value of device capacitance can generally be neutralized. At a given frequency, therefore, the **maximum usable power gain MUG** of a neutralized circuit depends on the transconductance g_m and the amount of internal feed-

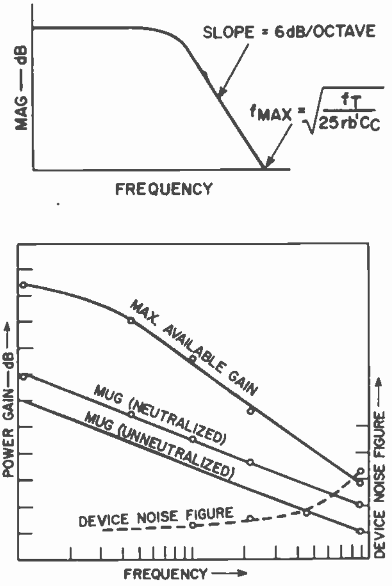


Figure 71. Maximum available gain MAG, maximum usable gain MUG, and noise figure NF as functions of frequency.

back capacitance C_f. In unneutralized circuits, however, both socket and stray capacitances are involved in the determination of gain and must be included in the value of C_f. The ratio of g_m to C_f should be high to provide high power gain. Fig. 71 shows typical curves of MAG and MUG (for both the neutralized and the unneutralized case) for a low-level rf transistor used in a common-emitter circuit.

The transistor requirements for high power gain and low noise figure are essentially the same. Published data for transistors intended for low-level rf applications generally indicate a minimum power gain and a maximum noise figure in a circuit typical of the intended use. A curve of noise figure NF as a function of frequency is also shown in Fig. 71. Circuit design factors for lowest noise figure include use of a low-noise transistor, choice of optimum bias current and source resistance, and use of low-loss input circuits. Optimum low-noise bias current for most low-level rf transistors is about 1 milliampere, or slightly higher in the uhf range. Optimum source resistance is a function of operating frequency and bias current for a given transistor.

The input circuit to the first stage of the amplifier should have as little loss as possible because such loss adds directly to the otherwise attainable noise figure. In other words, if the loss at the input to the first stage is 2 dB, the amplifier noise figure will be 2 dB higher than could be achieved with no loss at the input. To minimize such loss, it is generally desirable that the ratio of unloaded Q (Q_o) to loaded Q (Q_L) of the input circuit be high and that the bias resistors be isolated from the input by chokes or tuned circuits.

A typical tuned amplifier using neutralization is shown in Fig. 72. The input signal to the transistor is an if carrier (e.g., 455 kilocycles) amplitude-modulated by an audio signal. Capacitor C_1 and the primary winding of transformer T_1 form a parallel-tuned circuit resonant at 455 kilocycles. Transformer T_1 couples the signal power from the previous stage to the base of the transistor. Resistors R_1 and R_3 provide forward bias to the transistor. Capacitor C_3 provides a low-impedance path for the 455-kilocycle signal from the input tuned circuit to the emitter. Resistor R_2, which is bypassed for 455 kilocycles by capacitor C_4, is the emitter dc stabilizing resis-

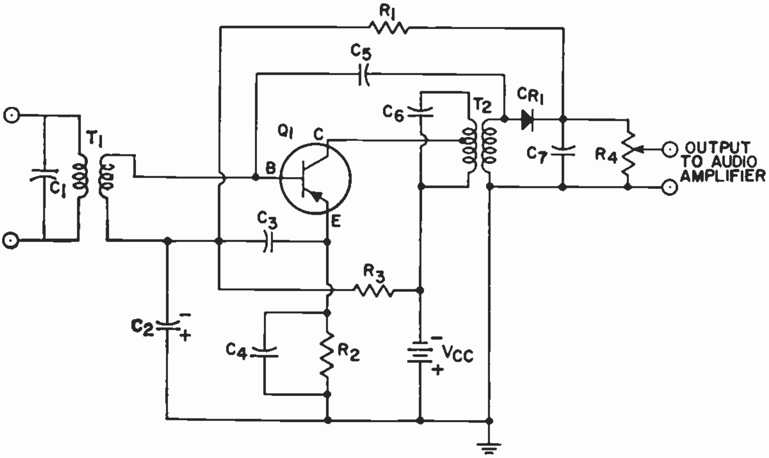


Figure 72. Neutralized if-amplifier and second-detector circuit.

tor. The amplified signal from the transistor is developed across the parallel resonant circuit (tuned to 455 kilocycles) formed by capacitor C_6 and the primary winding of transformer T_2, and is coupled by T_2 to the crystal-diode second detector CR.

Because of the phase reversal inherent in the common-emitter configuration, reactive feedback in the transistor due to the internal capacitance between the collector and the base is 180 degrees out of phase with the input. In the external feedback loop, therefore, current at the intermediate frequency is taken from the secondary winding of the single-tuned output transformer and applied to the base of the transistor through the feedback (neutralizing) capacitor C_5. Because this current is 180 degrees out of phase with the collector current, it cancels the reactive feedback in the transistor and thus improves the gain of the circuit.

The rectified output of the crystal diode CR_1 is filtered by capacitor C_7 and resistor R_4 so that the voltage across capacitor C_7 consists of an audio signal and a dc voltage (positive with respect to ground for the arrangement shown in Fig. 72) that is directly proportional to the amplitude of the if carrier. This dc voltage is fed back to the base of the transistor through the resistor R_1 to provide automatic gain control. Resistor R_1 and capacitor C_2 form an audio decoupling network to prevent audio feedback to the base of the transistor.

In high-frequency tuned amplifiers, where the input impedance is typically low, mutual inductive coupling may be impracticable because of the small number of turns in the secondary winding. It is extremely difficult in practice to construct a fractional part of a turn. In such cases, capacitance coupling may be used, as shown in Fig. 73. This arrangement, which is also called **capacitive division**, is similar to tapping down on a coil at or near resonance. Impedance transformation in this network is determined by the ratio between capacitors C_1 and C_2. Capacitor C_1 is normally much smaller than C_2; thus the capacitive reactance X_{C1} is normally much larger than X_{C2}. Provided the input resistance of the following transistor is much greater than X_{C2}, the effective turns ratio from the top of the coil to the input of the following transistor is $(C_1 + C_2)/C_1$. The total capacitance C_t across the inductance L is given by .

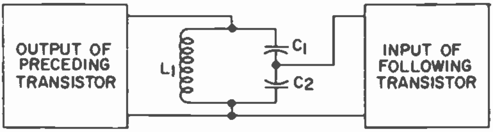


Figure 73. Single-tuned coupling network using capacitive division.

$$C_t = \frac{C_1C_2}{C_1 + C_2}$$

The resonant frequency f_r is then given by

$$f_r = \frac{1}{2\pi\sqrt{L_1C_t}}$$

Double-tuned interstage coupling networks are often used in preference to single-tuned networks to provide flatter frequency response within the pass band, a sharper drop in response immediately adjacent to the ends of the pass band, or more attenuation at frequencies far removed from resonance. In synchronous double-tuned networks, both the resonant circuit in the input of the coupling network and the resonant circuit in the output are tuned to the same resonant frequency. In "stagger-tuned" networks, the two resonant circuits are tuned to slightly different resonant frequencies to provide a more rectangular band pass with sharper selectivity at the ends of the pass band. Double-tuned or stagger-tuned networks may use capacitive, inductive, or mutual inductance coupling, or any combination of the three.

Automatic gain control (agc) is often used in rf and if amplifiers in AM radio and television receivers to provide lower gain for strong signals and higher gain for weak signals. (In radio receivers, this gain-compensation network may also be called **automatic volume control** or avc.) When the signal strength at the antenna changes, the agc circuit modifies the receiver gain so that the output of the last if-amplifier stage remains nearly constant and consequently maintains a nearly constant speaker volume or picture contrast.

The agc circuit usually reduces the rf and if gain for a strong signal by varying the bias on the rf-amplifier and if-amplifier stages when the signal increases. A simple reverse agc circuit is shown in Fig. 74. On each positive half-cycle of the signal voltage, when the diode anode is positive with respect to the cathode, the diode passes current. Because of the flow of diode current through R_1, there is a voltage drop across R_1 which makes the upper end of the resistor negative with respect to ground. This voltage drop across R_1 is applied, through the filter R_2 and C, as reverse bias on the preceding stages. When the signal strength at the antenna increases, therefore, the signal applied to the agc diode increases, the voltage drop across R_1 increases, the reverse bias applied to the rf and if stages increases, and the gain of the rf and if stages is decreased. As a result, the increase in signal strength at the antenna does not produce as much increase in the output of the last if-amplifier stage as it would without agc.

When the signal strength at the antenna decreases from a previous steady value, the agc circuit acts in the opposite direction, applying less reverse bias and thus permitting the rf and if gain to increase.

The filter C and R_2 prevents the agc voltage from varying at audio frequency. This filter is necessary because the voltage drop across R_1 varies with the modulation of the carrier being received. If agc voltage were taken directly from R_1 without filtering, the audio variations in agc voltage would vary the receiver gain so as to smooth out the modulation of the carrier. To avoid this effect, the agc voltage is taken from the capacitor C. Because of the resistance R_2 in series with C, the capacitor can charge and discharge at only a comparatively slow rate. The agc voltage therefore cannot vary at frequencies as high as the audio range, but can vary rapidly at frequencies high enough to compensate for most changes in signal strength.

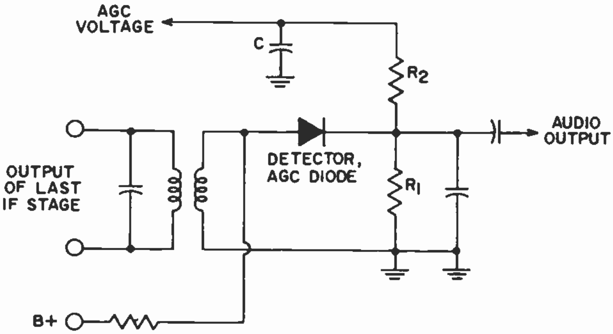


Figure 74. Simple reverse agc circuit.

In a television receiver, the video signal contains a dc component, and therefore the average carrier level varies with signal information. As a result, the agc circuit is designed to provide a control voltage proportional to the peak modulated carrier level rather than the average modulated carrier level. The time constant of the agc detector circuit is made large enough so that the picture content of the composite video signal does not influence the magnitude of the agc voltage. In addition, an electronic switch is often included in the circuit so that it can be operated only during the retrace portion of the scanning cycle. This "gated agc" technique prevents noise peaks from affecting agc operation.

There are two ways in which automatic gain control can be applied to a transistor. In the reverse agc method shown in Fig. 74, agc action is obtained by decreasing the collector or emitter current of the transistor, and thus its transconductance and gain. The use of **forward agc** provides improved cross-modulation characteristics and better signal-handling capability than reverse agc. For forward agc operation, however, the transistor used must be specially designed so that transconductance decreases with increasing emitter current. In such transistors, the current-cutoff characteristics are designed to be more remote than the typical sharp-cutoff characteristics of conventional transistors. (All transistors can be used with reverse agc, but only specially designed types with forward agc.)

Reverse agc is simpler to use, and provides less bandpass shift and tilt with signal-strength variations. The input and output resistances of a transistor increase when reverse agc is applied, but the input and output capacitances are not appreciably changed. The change in the loading of tuned circuits is minimal, however, because considerable mismatch already exists and the additional mismatch caused by agc has little effect. In forward agc, however, the input and output resistances of the transistor are reduced when the collector or emitter current is increased, and thus the tuned circuits are damped. In addition, the input and output capacitances change drastically, and alter the resonant frequency of the tuned circuits. In a practical circuit, the bandpass shift and tilt caused by forward agc can be compensated to a large extent by the use of passive coupling circuits.

Cross-modulation is an important consideration in the evaluation of transistorized tuner circuits. This phenomenon, which occurs in nonlinear systems, can be defined as the transfer of modulation from an interfering carrier to the desired carrier. In general, the severity of cross-modulation is independent of both the semiconductor material and the construction of the transistor (provided gain and noise factor are not sacrificed). At low frequencies, cross-modulation is also independent of the amplitude of the desired carrier, but varies as the square of the amplitude of the interfering signal.

In most rf circuits, the undesirable effects of cross-modulation can be minimized by good selectivity in the antenna and rf interstage coils. Minimum cross-modulation can best be achieved by use of the optimum circuit Q with respect to bandwidth and tracking considerations, which implies minimum loading of the tank circuits.

In rf circuits where selectivity is limited by the low unloaded Q's of the coils being used, improved cross-modulation can be obtained by mismatching the antenna circuit (that is, selecting the antenna primary-to-secondary turns ratio such that the reflected antenna impedance at the base of the rf amplifier is very low compared to the input impedance). This technique is commonly used in automobile receivers, and causes a slight degradation in noise figure. At high frequencies, such as in television, where low source impedances are difficult to obtain because of lead inductance or the impracticality of putting a tap on a coil having one or two turns, an unbypassed emitter resistor having a low value of resistance (e.g., 22 ohms) may be used to obtain the same effect.

Cross-modulation may occur in the mixer or rf amplifier, or both. Accordingly, it is important to analyze the entire tuner as well as the individual stages. Cross-modulation is also a function of agc. At sensitivity conditions where the rf stage is operating at maximum gain and the interfering signal is far removed from the desired signal, cross-modulation occurs primarily in the rf stage. As the desired signal level increases and agc is applied to the rf stage, the rf transistor gain decreases and provides improved cross-modulation. If the interfering signal is close to the desired signal, it is the rf gain at the undesired signal frequency which determines whether the rf stage or mixer stage is the prime contribution of cross-modulation. For example, it is possible that the rf stage gain (including selectivity of tuned circuits) at the undesired frequency is greater than unity. In this case, the undesired signal at the mixer input is larger than that at the rf input; thus the contribution of the mixer is appreciable. Intermediate and high signal conditions may be analyzed similarly by considering rf agc.

If adequate limiting is employed, cross-modulation does not occur in an FM signal.

Limiters

A limiter circuit is essentially an if-amplifier stage designed to provide clipping at a desired signal level. Such circuits are used in FM receivers to remove AM components from the if signal prior to FM detection. The limiter stage is normally the last stage prior to detection, and is similar to preceding if stages. At low input rf signal levels, it amplifies the if signal in the same manner as preceding stages. As the signal level increases, however, a point is reached at which the limiter stage is driven into saturation (i.e., the peak currents and voltages are limited by the supply voltage and load impedances and increases in signal produce very little increase in collector current). At this point, the if signal is "clipped" (or flattened) and further increases in rf signal level produce no further output in if signal to the detector.

Limiter stages may be designed to provide clipping at various input-signal levels. A high-gain FM tuner is usually designed to limit at very low rf input signal levels, and possibly even on noise signals. Additional AM rejection may be obtained by use of a ratio detector for the frequency discriminator.

Wideband (Video) Amplifiers

In some applications, it is necessary for a transistor circuit to amplify signals ranging from very low frequencies (several cycles per second) to high frequencies (tens of megacycles per second) with a minimum of frequency and time-delay distortion. For example, very exacting requirements are demanded for such applications as television camera chains, ac voltmeters, and vertical amplifiers for oscilloscopes. In response to these demands, circuit compensation techniques have been developed to minimize the amplitude and time-delay variation as the upper or lower frequency limits of the amplifier are approached.

The need for such compensation is evident when many identical stages of amplification are employed. If ten cascaded stages are used, a variation of 0.3 dB per stage results in a total variation of 3 dB. In an uncompensated amplifier, this total variation occurs two octaves (a frequency ratio of four) prior to the half-power point. Because two octaves are lost from both the high and low frequencies, the bandwidth of ten cascaded uncompensated amplifier stages is only one-sixteenth that of a single amplifier stage. Fig. 75 shows the

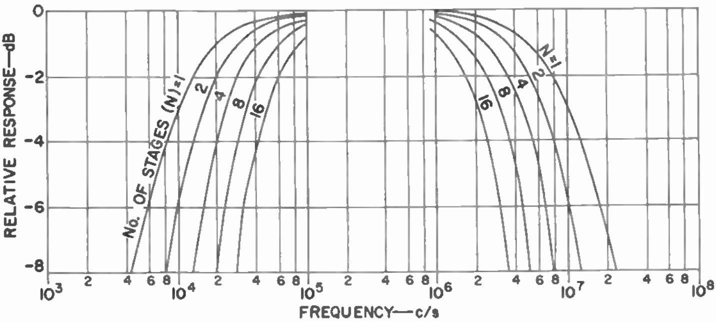


Figure 75. Amplitude response characteristics of various numbers (N) of identical uncompensated amplifiers.

amplitude response characteristics of various numbers of identical uncompensated amplifiers.

In general, the output of an amplifier may be represented by a current generator i_{out} and a load resistance R_L, as shown in Fig. 76a. Because the signal current is shunted by various capacitances at high frequencies, as shown in Fig. 76b, there is a loss in gain at these frequencies. If an inductor L is placed in series with the load resistor R_L, as shown in Fig. 76c, a low-Q circuit is formed which somewhat suppresses the capacitive loading. This method of gain compensation, called **shunt peaking,** can be very effective for improving high-frequency response. Fig. 76 shows the frequency response for the circuits shown in Fig. 76a, b, and c. If the inductor L shown in Fig. 76c is made **self-resonant** approximately one octave above the 3-dB frequency of the circuit of Fig. 76b, the amplifier response is extended by about

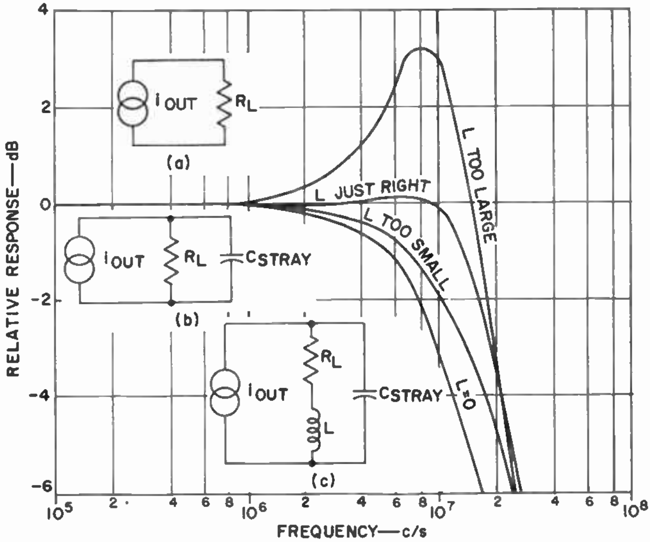


Figure 76. Equivalent circuits and frequency response of uncompensated and shunt-peaked amplifiers.

another 30 per cent.

If the stray capacitance C shown in Fig. 76b is broken into two parts C′ and C″ and an inductor L_1 is placed between them, a heavily damped form of series resonance may be employed for further improvement. This form of compensation, called series peaking, is shown in Fig. 77a.

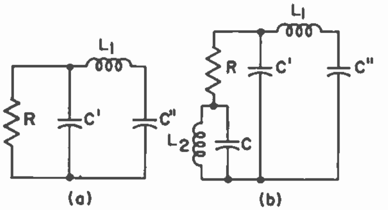


Figure 77. Circuits using (a) series peaking, and (b) both self-resonant shunt peaking and series peaking.

If C′ and C″ are within a factor of two of each other, series peaking produces an appreciable improvement in frequency response as compared to shunt peaking. A more complex form of compensation embodying both self-resonant shunt peaking and series peaking is shown in Fig. 77b.

The effects of various high-frequency compensation systems can be demonstrated by consideration of an amplifier consisting of three identical stages. If each of the three stages is down 3 dB at one megacycle per second, and if a total gain variation of plus 1 dB and minus 3 dB is allowed, the bandwidth of the amplifier is 0.5 megacycle per second without compensation. Shunt peaking raises the bandwidth to 1.3 megacycles per second. Self-resonant shunt peaking raises it to 1.5 megacycles per second. An infinitely complicated network of shunt-peaking techniques could raise it to 2 megacycles per second. If the distribution of capacitance permits it, series peaking alone can provide a bandwidth of about 2 megacycles per second, while a combination of shunt and series peaking can provide a bandwidth of approximately 2.8 megacycles per second. If the capacitance is perfectly distributed, and if an infinitely complex network of shunt and series peaking is employed, the ultimate capability is about 4 megacycles per second.

The frequency response of a wideband amplifier is influenced greatly by variations in component values due to temperature effects, variation of transistor parameters with voltage and current (normal large-signal excursions), changes of stray capacitance due to relocated lead wires, or other variations. A change of 20 per cent in any of the critical parameters can cause a change of 0.7 dB in gain per stage over the last half-octave of the response for the most simple case of shunt peaking. As the bandwidth is extended by more complex peaking, a circuit becomes substantially more critical. (Measurement probes generally alter circuit performance because of their capacitance; this effect should be considered during frequency-response measurements.)

In the design of wideband amplifiers using many stages of amplification, it is necessary to consider time-delay variations as well as amplitude variation. When feedback capacitance is a major contributor to response limitation, the more complex compensating networks may produce severe ringing or even sustained oscillation. If feedback capacitance is treated as input capacitance produced by the Miller effect, the added input capacitance C_f' caused by the feedback capacitor C_f is given by

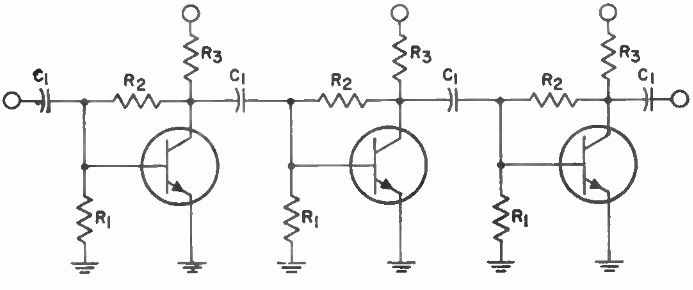
$$C_f' = C_f\,(1 - VG)$$

where VG is the input-to-output voltage gain. The gain VG, however, has a phase angle that varies with frequency. The phase angle is 180 degrees at low frequencies, but may lead or lag this value at high frequencies; the magnitude of VG then also varies. In the design of very wideband amplifiers (20 megacycles per second or more), the phase of the transconductance g_m must be considered.

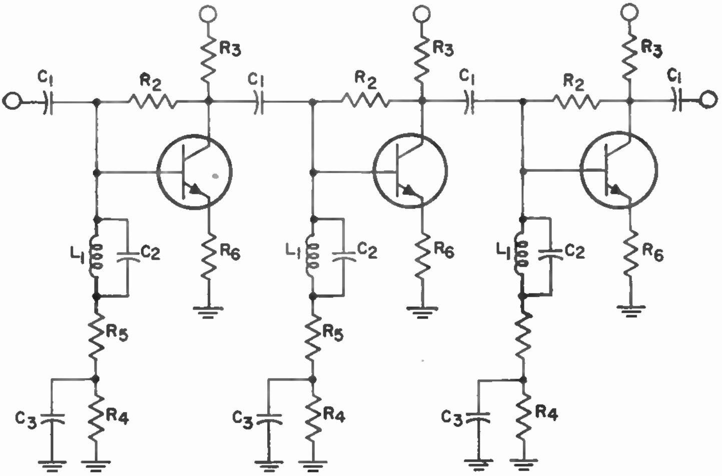
Fig. 78a shows three stages of a multi-stage wideband amplifier. The resistors R_3 merely provide a high-impedance bias path for the collectors of the transistors. The ac collector current of each transistor normally flows almost exclusively into the relatively low impedance offered by the base of the next stage through the coupling capacitor C_1. The resistive network R_1 and R_2 provides a stable dc bias for the transistor base.

The mid-frequency gain of each stage is approximately equal to the common-emitter current-transfer ratio (beta) of the transistor if the component values are properly chosen. The high-frequency response is limited primarily by the transistor gain-bandwidth product f_T, the transistor feedback capacitance, and sometimes the stray capacitance. The low-frequency response is limited primarily by the value of the coupling capacitor C_1.

Fig. 78b illustrates the use of high-frequency shunt peaking and low-frequency peaking at the expense of stage gain in the three stages of the wideband amplifier to extend the high- and low-frequency



(a)



(b)

Figure 78. (a) Uncompensated and (b) compensated versions of three stages of a multistage wideband amplifier.

response. The emitter resistors R_6 are made as small as possible, yet large enough to mask the variation of transconductance, and thus voltage gain, as a function of signal-current variation. For very small ratios of peak ac collector current to dc collector current, this variation is not substantial. The resistors R_6 also partially mask the effect of the intrinsic base-lead resistance r_b'.

The base-bias resistors R_1 of Fig. 78a are split into two resistors R_4 and R_5 in Fig. 78b, with R_4 well bypassed. The mid-frequency gain is then reduced to a value approximating R_5 divided by R_6. At this point, however, the high-frequency response is increased by the same factor. Shunt peaking is provided by L_1 and C_2 for additional high-frequency improvement.

When the reactance of the bypass capacitor C_3 is large compared to R_6, the low-frequency gain is increased because the resistor no longer heavily shunts the transistor input. Selection of the proper value for C_3 exactly offsets the loss of low-frequency gain caused by C_1. When the reactance of C_3 approaches R_4, however, the low-frequency peaking is no longer effective.

High-Frequency Power Amplifiers

Within their frequency capabilities, power transistors can be used to develop the power output required for communications transmitters operating in the vhf and uhf ranges. In most cases, power-amplifier circuits are designed to provide desired values of power output and power gain when operated at a specified supply voltage and frequency. The dc supply voltage is usually fixed at 12 volts for ground mobile equipment and 28 volts for aircraft transmitting equipment. The operating frequency varies for different types of transmitters; the upper frequency is often limited by the power-frequency capability of commercially available transistors. The desired rf power output, which is usually dictated by the transmitting system requirements, determines whether a single device or a suitable parallel arrangement of devices should be used.

The ability of a transistor to operate satisfactorily as a vhf or uhf power amplifier depends on its ability to handle large amounts of peak currents at high frequencies. One of the most important considerations in rf power-amplifier design is the power-dissipation capability of the transistor. The maximum power that can be dissipated before "thermal runaway" occurs depends on how well the heat generated within the transistor is removed. When heat is removed by conduction, the heat transfer is an inverse function of the thermal resistance. The maximum dc power-dissipation capability $P_{max}(dc)$ can be expressed as follows:

$$P_{max}(dc) = \frac{T_J - T_A}{\theta}$$

where T_J and T_A are the maximum allowable junction temperature and the ambient temperature, respectively, in degrees centigrade, and θ is the total thermal resistance of the transistor and the heat sink. For most silicon power transistors, T_J is 200°C.

The maximum dc voltage which can safely be applied to the collector junction is limited by the voltage breakdown ratings for the particular transistor used. The V_{CER} rating defines the maximum value that can be applied under forward-biased conditions. If the transistor is required to be forward-biased, as in the case of a class A power stage, the maximum dc voltage should be no more than one-half this rating. The V_{CEV} rating defines the maximum value that can be applied under reverse-biased conditions. For class C operation of the transistor, the supply voltage must be limited to one-half this value for safe operation. The maximum dc or peak collector current rating for a transistor is usually established at some practical value of current gain.

In a high-frequency power amplifier, it is usually desirable to obtain as much power output as possible with good efficiency and a minimum amount of harmonic distortion. Both common-emitter and common-base circuits are used in rf power amplifiers. The choice of circuit configuration is influenced primarily by operating frequency, power gain, bandwidth, and rf stability requirements. At extremely high frequencies, the power-gain capability of the common-emitter circuit is restricted somewhat by the emitter-lead inductance. Provided some sacrifice in power gain is acceptable, however, this circuit is generally used because it has better rf stability and can more easily be designed with controlled bandwidths. Because the power gain of the common-base circuit is not limited by the degenerative effects of the emitter-lead inductance, the apparent power gain of this configuration is somewhat greater at very high frequencies than that of the common-emitter circuit. However, the common-base circuit is only conditionally stable at high frequencies and controlled bandwidths may be more difficult to obtain.

Because rf transistor amplifiers are designed to handle a selected frequency or band of frequencies, tuned circuits are usually employed for the input and output coupling networks. The collector current in an rf power-amplifier stage contains an appreciable amount of harmonics as a result of the large dynamic swing of voltages and currents. The tuned coupling networks are designed to isolate the unwanted harmonic currents and permit only the fundamental component of current to flow in the load circuit. A high ratio of unloaded Q (Q_o) to loaded Q (Q_L) must be maintained to obtain good tuned-circuit efficiency.

Transistor rf power amplifiers can be operated in class A, B, or C service. The choice of the mode of operation depends upon several factors, including the amount of power output, power gain, and power efficiency desired. Class A power amplifiers are normally used when extremely good linearity is required. Class A amplifiers provide more power gain than either class B or class C amplifiers, but their maximum theoretical collector efficiency is limited to 50 per cent. Because the zero-signal collector power dissipation is high in class A operation, the bias network must be selected to provide good thermal stability.

The input coupling network of a class A power amplifier must be designed to transform the input resistance to the appropriate value to provide the proper load on the driving source. The reactive portion of the input network must resonate with the transistor input reactance. When the input circuit is driven from a signal generator that has a known internal impedance, the input coupling network is usually designed to provide maximum power transfer.

Maximum power transfer occurs when the load resistance is matched to the dynamic output resistance of the transistor. However, matching for maximum power transfer may be impractical in a particular power-amplifier design because of the collector-supply-voltage (V_{CC}) and power-output (P_o) requirements. The collector load resistance R_L is determined by these requirements as follows:

$$R_L = V_{CC}^2/2P_o$$

The reactive portion of the output impedance is also important and must be considered in the design of a class A power amplifier. The output coupling network must be designed to resonate out this reactance and provide the required collector-circuit loading.

When the circuit-design requirements for a power amplifier demand several watts of rf power output, one of the cutoff modes of operation is used. The class B and class C modes are characterized by good collector-circuit efficiency and relatively high power output in proportion to the average dissipation in the transistor. During periods of zero input signal, the power-supply drain and collector dissipation are low. The choice between class B and class C operation is usually determined by the power-gain or collector-efficiency requirements. Class B amplifiers generally have higher power gain, while class C amplifiers have higher collector efficiency. The following discussion of design considerations for a class C rf power amplifier is also applicable in most respects to class B circuits.

As in the case of a class A power amplifier, the collector load resistor for a class C circuit is determined by the supply-voltage and power-output requirements. The output tuned circuit must be designed to obtain the proper load matching and also maintain good tuned-circuit efficiency.

Because class C amplifiers are reverse-biased beyond collector-current cutoff, the harmonic currents generated in the collector are comparable in amplitude with the fundamental component. The tuned coupling networks must provide a relatively high impedance to these harmonic currents and a low impedance to the fundamental current. If the impedance of the tuned circuit is sufficiently high at the harmonic frequencies, however, the amplitude of the harmonic currents is reduced and their contribution to the average current flowing in the collector is minimized. As a result, the collector power dissipation is reduced and the collector-circuit output efficiency is increased.

Fig. 79 shows an output-coupling network in which a parallel tuned circuit is used for coupling the load to the collector circuit. The collector electrode of the transistor is tapped down on the coil L_1 in this network. The capacitor C_1 provides tuning for the fundamental frequency, and capacitor C_2 provides load matching of R_L to the tuned circuit. The transformed R_L across the entire tuned circuit is stepped down to the collector by proper selection of the turns ratio for the coil L_1. If the value of L_1 is chosen properly and the portion of the coil inductance between the collector and ground is sufficiently high, the harmonic portion of the collector current is low in the tuned circuit and its contribution to the dc component flowing in the collector circuit is minimized. Tapping the collector down on the coil maintains the loaded Q_L of the circuit and minimizes the variation of bandwidth of the output circuit with changes in the output capacitance of the transistor.

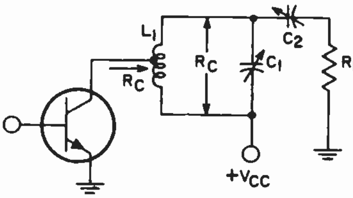


Figure 79. Output-coupling network using parallel tuned circuit.

The circuit shown in Fig. 79 has one serious limitation at very high frequencies. Because of the poor coefficient of coupling in coils at such frequencies, the tap position is usually established empirically to obtain the proper collector loading. Fig. 80 shows suitable output-coupling networks which provide the required collector loading and also suppress the circulation of collector harmonic currents. These networks, which include the collector output capacitance, are not dependent upon coupling coefficient for load-impedance transformation.

The input network for a class C rf power amplifier must provide coupling of the base-emitter circuit to the driving source. Because the driving stage is usually another power transistor, the load required by the collector of the driver stage is generally higher than the base-to-emitter impedance of the amplifier transistor. Therefore, the base-to-emitter

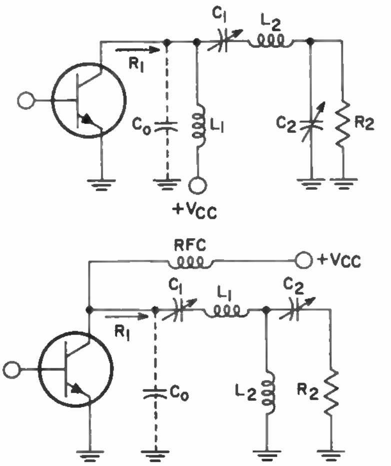


Figure 80. Output-coupling networks including collector output capacitance C_o.

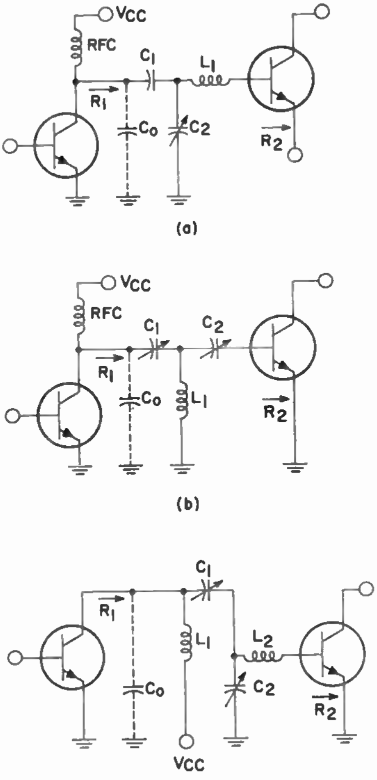
impedance of the output stage must be transformed up to the appropriate value of load for the collector circuit of the driver stage. The input circuit of the transistor can be represented as a resistor r_b' in series with a capacitor C_i. The input network must tune out the capacitance C_i and provide a purely resistive load to the collector of the driver stage.

Fig. 81 shows several input-coupling networks which can be used to couple the base to the output of the driver stage and to tune out the input capacitance C_i. In Fig. 81a, the input circuit is formed by the T network consisting of C_1, C_2, and L_1. If the value of the inductance L_1 is chosen so that its reactance is much greater than that of C_i, series tuning of the base-to-emitter circuit is obtained by L_1 and the parallel combination of C_2 and $(C_1 + C_o)$. Capacitors C_1 and C_o provide the impedance matching to the collector of the driver stage.

Fig. 81b shows a T network with the location of L_1 and C_2 interchanged. If the value of the capacitor C_2 is chosen so that its reactance is much greater than that of C_i, then C_2 can be used to step up r_b' to an appropriate value across L_1. The resultant parallel resistance across L_1 is transformed to the required collector load value by capacitors C_1 and C_o. Parallel resonance of the circuit is obtained by means of L_1 and the parallel combination of $(C_1 + C_o)$ and C_2.

The circuits shown in Figs. 81a and 81b require the collector of the driving transistor to be shunt fed by a high-impedance rf choke. Fig. 81c shows a coupling network which eliminates the need for a choke. In this circuit, the collector of the driving transistor is parallel tuned and the base-to-emitter junction of the output transistor is series tuned.

As mentioned previously, the base-to-emitter junction of a transistor is reverse-biased for class C operation.



(a)

(b)

(c)

Figure 81. Input-coupling networks for high-frequency power amplifiers.

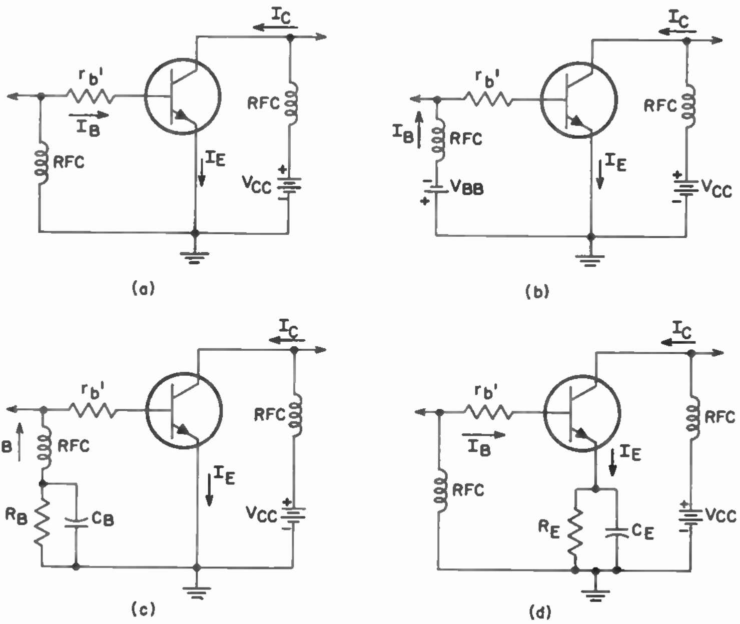


Figure 82. Biasing networks for high-frequency power amplifiers.

Fig. 82 shows several ways of obtaining this reverse bias. In Fig. 82a, the base lead is returned to ground through an rf choke. When the transistor is driven, the dc base current causes a voltage drop across the ohmic base lead resistance r_b' in the right direction to provide a slight reverse bias for the base-to-emitter junction. However, this bias is usually small in magnitude and is difficult to control because the value of r_b' varies for different transistors. The separate battery supply included in the base circuit in Fig. 82b is a good way of obtaining reverse bias for the transistor, but a particular circuit design may not permit an additional supply to be used. In Fig. 82c, the resistor R_B included in the base circuit constitutes a form of "self-bias". However, a disadvantage of this circuit is that too high a value of R_B restricts the usable collector-to-emitter breakdown voltage to a value close to the V_{CEO} rating.

The arrangement shown in Fig. 82d represents the best way of obtaining reverse bias for class C operation. This method does not affect the breakdown characteristic of the transistor, and provides both thermal stability and high efficiency. The capacitor C_E must provide an effective bypass at the operating frequency to reduce the degenerative effects of R_E. For transistors in which the emitter is internally connected to the case, such as the 40341, the case should be electrically isolated from the chassis, and the biasing resistor and bypass capacitor should then be connected from case to ground. An alternate method is to connect the negative end of the power supply to the chassis through a biasing resistor, bolt the transistor directly to the chassis, and then return the base of the transistor through an rf choke to the negative end of the supply.

When more power is required from an rf-power-amplifier circuit than can be obtained from a single transistor, several transistors can be arranged in either parallel or push-pull. In a push-pull arrangement, transformers must be used for proper input-signal phase. Because it is difficult to build transformers which provide the required impedance transfer at very high frequencies, this type of operation can be inefficient for transistors.

Power transistors have been operated successfully in parallel arrangements in many practical circuit designs at frequencies up to 500 megacycles per second. The major design problem in the parallel operation of transistors is equal load sharing, i.e., all transistors in the parallel setup should deliver equal power to the load. In general, load sharing depends on the degree of match of the separate units. Transistors used in an ideal, perfectly balanced circuit should have identical power gain, input and output impedances, and thermal resistance. In practice, experiments have shown that a circuit can generally be considered as balanced if the static currents match within 10 per cent. If a closer degree of balance is required, it is necessary to pre-select transistors in a single-stage circuit.

Fig. 83 shows two 2N3733 overlay transistors operated in a parallel arrangement. This circuit includes provisions for monitoring the collector currents to assure equal load sharing. The effects of the emitter-lead inductance are tuned out by capacitor C_E. Total direct current for each transistor can also be determined by measuring the dc voltage across the emitter resistor R_E and dividing by the value of the emitter resistor used. The emitter circuit represents the best place for monitoring current sharing in a parallel arrangement to establish that both input and output currents are equal.

Paralleling of transistors for low-voltage operation is somewhat more complex. Because collector load impedances are very low and currents very high, it is mechanically difficult to locate the paralleled transistors in such a manner that the same load impedance is presented to both collectors. For example, the collector load impedance R_L for the 18-watt amplifier of Fig. 83 operating at 28 volts

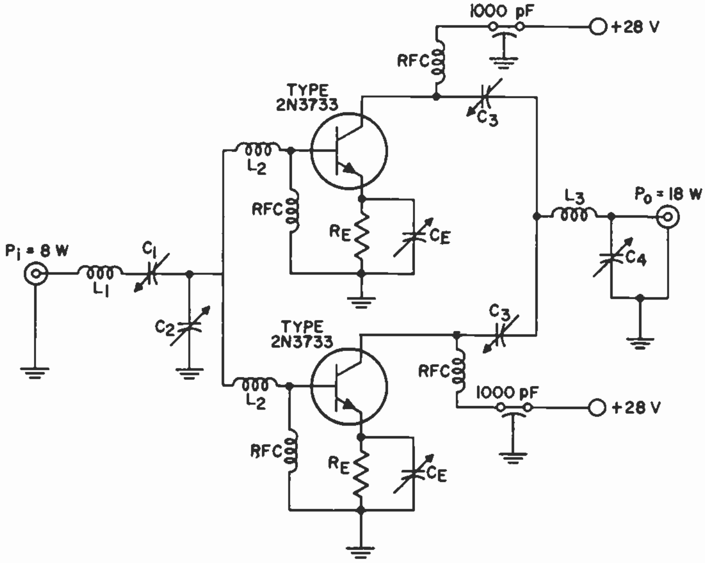


Figure 83. High-frequency power amplifier using two 2N3733 overlay transistors in a parallel arrangement.

is approximately equal to $V_{CC}^2/2P_o$ = 784/36 = 21.8 ohms. For a similar 18-watt amplifier operated at 12 volts, the value of R_L is equal to 144/36, or only 4 ohms. At low voltages, therefore, it is necessary to step up the impedance for the individual collectors by means of rf chokes inserted in the collector leads before the outputs of the individual transistors are tied together.

One of the most common problems encountered in the design of vhf power amplifiers is low-frequency parasitic oscillations. Such oscillations are caused both by stray low-frequency resonances formed between external circuits and internal transistor capacitances and by the very large power gains of which vhf transistors are capable at low frequencies. The following methods can be used to minimize these low-frequency oscillations:

1. A low-Q ferrite choke should be used for the base return to ground; the value should be the smallest possible that does not impair the amplifier gain at operating frequencies.
2. The emitter should be bypassed at the operating frequency with a capacitor of relatively low value to make the stage degenerative at lower frequencies.
3. Wherever possible, the output circuit should utilize a dc feed coil as an integral part of the network.
4. The power leads should be effectively bypassed with a feedthrough capacitor at the operating frequency and a disc ceramic capacitor that makes an effective short at low frequencies.

In many military and amateur radio applications, rf power transistors are often used in **single-sideband circuits**. Single-sideband (SSB) modulation is a special form of amplitude modulation (AM) in which only one sideband is transmitted and the carrier is suppressed to the point of extinction. A brief review of AM characteristics helps to explain the principles of SSB operation.

When a carrier frequency is modulated by an audio modulating frequency, three components are produced: the carrier, which has an amplitude independent of modulation, and two other components which have equal amplitude but have frequencies above and below the carrier frequency by the amount of the modulating frequency. The two latter components, which carry identical intelligence, are called sideband frequencies. Their amplitude depends on the degree of modulation. Because only these sidebands transmit intelligence and each sideband is a mirror image of the other, the carrier and one sideband can be eliminated and only the remaining sideband used for transmission of intelligence. This technique results in single-sideband transmission.

One advantage of single-sideband transmisison is a reduction in average power. A comparison of total average power radiated by AM and SSB transmitters for equal signal-to-noise ratios shows that the carrier power is twice the total sideband power in a 100-per-cent modulated AM wave. If the carrier power is unity, the total radiated power is 1.5 units (1 + 0.25 + 0.25 = 1.5). An SSB transmitter under similar conditions has 0.5 unit of radiated power (peak envelope power = 2 × 0.25). Thus, the total average power for AM is three times the average power for SSB. If a conservative 10-to-1 peak-to-average power ratio is assumed for a voice signal, the average power output is 1.05 units for AM and 0.05 unit for SSB.

Another advantage of SSB is that it requires a narrower frequency spectrum, one-half that required by AM. The use of minimum bandwidth in the transmitter permits a greater number of channel allocations within a given frequency range. To ensure that a minimum band is occupied by the transmission, it is important to make use of low-distortion linear amplifiers. As a result, class B, AB, and A amplifiers are generally used in preference to class C amplifiers and frequency multipliers.

TV SCANNING, SYNC, AND DEFLECTION

For reproduction of a transmitted picture in a television receiver, the face of a cathode-ray tube is scanned with an electron beam while the intensity of the beam is varied to control the emitted light at the phosphor screen. The scanning is synchronized with a scanned image at the TV transmitter, and the black-through-white picture areas of the scanned image are converted into an electrical signal that controls the intensity of the electron beam in the picture tube at the receiver.

Scanning Fundamentals

The scanning procedure used in the United States employs horizontal linear scanning in an odd-line interlaced pattern. The standard scanning pattern for television systems includes a total of 525 horizontal scanning lines in a rectangular frame having an aspect ratio of 4 to 3. The frames are repeated at a rate of 30 per second, with two fields interlaced in each frame. The first field in each frame consists of all odd-number scanning lines, and the second field in each frame consists of all even-number scanning lines. The field repetition rate is thus 60 per second, and the vertical scanning rate is 60 cycles per second.

The geometry of the standard odd-line interlaced scanning pattern is illustrated in Fig. 84. The scanning beam starts at the upper left corner of the frame at point A, and sweeps across the frame with uniform velocity to cover all the picture elements in one horizontal line. At the end of each trace, the beam is rapidly returned to the left side of the frame, as shown by the dashed line, to begin the next horizontal line. The horizontal lines slope downward in the direction of scanning because the vertical deflecting signal simultaneously produces a vertical scanning motion, which is very slow compared with the horizontal scanning speed. The slope of the horizontal line trace from left to right is greater than the slope of the retrace from right to left because the shorter time of the retrace does not allow as much time for vertical deflection of the beam. Thus, the beam is continuously and slowly deflected downward as it scans the horizontal lines, and its position is successively lower as the horizontal scanning proceeds.

At the bottom of the field, the vertical retrace begins, and the beam is brought back to the top of the frame to begin the second or even-number field. The vertical "flyback" time is very fast compared to the trace, but is slow compared to the horizontal scanning speed; therefore, some horizontal lines are produced during the vertical flyback.

All odd-number fields begin at point A in Fig. 84 and are the same. All even-number fields begin at point C and are the same. Because the beginning of the even-field scanning at C is on the same horizontal level as

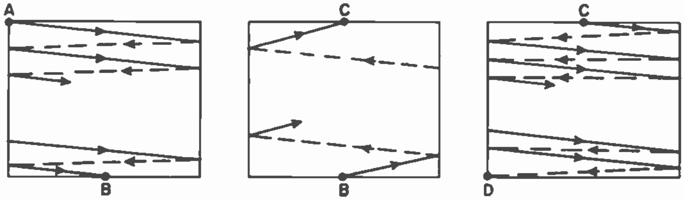


Figure 84. The odd-line interlaced scanning procedure.

A, with a separation of one-half line, and the slope of all lines is the same, the even-number lines in the even fields fall exactly between the odd-number lines in the odd field.

Sync

In addition to picture information, the composite video signal from the video detector of a television receiver contains timing pulses to assure that the picture is produced on the faceplate of the picture tube at the right instant and in the right location. These pulses, which are called sync pulses, control the horizontal and vertical scanning generators of the receiver.

Fig. 85 shows a portion of the detected video signal. When the picture is bright, the amplitude of the signal is low. Successively deeper grays are represented by higher amplitudes until, at the "blanking level" shown in the diagram, the amplitude represents a complete absence of light. This "black level" is held constant at a value equal to 75 per cent of the maximum amplitude of the signal during transmission. The remaining 25 per cent of the signal amplitude is used for synchronization information. Portions of the signal in this region (above the black level) cannot produce light.

In the transmission of a television picture, the camera becomes inactive at the conclusion of each horizontal line and no picture information is transmitted while the scanning beam is retracing to the beginning of the next line. The scanning beam of the receiver is maintained at the black level during this retrace interval by means of the blanking pulse shown in Fig. 85. Immediately after the beginning of the blanking period, the signal amplitude rises further above the black level to provide a horizontal-synchronization pulse that initiates the action of the horizontal scanning generator. When the bottom line of the picture is reached, a similar vertical-synchronization pulse initiates the action of the vertical scanning generator to move the scanning spot back to the top of the pattern.

The sync pulses in the composite video signal are separated from the picture information in a **sync-separator** stage, as shown in Fig. 86. This stage is biased sufficiently beyond cutoff so that current flows and an output signal is produced only at the peak positive swing of the input signal. In the diode circuit of Fig. 86a, negative bias for the diode is developed by R and C as a result of the flow of diode current on the positive extreme of signal input. The bias automatically adjusts itself so that the peak positive swing of the input signal drives the anode of the diode positive and allows the flow of current only for the sync pulse. In the circuit shown in Fig. 86b, the base-emitter junction of the transistor functions in the same manner as the diode in Fig. 86a, but in addition the pulses are amplified.

After the synchronizing signals are separated from the composite video signal, it is necessary to filter out the horizontal and vertical sync

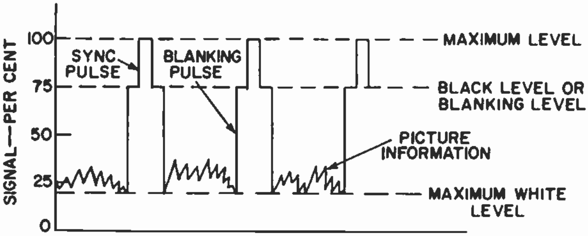


Figure 85. Detected video signal.

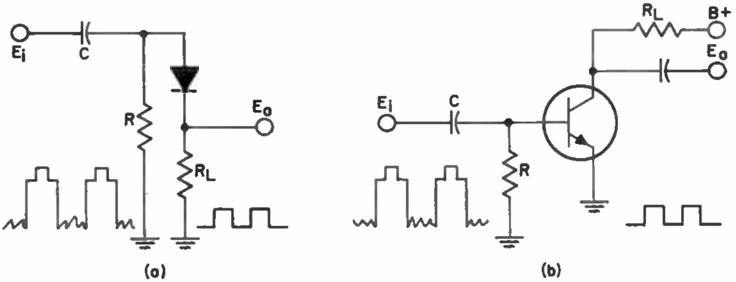


Figure 86. Sync-separator circuits using (a) a diode, and (b) a transistor.

signals so that each can be applied to its respective deflection generator. This filtering is accomplished by RC circuits designed to filter out all but the desired synchronizing signals. Although the horizontal, vertical, and equalizing pulses are all rectangular pulses of the same amplitude, they differ in frequency and pulse width, as shown in Fig. 87. The horizontal sync pulses have a repetition rate of 15,750 per second (one for each horizontal line) and a pulse width of 5.1 microseconds. The equalizing pulses have a width approximately half the horizontal pulse width, and a repetition rate of 31,500 per second; they occur at half-line intervals, with six pulses immediately preceding and six following the vertical synchronizing pulse. The vertical pulse is repeated at a rate of 60 per second (one for each field), and has a width of approximately 190 microseconds. The serrations in the vertical pulse occur at half-line intervals, dividing the complete pulse into six individual pulses that provide horizontal synchronization during the vertical retrace. (Although the picture is blanked out during the vertical retrace time, it is necessary to keep the horizontal scanning generator synchronized.)

All the pulses described above are produced at the transmitter by the synchronizing-pulse generator; their waveshapes and spacings are held within very close tolerances to provide the required synchronization of receiver and transmitter scanning.

The horizontal sync signals are separated from the total sync in a differentiating circuit that has a short time constant compared to the width of the horizontal pulses. When the total sync signal is applied to the differentiating circuit shown in Fig. 88, the capacitor charges completely very soon after the leading edge of each pulse, and remains charged for a period of time equal to practically the entire pulse width. When the applied voltage is removed at the time corresponding to the trailing edge of each pulse, the capacitor discharges completely within a very short time. As a result, a positive peak of voltage is obtained for each leading edge and a negative

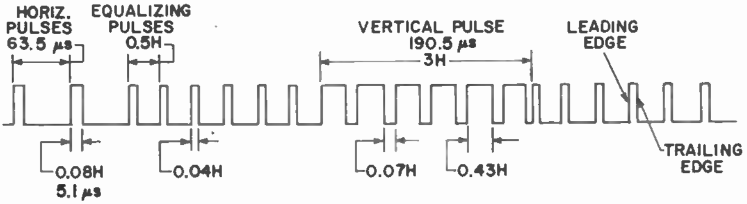


Figure 87. Waveform of TV synchronizing pulses (H = horizontal line period of 1/15,750 seconds, or 63.5 μs).

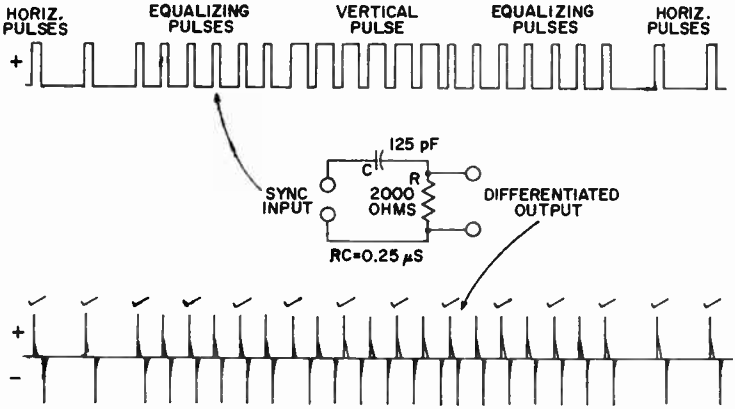


Figure 88. Separation of the horizontal sync signals from the total sync by a differentiating circuit.

peak for the trailing edge of every pulse. One polarity is produced by the charging current for the leading edge of the applied pulse, and the opposite polarity is obtained from the discharge current corresponding to the trailing edge of the pulse.

As mentioned above, the serrations in the vertical pulse are inserted to provide the differentiated output needed to synchronize the horizontal scanning generator during the time of vertical synchronization. During the vertical blanking period, many more voltage peaks are available than are necessary for horizontal synchronization (only one pulse is used for each horizontal line period). The check marks above the differentiated output in Fig. 88 indicate the voltage peaks used to synchronize the horizontal deflection generator for one field. Because the sync system is made sensitive only to positive pulses occurring at approximately the right horizontal timing, the negative sync pulses and alternate differentiated positive pulses produced by the equalizing pulses and the serrated vertical information have no effect on horizontal timing. It can be seen that although the total sync signal (including vertical synchronizing information) is applied to the circuit of Fig. 88, only horizontal synchronization information appears at the output.

The vertical sync signal is separated from the total sync in an integrating circuit which has a time constant that is long compared with the duration of the 5-microsecond horizontal pulses, but short compared with the 190-microsecond vertical pulse width. Fig. 89 shows the general circuit configuration used, together with the input and output signals for both odd and even fields.

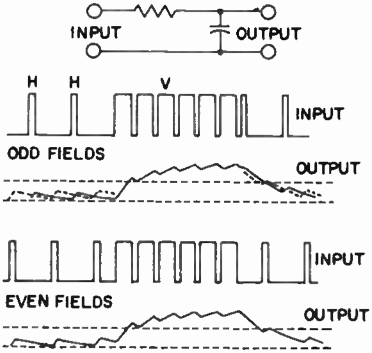


Figure 89. Separation of vertical sync signals from the total sync for odd and even fields with no equalizing pulses. (Dashed line indicates triggering level for vertical scanning generator.)

The period between horizontal pulses, when no voltage is applied to the RC circuit, is so much longer than the horizontal pulse width that the capacitor has time to discharge almost down to zero. When the vertical pulse is applied, however, the integrated voltage across the capacitor builds up to the value required for triggering the vertical scanning generator. This integrated voltage across the capacitor reaches its maximum amplitude at the end of the vertical pulse, and then declines practically to zero, producing a pulse of the triangular wave shape shown for the complete vertical synchronizing pulse. Although the total sync signal (including horizontal information) is applied to the circuit of Fig. 89, therefore, only vertical synchronization information appears at the output.

The vertical synchronizing pulses are repeated in the total sync signal at the field frequency of 60 per second. Therefore, the integrated output voltage across the capacitor of the RC circuit of Fig. 89 can be coupled to the vertical scanning generator to provide vertical synchronization. The six equalizing pulses immediately preceding and following the vertical pulse improve the accuracy of the vertical synchronization for better interlacing. The equalizing pulses that precede the vertical pulses make the average value of applied voltage more nearly the same for even and odd fields, so that the integrated voltage across the capacitor adjusts to practically equal values for the two fields before the vertical pulse begins. The equalizing pulses that follow the vertical pulse minimize any difference in the trailing edge of the vertical synchronizing signal for even and odd fields.

Horizontal Deflection

In the horizontal-deflection stages of a television receiver, a current that varies linearly with time and has a sufficient peak-to-peak amplitude must be passed through the horizontal-deflection-yoke winding to develop a magnetic field adequate to deflect the electron beam of the television picture tube. (This type of deflection is different from that used in a cathode-ray oscilloscope, where the beam is deflected electrostatically.) After the beam is deflected completely across the face of the picture tube, it must be returned very quickly to its starting point. (As explained previously, the beam is extinguished during this retrace by the blanking pulse incorporated in the composite video signal, or in some cases by additional external blanking derived from the horizontal-deflection system.)

The simplest form of a deflection circuit is shown in Fig. 90. In this circuit, the yoke impedance L is assumed to be a perfect inductor. When the switch is closed, the yoke current starts from zero and increases linearly. At any time t, the current i is equal to Et/L, where E is the applied voltage. When the switch is opened at a later time t_1, the current instantly drops from a value of Et_1/L to zero.

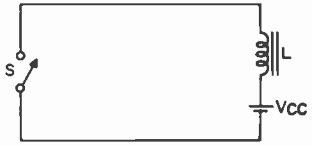


Figure 90. Simplest form of deflection circuit.

Although the basic circuit of Fig. 90 crudely approaches the requirements for deflection, it presents some obvious problems and limitations. The voltage across the switch becomes extremely high, theoretically approaching infinity. In addition, if very little of the total time is spent at zero current, the circuit would require a tremendous amount of dc power. Furthermore, the operation of the switch would be rather critical with regard to both its opening and its closing. Finally, because the deflection field would be phased in only one direction, the beam would have to be centered at the extreme left of the screen for zero yoke current.

If a capacitor is placed across the switch, as shown in Fig. 91, the yoke current still increases linearly when the switch is closed at time $t = 0$. However, when the switch is opened at time $t = t_1$, a tuned circuit is formed by the parallel combination of L and C. The resulting yoke currents and switch voltages are then as shown in Fig. 91. The current is at a maximum when the voltage equals zero, and the voltage is at a maximum when the current equals zero. If it is assumed that there are no losses, the ringing frequency f_{osc} is equal to $1/(2\pi\sqrt{LC})$.

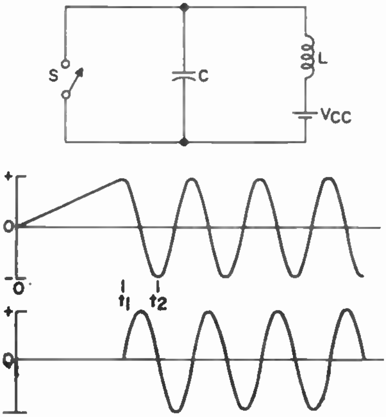


Figure 91. Addition of capacitor to permit flyback ringing, and yoke-current (upper) and switch-voltage (lower) waveforms.

If the switch is closed again at any time the capacitor voltage is not equal to zero, an infinite switch current flows as a result of the capacitive discharge. However, if the switch is closed at the precise moment t_2 that the capacitor voltage equals zero, the capacitor current effortlessly transfers to the switch, and a new transient condition results. Fig. 92 shows the yoke-current and switch-voltage waveforms for this new condition.

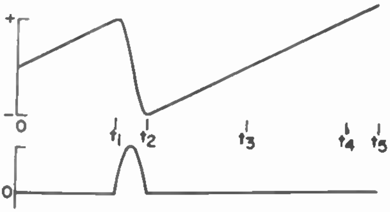


Figure 92. Yoke-current (upper) and switch-voltage (lower) waveforms when switch is closed at t_2.

If the switch is again opened at t_4, closed at t_5, and so on, the desired sweep results, the peak switch voltage is finite, and the average supply current is zero. The deflection system is then lossless and efficient and, because the average yoke current is zero, beam decentering is avoided. The only fault of the circuit of Fig. 91 is the critical timing of the switch, particularly at time $t = t_2$. However, if the switch is shunted by a damper diode, as shown in Fig. 93, the diode acts as a closed switch as soon as the capacitor voltage reverses slightly.

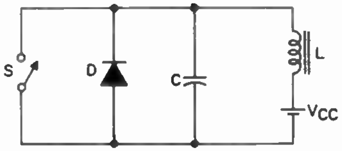


Figure 93. Incorporation of damper diode.

The switch may then be closed at any time between t_2 and t_3.

In typical horizontal-deflection circuits, the switch is a transistor, as shown in Fig. 94. Although the transistor is forward-biased prior to t_3, it is not an effective switch for the reverse collector current; therefore, the damper diode carries most of this current. High voltage is generated by use of the step-up transformer T_1 in parallel with the yoke. This step-up transformer is designed so that its leakage inductance, distributed capacitance, and output stray capacitance complement the yoke inductance and retrace tuning capacitance in such a manner that the peak voltage across the primary

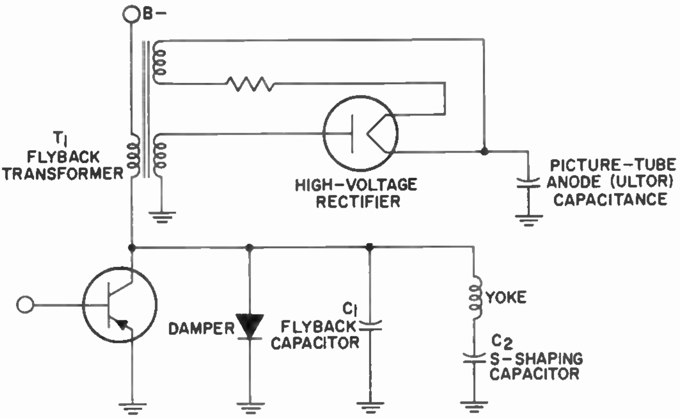


Figure 94. Simple transistor horizontal-deflection circuit.

winding is reduced and the peak voltage across the secondary winding is increased, as compared to the values that would be obtained in a perfect transformer. This technique, which is referred to as "third-harmonic tuning", yields a voltage ratio of secondary-to-primary peak voltage of approximately 1.7 times the value expected in a perfect transformer.

To provide linearity correction for wide-angle television picture tubes, it is necessary to retard the sweep rate at the beginning and end of scan. Therefore, a suitable capacitor C_2 is placed in series with the yoke, as shown in Fig. 94, so that the direct current required to supply circuit losses is fed through the flyback-transformer primary. A parabolic waveform is then developed across C_2 (called the S-shaping capacitor) so that the trace voltage across the yoke is less at the ends of the sweep than in the middle of the sweep. (This capacitor actually provides a series resonant circuit tuned to approximately 5 kilocycles per second so that an S-shaped current portion of a sine wave results.) It is desirable to place the S-shaping capacitor and the yoke between the collector and the emitter of the transistor so that the yoke current does not have to flow through the power supply.

The highest anticipated peak voltage across the transistor in Fig. 94 is a function of the dc voltage obtained at high ac line voltage and at the lowest horizontal-oscillator frequency. (At these conditions, of course, the receiver is out of sync.) The tolerance on the inductors and capacitors alters the trace time only slightly and usually may be ignored if a 10-per-cent tolerance is used for the tuning capacitor.

Vertical Deflection

The vertical-deflection circuit in a television receiver is essentially a class A audio amplifier with a complex load line, severe low-frequency requirements (much lower than 60 cycles per second), and a need for controlled linearity. The equivalent low-frequency response for a 10-per-cent deviation from linearity is one cycle per second. The basic circuit configuration is shown in Fig. 95.

The required performance can be obtained in a vertical-deflection circuit in any of three ways. The amplifier may be designed to provide a flat response down to one cycle per second. This design, however, requires an extremely large output transformer and immense capacitors. Another arrangement is to design the amplifier for fairly good low-frequency response and predistort the generated signal.

The third method is to provide extra gain so that feedback techniques can be used to provide linearity. If loop feedback of 20 or 30 dB is used, transistor gain variations and nonlinearities become fairly insignificant. The feedback automatically provides the necessary "predistortion" to correct low-frequency limitations. In addition, the coupling of miscellaneous signals (such as power-supply hum or horizontal-deflection signals) in the amplifying loop is suppressed.

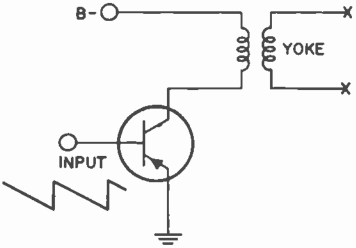


Figure 95. Simple vertical-deflection circuit.

OSCILLATION

Transistor oscillator circuits are similar in many respects to the amplifiers discussed previously, except that a portion of the output power is returned to the input network in phase with the starting power (regenerative or positive feedback) to sustain oscillation. DC bias-voltage requirements for oscillators are similar to those discussed for amplifiers.

The maximum operating frequency of an oscillator circuit is limited by the frequency capability of the transistor used. The maximum frequency of oscillation of a transistor is defined as the frequency at which the power gain is unity. Because some power gain is required in an oscillator circuit to overcome losses in the feedback network, the operating frequency must be some value below the transistor maximum frequency of oscillation.

For sustained oscillation in a transistor oscillator, the power gain of the amplifier network must be equal to or greater than unity. When the amplifier power gain becomes less than unity, oscillations become smaller with time (are "damped") until they cease to exist. In practical oscillator circuits, power gains greater than unity are required because the power output is divided between the load and the feedback network, as shown in Fig. 96. The feedback power must be equal to the input power plus the losses in the feedback network to sustain oscillation.

LC Resonant Feedback Oscillators

The frequency-determining elements of an oscillator circuit may consist of an inductance-capacitance

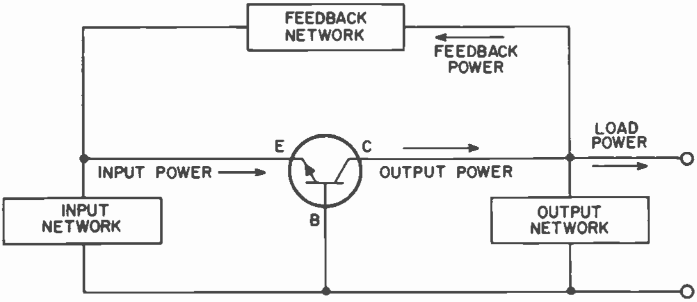


Figure. 96 Block diagram of transistor oscillator showing division of output power.

(LC) network, a crystal, or a resistance-capacitance (RC) network. An LC tuned circuit may be placed in either the base circuit or the collector circuit of a common-emitter transistor oscillator. In the tuned-base oscillator shown in Fig. 97, one battery is used to provide all the dc operating voltages for the transistor. Resistors R_1, R_3, and R_4 provide the necessary bias conditions. Resistor R_2 is the emitter stabilizing resistor. The components within the dotted lines comprise the transistor amplifier. The collector shunt-feed arrangement prevents dc current flow through the tickler (primary) winding of transformer T. Feedback is accomplished by the mutual inductance between the transformer windings.

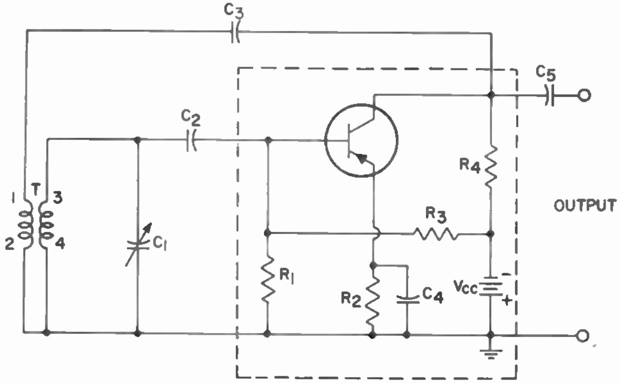


Figure 97. Tuned-base oscillator.

The tuned circuit consisting of the secondary winding of transformer T and variable capacitor C_1 is the frequency-determining element of the oscillator. Variable capacitor C_1 permits tuning through a range of frequencies. Capacitor C_2 couples the oscillation signal to the base of the transistor, and also blocks dc. Capacitor C_4 bypasses the ac signal around the emitter resistor R_3 and prevents degeneration. The output signal is coupled from the collector through coupling capacitor C_5 to the load.

A tuned-collector transistor oscillator is shown in Fig. 98. In this circuit, resistors R_1 and R_3 establish the base bias. Resistor R_2 is the emitter stabilizing resistor. Capacitors C_1 and C_2 bypass ac around resistors R_1 and R_2, respectively. The tuned circuit consists of the primary winding of transformer T and the variable capacitor C_3. Regeneration is accomplished by coupling the feedback signal from transformer winding 3-4 to the tickler coil winding 1-2. The secondary winding of the transformer couples the signal output to the load.

Another form of LC resonant feedback oscillator is the transistor

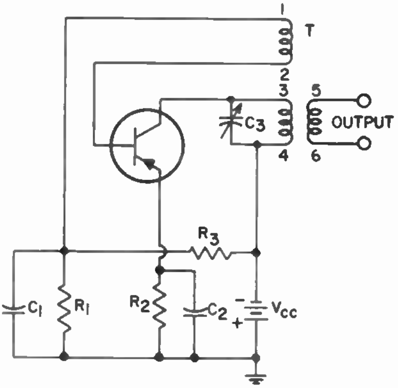


Figure 98. Tuned-collector oscillator.

version of the Colpitts oscillator, shown in Fig. 99. Regenerative feedback is obtained from the tuned circuit consisting of capacitors C_2 and C_3 in parallel with the primary winding of the transformer,

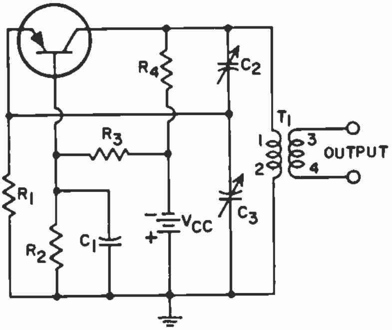


Figure 99. Transistor Colpitts oscillator.

and is applied to the emitter of the transistor. Base bias is provided by resistors R_2 and R_3. Resistor R_4 is the collector load resistor. Resistor R_1 develops the emitter input signal and also acts as the emitter stabilizing resistor. Capacitors C_2 and C_3 form a voltage divider; the voltage developed across C_3 is the feedback voltage. The frequency and the amount of feedback voltage can be controlled by adjustment of either or both capacitors. For minimum feedback loss, the ratio of the capacitive reactance between C_2 and C_3 should be approximately equal to the ratio between the output impedance and the input impedance of the transistor.

A Clapp oscillator is a modification of the Colpitts circuit shown in Fig. 99 in which a capacitor is added in series with the primary winding of the transformer to improve frequency stability. When the added capacitance is small compared to the series capacitance of C_3 and C_4, the oscillator frequency is determined by the series LC combination of the transformer primary and the added capacitor. A Hartley oscillator is similar to the Colpitts oscillator, except that a split inductance is used instead of a split capacitance to obtain feedback.

Crystal Oscillators

A quartz crystal is often used as the frequency-determining element in a transistor oscillator circuit because of its extremely high Q (narrow bandwidth) and good frequency stability over a given temperature range. A quartz crystal may be operated as either a series or parallel resonant circuit. As shown in Fig. 100, the electrical equivalent of the mechanical vibrating characteristic of the crystal can be represented by a resistance R, an inductance L, and a capacitance C_s in series. The lowest impedance of the crystal occurs at the series resonant frequency of C_s and L; the resonant frequency of the circuit is then determined only by the mechanical vibrating characteristics of the crystal.

The parallel capacitance C_p shown in Fig. 100 represents the electrostatic capacitance between the crystal electrodes. At frequencies above the series resonant frequency, the combination of L and C_s has the effect of a net inductance because the inductive reactance of L is greater than the capacitive reactance of C_s. This net inductance forms a parallel resonant circuit with C_p and any circuit capacitance across the crystal. The impedance of the crystal is highest at the parallel resonant frequency; the resonant frequency of

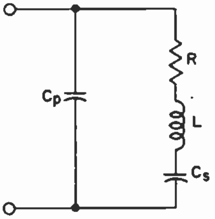


Figure 100. Equivalent circuit of quartz crystal.

the circuit is then determined by both the crystal and externally connected circuit elements.

Increased frequency stability can be obtained in the tuned-collector and tuned-base oscillators discussed previously if a crystal is used in the feedback path. The oscillation frequency is then fixed by the crystal. At frequencies above and below the series resonant frequency of the crystal, the impedance of the crystal increases and the feedback is reduced. Thus, oscillation is prevented at frequencies other than the series resonant frequency.

The parallel mode of crystal resonance is used in the Pierce oscillator shown in Fig. 101. (If the crystal were replaced by its equivalent circuit, the functioning of the oscillator would be analogous to that of the Colpitts oscillator shown in Fig. 99.) The resistances shown in Fig. 101 provide the proper bias and stabilizing conditions for the common-emitter circuit. Capacitor C_1 is the emitter bypass capacitor. The required 180-degree phase inversion of the feedback signal is accomplished through the arrangement of the voltage-divider network C_2 and C_3. The connection between the capacitors is grounded so that the voltage developed across C_3 is applied between base and ground and 180-degree phase reversal is obtained. The oscillating frequency of the circuit is determined by the crystal and the capacitors connected in parallel with it.

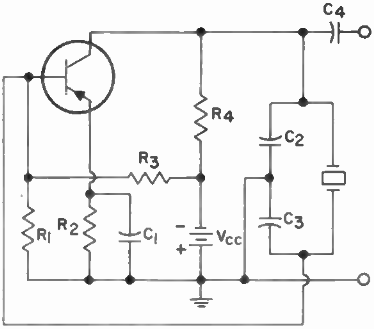


Figure 101. Pierce-type transistor crystal oscillator.

RC Feedback Oscillators

A resistance-capacitance (RC) network is sometimes used in place of an inductance-capacitance network when phase shift is required in a transistor oscillator. In the phase-shift oscillator shown in Fig. 102, the RC network consists of three sections (C_1R_1, C_2R_2, and C_3R_3), each of which contributes a phase shift of 60 degrees at the frequency of oscillation. Because the capacitive reactance of the network increases or decreases at other frequencies, the 180-degree phase shift required for the common-emitter oscillator occurs only at one frequency; thus, the output frequency of the oscillator is fixed. Phase-shift oscillators may be made variable over particular frequency ranges by the use of ganged variable capacitors or resistors in the RC networks. Three or more sections must be used in the phase-shifting networks to reduce feedback losses. The use of more sections contributes to increased stability.

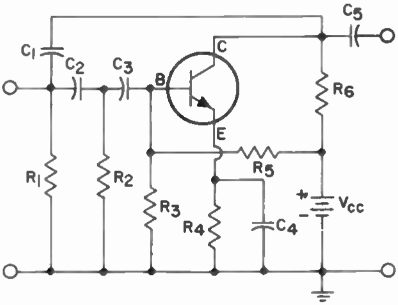


Figure 102. Transistor RC phase-shift oscillator.

Nonsinusoidal Oscillators

Oscillator circuits which produce nonsinusoidal output waveforms use a regenerative circuit in conjunction with resistance-capacitance (RC) or resistance-inductance (RL) components to produce a switching action. The charge and discharge times of the reactive elements (R x C or L/R) are used to produce sawtooth, square, or pulse output waveforms.

A **multivibrator** is essentially a nonsinusoidal two-stage oscillator in which one stage conducts while the other is cut off until a point is reached at which the conditions of the stages are reversed. This type of oscillator is normally used to produce a square-wave output. In the RC-coupled common-emitter multivibrator shown in Fig. 103, the output of transistor Q_1 is coupled to the input of transistor Q_2 through the feedback capacitor C_1, and the output of Q_2 is coupled to the input of Q_1 through the feedback capacitor C_2.

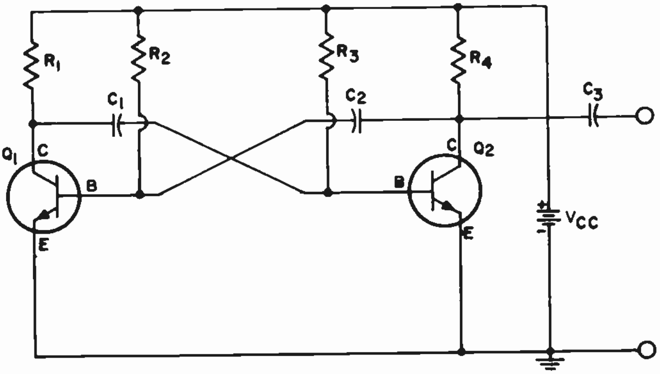


Figure 103. RC-coupled common-emitter multivibrator.

In the multivibrator circuit, an increase in the collector current of transistor Q_1 causes a decrease in the collector voltage which, when coupled through capacitor C_1 to the base of transistor Q_2, causes a decrease in the collector current of Q_2. The resultant rising voltage at the collector of Q_2, when coupled through capacitor C_2 to the base of Q_1, drives Q_1 further into conduction. This regenerative process occurs rapidly, driving Q_1 into heavy saturation and Q_2 into cutoff. Q_2 is maintained in a cutoff condition by C_1 (which was previously charged to the supply voltage through resistor R_1) until C_1 discharges through R_3 toward the collector-supply potential. When the junction of C_1 and R_3 reaches a slight positive voltage, however, transistor Q_2 begins to start into conduction and the regenerative process reverses. Q_2 then reaches a saturation condition, Q_1 is cut off by the reverse bias applied to its base through C_2, and the C_2R_2 junction starts charging toward the collector supply voltage. The oscillating frequency of the multivibrator is determined by the values of resistance and capacitance in the circuit.

A **blocking oscillator** is a form of nonsinusoidal oscillator which conducts for a short period of time and is cut off (blocked) for a much longer period. A basic circuit for this type of oscillator is shown in Fig. 104. Regenerative feedback through the tickler-coil winding 1-2 of transformer T_1 and capacitor C causes current through the transistor to rise rapidly until saturation is reached. The transistor is then cut off until C discharges through resistor R. The output waveform is a pulse, the width of which is primarily determined by winding 1-2. The time between pulses (resting or blocking time) is deter-

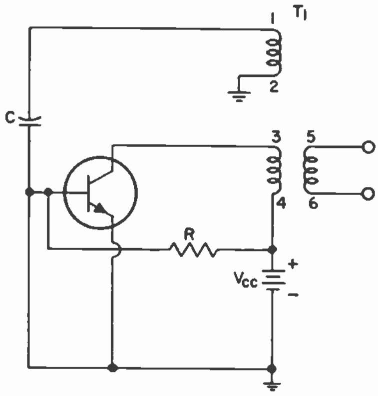


Figure 104. Basic circuit of blocking oscillator.

mined by the time constant of capacitor C and resistor R.

FREQUENCY CONVERSION

Transistors can be used in various types of circuits to change the frequency of an incoming signal. In radio and television receivers, frequency conversion is used to change the frequency of the rf signal to an intermediate frequency. In communications transmitters, frequency multiplication is often used to raise the frequency of the developed rf signal.

In a radio or television receiver, the oscillating and mixing functions are performed by a nonlinear device such as a diode or a transistor. As shown in the diagram of Fig. 105, two voltages of different frequencies, the rf signal voltage and the voltage generated by the oscillator, are applied to the input of the mixer. These voltages "beat," or heterodyne, within the mixer transistor to produce a current having, in addition to the frequencies of the input voltages, numerous sum and difference frequencies.

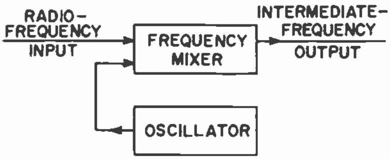


Figure 105. Block diagram of simple frequency-converter circuit.

The output circuit of the mixer stage is provided with a tuned circuit which is adjusted to select only one beat frequency, i.e., the frequency equal to the difference between the signal frequency and the oscillator frequency. The selected output frequency is known as the intermediate frequency, or if. The output frequency of the mixer transistor is kept constant for all values of signal frequency by tuning of the oscillator transistor.

In AM broadcast-band receivers, the oscillator and mixer functions are often accomplished by use of a single transistor called an "autodyne converter". In FM and television receivers, stable oscillator operation is more readily obtained when a separate transistor is used for the oscillator function. In such a circuit, the oscillator voltage is coupled to the mixer by inductive coupling, capacitive coupling, or a combination of the two.

An **automatic frequency control** (afc) circuit is often used to provide automatic correction of the oscillator frequency of a superheterodyne receiver when, for any reason, it drifts from the frequency which produces the proper if center frequency. This correction is made by adjustment of the frequency of the oscillator. Such a circuit automatically compensates for slight changes in rf carrier or oscillator frequency, as well as for inaccurate manual or push-button tuning.

An afc system requires two sections: a frequency detector and a variable reactance. The detector section may be essentially the same as the FM detector illustrated in Fig. 42. In the afc system, however, the output is a dc control voltage, the magnitude of which is proportional to the amount of frequency shift. This dc control voltage is used to control the bias on a transistor or diode which comprises the variable reactance.

Automatic frequency control is also used in television receivers to keep the horizontal oscillator in step with the horizontal-scanning frequency at the transmitter. A widely used horizontal afc circuit is shown in Fig. 106. This circuit, which is often referred to as a balanced-phase-detector or phase-discriminator circuit, is usually employed to control the frequency of the horizontal-oscillator circuit. The detector diodes supply a dc control voltage to the horizontal-oscillator circuit which counteracts changes in its operating frequency. The magnitude and polarity of the control voltages are determined by phase relationships in the afc circuit.

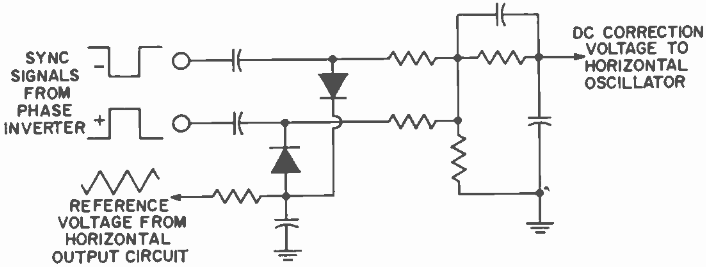


Figure 106. Balanced-phase-detector or phase-discriminator circuit for horizontal afc.

The horizontal sync pulses obtained from the sync-separator circuit are fed through a phase-inverter or phase-splitter circuit to the two diode detectors. Because of the action of the phase-inverter circuit, the signals applied to the two diode units are equal in amplitude but 180 degrees out of phase. A reference sawtooth voltage obtained from the horizontal output circuit is also applied simultaneously to both units. The diodes are biased so that conduction takes place only during the tips of the sync pulses. Any change in the oscillator frequency alters the phase relationship betwen the reference sawtooth and the incoming horizontal sync pulses, and thus causes one of the diodes to conduct more heavily than the other so that a correction signal is produced. The system remains balanced at all times, therefore, because momentary changes in oscillator frequency are instantaneously corrected by the action of this control voltage. The network between the diodes and the horizontal-oscillator circuit is essentially a low-pass filter which prevents the horizontal sync pulses from affecting the horizontal-oscillator performance.

Frequency multipliers are another type of frequency-conversion circuits. Because the output-current waveform of power transistors can be made to contain both fundamental and harmonic frequency components, power output can be obtained at a desired harmonic frequency by use of a special type of output circuit coupled to the collector of the transistor. Transistors can be connected in either the common-base or the common-emitter configuration for frequency multiplication.

The design of transistor frequency-multiplier circuits consists of selection of a suitable transistor and design of filtering and matching networks for optimum circuit performance. The transistor must be capable of power and gain at the fundamental frequency and capable of converting power from the fundamental to a harmonic frequency. At a given input power level, the output power at a desired harmonic frequency is equal to the product of the power gain of the transistor at the drive frequency and the conversion efficiency of the frequency-multiplier circuit. Conversion gain can be obtained only when the power gain of the transistor at the fundamental frequency is larger than the conversion loss of the circuit.

Various types of instabilities can occur in transistor frequency-multiplier circuits, including low-frequency resonances, parametric oscillations, hysteresis, and high-frequency resonances. Low-frequency resonances occur because the gain of the transistor is very high at low frequency compared to that at the operating frequency. "Hysteresis" refers to discontinuous mode jumps in output power when the input power or frequency is increased or decreased. A tuned circuit used in the output coupling network has a different resonant frequency under strong drive than under weaker driving conditions. It has been found experimentally that hysteresis effect can be minimized, and sometimes eliminated, by use of the common-emitter configuration.

Perhaps the most troublesome instability in transistor frequency-multiplier circuits is high-frequency resonance. Such instability shows up in the form of oscillations at a frequency very close to the output frequency when the input drive power is removed. This effect suggests that the transistor under this condition behaves as a locked oscillator at the fundamental frequency. Common-emitter circuits have been found to be less critical for high-frequency oscillatons than common-base circuits. High-frequency resonance is also strongly related to the input drive frequency, and can be eliminated if the input frequency is kept below a certan value. The input frequency at which stable operation can be obtained depends on the method used to ground the emitter of the transistor, and can be increased by use of the shortest possible path from the emitter to ground.

SWITCHING

Transistors are often used in pulse and switching circuits in radar, television, telemetering, pulse-code communication, and computing equipment. The basic concept in any switching circuit is a discrete change of state, usually a voltage change or a current change or both. This change of state may be used to perform logical functions, as in a computer, or to transfer energy, as in relay drivers and switching regulators.

A switch presents a high resistance when it is open and a low resistance when it is closed. When transistors are used as switches, they offer the dual advantages of having no moving or wearing parts and of being easily actuated from various electrical inputs. Transistor switching circuits act as generators, amplifiers, inverters, frequency dividers, and waveshapers to provide limiting, triggering, gating, and signal-routing functions. These applications are normally characterized by large-signal or nonlinear operation of the transistor.

When a transistor switching circuit is ON, the resistance should be as low as possible across the transistor to avoid loss of power across the switch. To achieve this low resistance, it is necessary that the transistor be in the saturation region. Enough base current must be supplied to assure that saturation is maintained under "worst-case" operating conditions. ("Worst-case" design is essential to guarantee reliable operation of a circuit under the most adverse conditions. Resistor, capacitor, and voltage tolerances, variations in transistor parameters, temperature effects, and end-of-life degradation are the primary factors considered in "worst-case" design of circuits.) In the OFF condition, the impedance across the transistor should be as high as possible.

In large-signal operation, the transistor acts as an overdriven amplifier which is driven from the cutoff region to the saturation region. In the simple transistor-switching circuit shown in Fig. 107, the collector-base junction is reverse-biased by battery V_{CC}

through resistor R_3. Switch S_1 controls the polarity and amount of base current from battery V_{B1} or V_{B2}. When S_1 is in the OFF position, the emitter-base junction of the transistor is reverse-biased by battery V_{B2} through the current-limiting resistor R_2. The transistor is then in the OFF (cutoff) state. (Normal quiescent conditions for a transistor switch in the cutoff region require that both junctions be reverse-biased.)

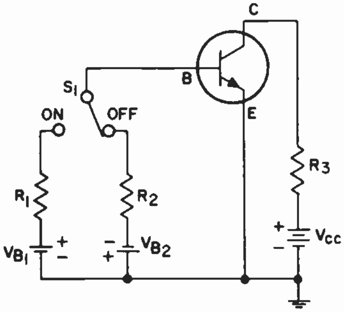


Figure 107. Simple switching circuit.

When the switch is in the ON position, forward bias is applied to the emitter-base junction by battery V_{B1} through the current-limiting resistor R_1. The base current and collector current then increase rapidly until the transistor reaches saturation. (The transistor is saturated when the collector current reaches a value at which it is limited by R_3 and V_{CC}. Collector current is then approximately equal to V_{CC}/R_3, and further increases in base drive produce no further increase in collector current.) The active linear region is called the transition region in switching operation because the signal passes through this region rapidly.

In the saturation region, the collector current is usually at a maximum and collector voltage at a minimum. This value of collector voltage is referred to as the saturation voltage, and is an important characteristic of the transistor. A transistor operating in the saturation region is in the ON (conducting) state. (Both junctions are forward-biased.)

Regions of operation are similar for all transistor configurations used as switches. When both junctions of the transistor are reverse-biased (cutoff condition), the output current is very small and the output voltage is high. When both junctions are forward-biased (saturation condition), the output current is high and the output voltage is small. For most practical purposes, the small output current in the cutoff condition and the small output voltage in the saturated condition may be neglected.

Switching Times

When switch S_1 in Fig. 107 is operated in sequence from OFF to ON and then back to OFF, the current pulses shown in Fig. 108 are obtained. The rectangular input current pulse I_B drives the transistor from cutoff to saturation and back to cutoff. The output current pulse I_C is distorted because the transistor cannot respond instantaneously to a change in signal level. The response of the transistor during the rise time t_r and the fall time t_f is called the transient response, and is essentially determined by the transistor characteristics in the active linear region.

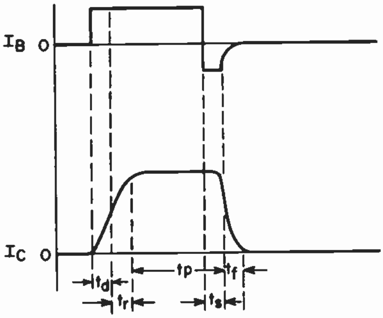


Figure 108. Current waveforms obtained in switching circuit.

The delay time t_d is the length of time that the transistor remains cut off after the input pulse is applied.

This finite time is required before the applied forward bias overcomes the emitter depletion capacitance of the transistor and collector current begins to flow.

The rise time t_r (which is also referred to as build-up time) is the time required for the leading edge of the pulse to increase in amplitude from 10 to 90 per cent of its maximum value. Rise time can be reduced by overdriving the transistor, but only small amounts of overdrive are normally used because turn-off time (storage time plus fall time) is also affected.

The pulse time t_p (or pulse duration) is the length of time that the pulse remains at, or very near, its maximum value. Pulse-time duration is measured between the points on the leading edge and on the trailing edge where the amplitude is 90 per cent of the maximum value.

The storage time t_s is the length of time that the output current I_C remains at its maximum value after the input current I_B is reversed. The length of storage time is essentially governed by the degree of saturation into which the transistor is driven and by the amount of reverse (or turn-off) base current supplied.

The fall time t_f (or decay time) of the pulse is the time required for the trailing edge to decrease in amplitude from 90 to 10 per cent of its maximum value. Fall time may be reduced by the application of a reverse current at the end of the input pulse.

The total **turn-on** time of a transistor switch is the sum of the delay time and the rise time. The total **turn-off** time is the sum of the storage time and the fall time. A reduction in either storage time or fall time decreases turn-off time and increases the usable pulse repetition rate of the circuit.

Triggered Circuits

When an externally applied signal is used to cause an instantaneous change in the operating state of a transistor circuit, the circuit is said to be triggered. Such circuits may be astable, monostable, or bistable. Astable triggered circuits have no stable state; they operate in the active linear region, and produce relaxation-type oscillations. A **monostable** circuit has one stable state in either of the stable regions (cutoff or saturation); an external pulse "triggers" the transistor to the other stable region, but the circuit then switches back to its original stable state after a period of time determined by the time constants of the circuit elements. A **bistable (flip-flop)** circuit has a stable state in each of the two stable regions. The transistor is triggered from one stable state to the other by an external pulse, and a second trigger pulse is required to switch the circuit back to its original stable state.

The multivibrator circuit shown in Fig. 109 is an example of a monostable circuit. The bias network holds transistor Q_2 in saturation and transistor Q_1 at cutoff during the quiescent or steady-state period. When an input signal is applied through the coupling capacitor C_1, however, transistor Q_1 begins to conduct. The decreasing collector voltage of Q_1 (coupled to the base of Q_2 through capacitor C_2) causes the base current and collector current of Q_2 to de-

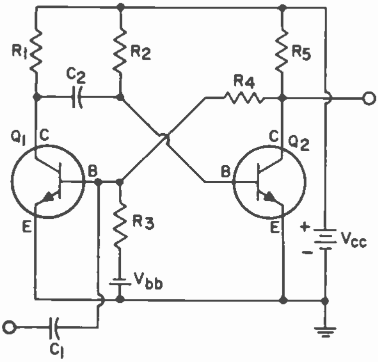


Figure 109. Monostable multivibrator.

crease. The increasing collector voltage of Q_2 (coupled to the base of Q_1 through resistor R_4) then increases the forward base current of Q_1. This regeneration rapidly drives transistor Q_1 into saturation and transistor Q_2 into cutoff. The base of transistor Q_2 at this point is at a negative potential almost equal to the magnitude of the battery voltage V_{cc}.

Capacitor C_2 then discharges through resistor R_2 and the low saturation resistance of transistor Q_1. As the base potential of Q_2 becomes slightly positive, transistor Q_2 again conducts. The decreasing collector potential of Q_2 is coupled to the base of Q_1 and transistor Q_1 is driven into cutoff, while transistor Q_2 becomes saturated. This stable condition is maintained until another pulse triggers the circuit. The duration of the output pulse is primarily determined by the time constant of capacitor C_2 and resistor R_2 during discharge.

The Eccles-Jordan-type multivibrator circuit shown in Fig. 110 is an example of a bistable circuit. The resistive and bias values of this circuit are chosen so that the initial application of dc power causes one transistor to be cut off and the other to be driven into saturation. Because of the feedback arrangement, each transistor is held in its original state by the condition of the other. The application of a positive trigger pulse to the base of the OFF transistor or a negative pulse to the base of the ON transistor switches the conducting state of the circuit. The new condition is then maintained until a second pulse triggers the circuit back to the original condition.

In Fig. 110, two separate inputs are shown. A trigger pulse at input A will change the state of the circuit. An input of the same polarity at input B or an input of opposite polarity at input A will then return the circuit to its original state. (Collector triggering can be accomplished in a similar manner.) The capacitors C_3 and C_4 are used to speed up the regenerative switching action. The output of the circuit is a unit step voltage when one trigger is applied, or a square wave when continuous pulsing of the input is used.

Gating Circuits

A transistor switching circuit in which the transistor operates as an

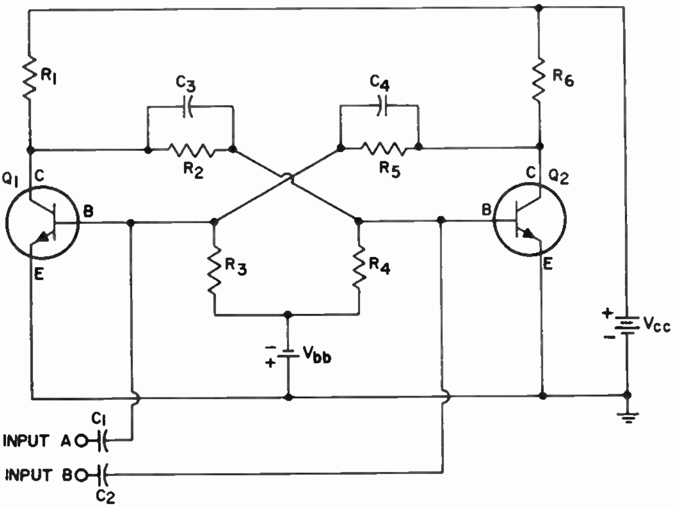


Figure 110. Eccles-Jordan-type bistable multivibrator.

effective open or short circuit is called a "gate". These circuits are used extensively in computer applications to provide a variety of functions such as circuit triggering at prescribed intervals and level and waveshape control. Because these circuits are designed to evaluate input conditions to provide a predetermined output, they are primarily used as logic circuits. Logic circuits include OR, AND, NOR (NOT-OR), NAND (NOT-AND), series (clamping), and shunt or inhibitor circuits.

An OR gate has more than one input, but only one output. It provides a prescribed output condition when one or another prescribed input condition exists. When a pulse of the proper polarity is applied at one or more of the inputs to an OR gate, an output pulse of the same polarity is obtained. If the circuit provides phase inversion of the input signal, the OR gate becomes a NOT-OR (NOR) gate. Fig. 111 shows a simple NOR gate that uses diode inputs.

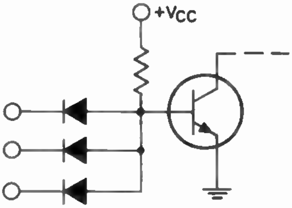


Figure 111. Simple diode NOR gate.

Fig. 112 shows a transistor NOR gate in which bias is provided by the battery V_{bb}. The bias value is chosen so that the transistor is cut off when all inputs are low and is turned on and saturated when either or both of the inputs are high.

An AND gate also has more than one input, but only one output. However, it provides an output only when all the inputs are applied simultaneously. As in the case of the OR gate, the use of a configuration which provides phase inversion provides a NOT-AND (NAND) gate.

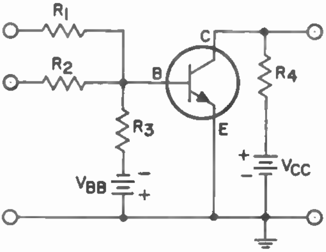


Figure 112. Simple transistor NOR gate.

The AND-OR gate shown in Fig. 113 illustrates the use of a direct-coupled transistor logic circuit to trigger a bistable multivibrator. The over-all gating function, which consists of a NAND function and a NOR function, is performed by transistors Q_1, Q_2, and Q_3. Transistor Q_4 is part of the bistable multivibrator.

Transistors Q_1 and Q_2 are series-connected and form a NAND gate. Similarly, transistors Q_1 and Q_3 are series-connected and form a NAND gate. Transistors Q_2 and Q_3 are parallel-connected and form a NOR gate. Provided all transistors are cut off (quiescent condition), triggering of the bistable multivibrator is accomplished when the prescribed input conditions for either of the NAND gates are met, i.e., when either transistors Q_1 and Q_2 or transistors Q_1 and Q_3 are triggered into conduction.

Gating circuits are also used as amplitude discriminators (limiters), clippers, and clamping circuits, and as signal-shunting or transmission gates.

Propagation delay per stage or per pair of stages is the most important consideration in determining the speed capabilities of a logic system for computer applications. This delay time limits the maximum speed with which information can be processed in a computer. Typical propagation delays ranging from several microseconds to less than 10 nanoseconds can be obtained, depending upon the type of circuit and transistor used.

The simplest computer building

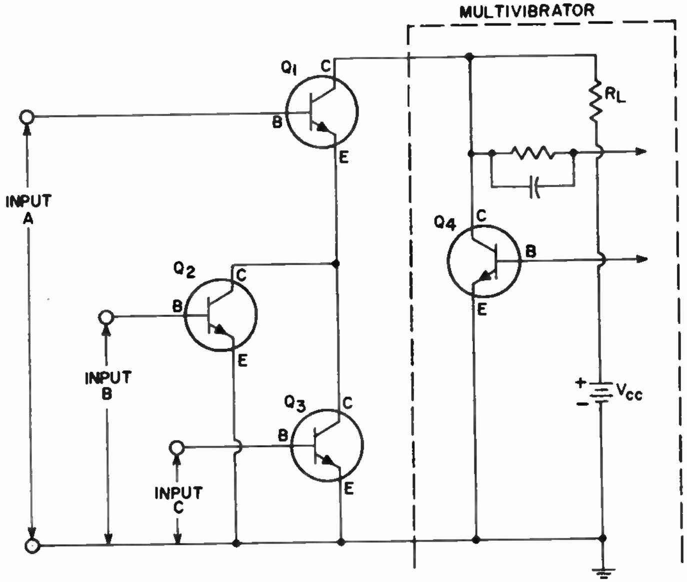


Figure 113. AND-OR gate or trigger circuit.

block is the RTL (resistance-transistor-logic) circuit shown in Fig. 114. This circuit performs a NOR function if positive voltage levels are defined as binary "1" and negative voltages are defined as binary "0". RTL circuits must be designed so that dc stability is obtained under "worst-case" conditions. However, if optimum switching performance is desired, circuits are designed to provide maximum reverse base current for a given fan-in (number of inputs) and fan-out (number of outputs). This approach decreases storage and fall times and thus provides smaller propagation delays per stage, but decreases the fan-out capability of the circuit.

The measurement of propagation delay in RTL circuits is made under "worst-case" conditions, i.e., alternate stages are subjected in turn to maximum and then minimum drive conditions. Maximum drive produces short delay and rise times but long

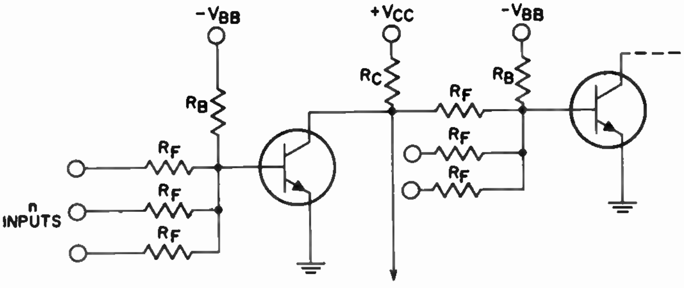


Figure 114. Simple RTL (resistance-transistor-logic) NOR circuit.

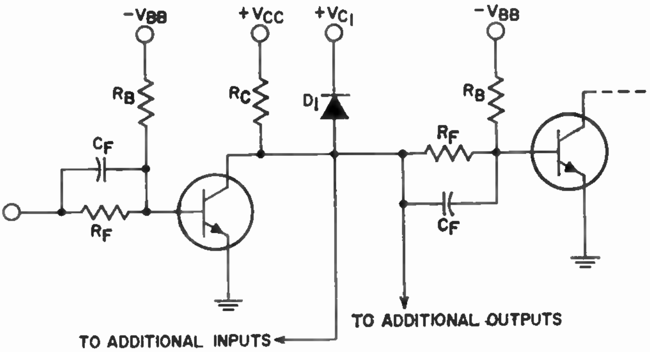


Figure 115. Generalized RCTL (resistance-capacitance-transistor-logic) NOR circuit.

storage and fall times; it occurs when a given stage is driven by three unloaded stages. Minimum drive produces short storage and fall times but long delay and rise times; it occurs when a given stage is driven at only one input by a fully loaded stage.

A generalized RCTL (resistance-capacitance-transistor-logic) circuit is shown in Fig. 115. This type of logic circuit is characterized by a large number of transistors and is capable of extremely fast operation. The logic function performed by the RCTL arrangement of Fig. 115 is the same as that described for the RTL system shown in Fig. 114.

The high-speed operation of RCTL systems is a result of the use of the "speed-up" capacitor C_F. This capacitor compensates for stored charge in the transistor, and also provides large forward-base-current overdrive on an instantaneous basis. Therefore, extremely fast transistor switching times can be obtained. However, the maximum repetition rate of the circuit is limited by the value of C_F. Therefore, C_F must be selected just large enough to compensate for the transistor stored charge.

Fig. 116 shows a generalized DTL (diode-transistor-logic) circuit which performs either a NAND or a NOR function depending upon the definition of voltage levels. The DTL circuit is characterized by extremely high speed, a large number of diodes, and relatively few transistors. Such circuits may use a collector clamp voltage, as shown, or may be designed without collector clamping provided all input diodes are reverse-biased when a transistor is to be ON. The latter approach makes possible larger fan-in and fan-out, but

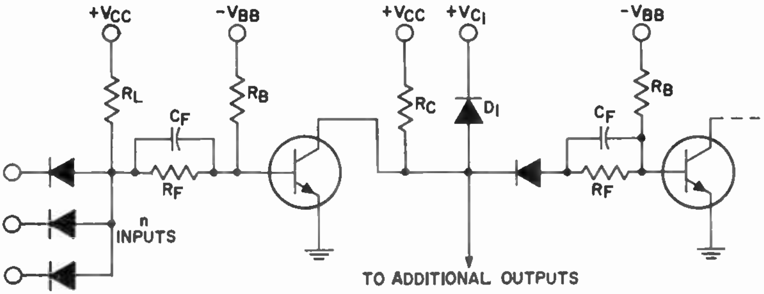


Figure 116. Generalized DTL (diode-transistor-logic) circuit.

is somewhat slower in speed than the design shown. The DTL system is more economical than the RCTL system because fewer transistors are required to perform a given logic function.

Figs. 117 and 118 show two approaches to the design of ultra-high-speed, non-saturating logic circuits. The circuit in Fig. 117 is the generalized circuit for a current-steering system using reference diodes and transistors; Fig. 118 shows the generalized circuit for a complementary-symmetry current-steering system using only transistors.

Current-steering logic (CSL) circuits are characterized by a large number of transistors, high power dissipation, and ultra-high-speed operation. The logic function performed by these circuits is somewhat different from those discussed previously. Because of the extra transistors involved, such circuits can perform both a desired function and its inverse. For example, both NAND and AND or NOR and OR functions are directly obtained, the combination depending upon the definition of voltage levels.

The design of current-steering circuits must be optimized to use the smallest load resistor R_L possible because the ultimate speed of the circuit is limited by the time constant of this load resistance and the load capacitance. The complementary-symmetry approach is superior to diode current steering because it is

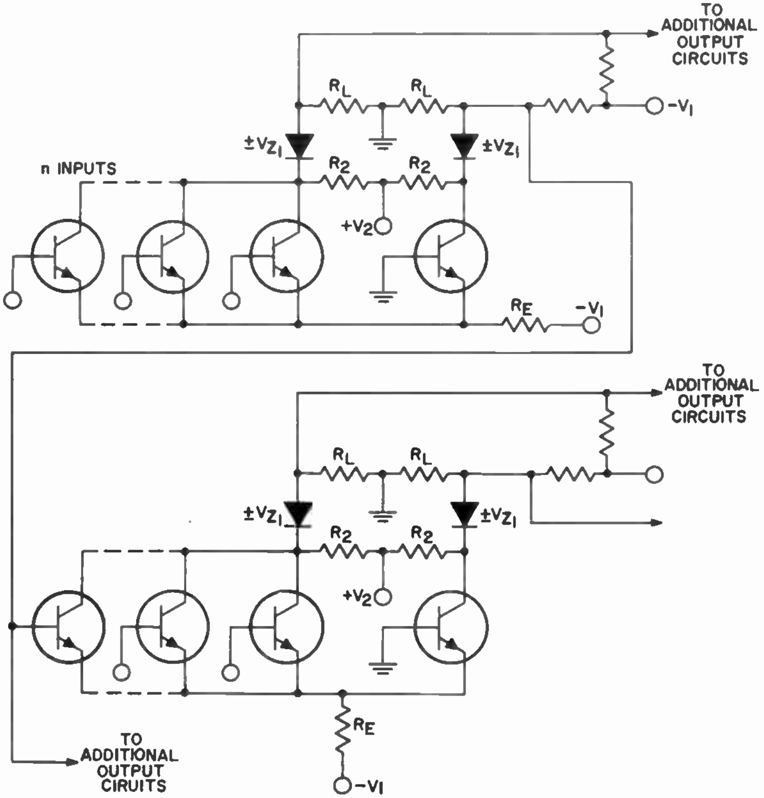


Figure 117. Generalized current-steering system using reference diodes and transistors.

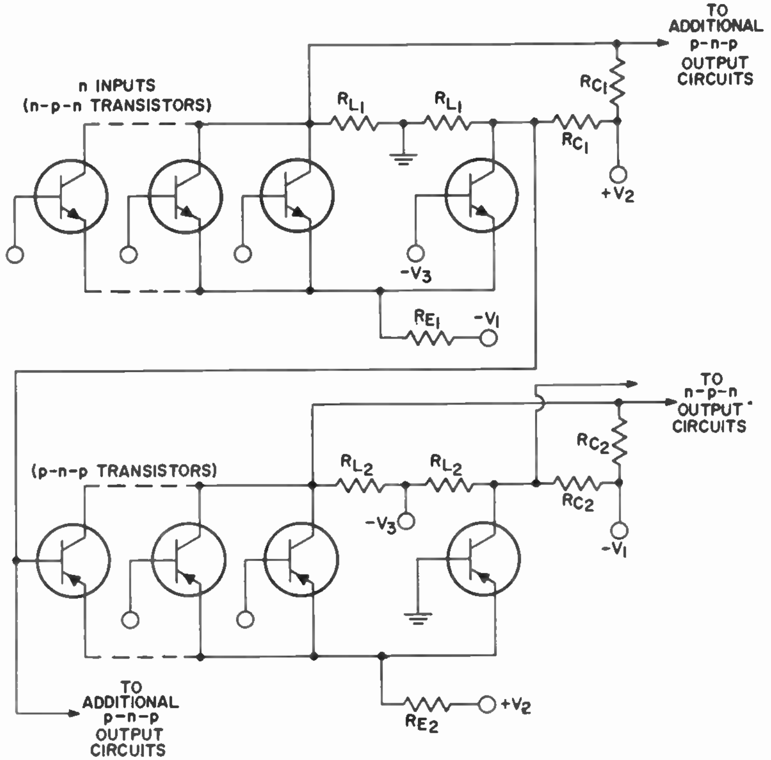


Figure 118. Generalized circuit for complementary-symmetry current-steering system using only transistors.

equivalent in speed, provides the same transistor dissipation (and is thus equally reliable), and may be designed with less critical tolerances.

Computer operation requires the use of many flip-flop circuits for temporary storage of data. "Set-reset" flip-flops may be formed readily by use of any of the basic logic blocks described. A binary-counter-type flip-flop is shown in Fig. 119.

The design of the flip-flop circuit is the same as for the RCTL system except for the trigger gating circuit and the value of C_F. The trigger gating circuit is designed so that a negative pulse at the input turns the ON transistor off. Therefore, the size of the input capacitors must be determined by the maximum stored charge of the transistor and the size of the input voltage swing. The two additional diodes connected from base to emitter of each transistor and the two diodes shunting the gating resistors connected to the collectors are used to eliminate time-constant problems at high frequencies. These diodes may be eliminated if high-frequency operation is not required.

The problem of noise control in computer systems increases in importance with the use of ultra-high-speed transistors and circuits. Noise immunity is defined as the ability of a given circuit to be relatively immune to a certain amplitude and duration of noise voltage. In computer circuits, there are essentially three sources of noise: (1) capaci-

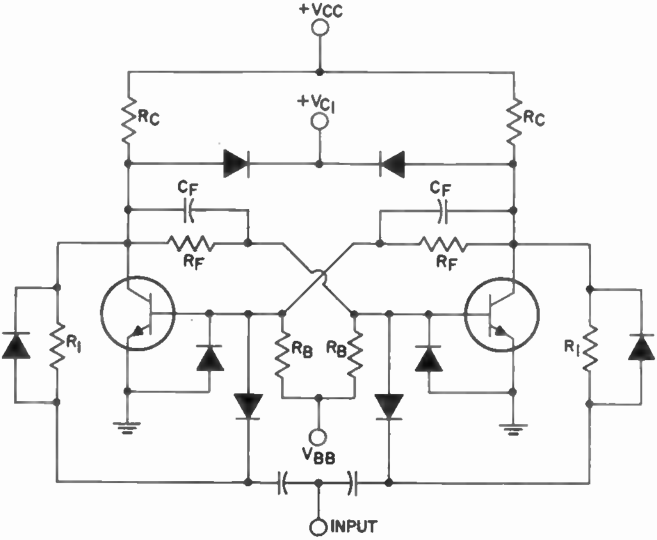


Figure 119. Binary-counter-type flip-flop circuit.

tive cross-coupling, (2) inductive cross-coupling, and (3) coupling through common impedances. The inductive noise component is generally the most significant in transistor circuits because relatively low voltages and high currents are present.

To optimize a switching design for noise immunity, it is necessary to determine what noise-voltage amplitude at the input is required to cause a change at the output. Because this amplitude is a function of the transient response of the switching circuit, the pulse width or duration of the noise voltage must also be considered. In the following discussion, it is assumed that the noise voltage is of sufficient duration that effects of the circuit transient response may be neglected (i.e., that the noise-voltage duration is no less than the longest turn-on or turn-off time of the switching circuit).

The DTL circuit shown in Fig. 116 can be used to illustrate the design of a logic circuit for noise immunity. When all inputs are high, a negative noise pulse at any input tends to turn the ON transistor off; a positive noise pulse has no effect. The amplitude of noise required to effect a change is determined by the reverse bias V_R on the input diodes, the amount of forward bias V_F necessary to cause appreciable conduction of an input diode, and the stored charge Q_S of the ON transistor. For the ON condition, therefore, the negative noise-voltage amplitude required to cause a change in the output is given by

$$-V_n = V_R + V_F + (Q_S/C_F)$$

When any one of the inputs is low and the transistor is OFF, only a positive noise pulse at a low input has any effect on the transistor output. The amplitude of the positive noise voltage required to start the transistor turning ON is determined by the amount of reverse bias V_B on the base-to-emitter junction of the transistor, the forward bias V_{BE} required across the base-to-emitter junction to cause appreciable conduction of base current, and the amount of charge necessary to charge the input capacitance C_i at the base through the voltage $V_B + V_{BE}$. For the OFF condition, therefore, the positive noise-voltage amplitude required is given by

$$V_R = (V_B + V_{BE}) \left(1 + \frac{C_I}{C_F}\right)$$

A per-cent noise-immunity figure can be defined for a particular circuit as the ratio of the noise voltages determined above to the normal voltage swing of a true input, which is approximately equal to the collector supply voltage. It is desirable to have equal noise immunity for both the ON and OFF conditions because the per-cent noise-immunity figure for the circuit is no better than the lower value.

Because the values V_F, V_{BE}, Q_B, C_F, and C_I are constants for a specific transistor and diode, the values of V_R and V_B may be chosen to obtain a desired noise immunity for a given circuit design. However, circuit noise immunity and fan-out capability are interdependent; if noise immunity is made too large; fan-out capability will suffer. Therefore, a compromise between the two must be made.

Power Switching

Because of their efficiency and reliability, transistor switches are ideally suited to the control of large amounts of power. However, the efficiency of a power switching circuit is affected by the switching speed of the transistor. In some applications a faster transistor that has a low power rating may be preferred to a slower transistor that has a higher power rating.

In a practical switching circuit, the average power dissipated in the transistor is much less than the peak dissipation. The peak dissipation varies considerably with the type of load. The average power dissipation can be reduced, and thus the efficiency of the circuit can be increased, by use of a transistor that has fast switching characteristics (minimum turn-on time and turn-off time), low collector-to-emitter saturation voltage $V_{CE}(sat)$, and low collector-cutoff current I_{CBO}.

An analysis of the transistor load line is an important consideration in achieving reliability in a high-power switch. In general, the load is a combination of resistive and reactive elements. It is almost never purely resistive, and for "worst-case" analysis can be assumed to be completely inductive.

Fig. 120 shows a simple test circuit which can be used for analysis of a load line. The current-sensing resistor R in the collector circuit should be non-inductive and have a resistance much smaller than any other impedance in series with the transistor. A typical load line (collector current I_C as a function of collector-to-emitter voltage V_{CE}) for this circuit is shown in Fig. 121. Fig. 122 shows typical voltage and current curves as a function of time for this switch. The curves of Figs. 121 and 122 can be used for calculation of the peak and average power dissipation, voltage limitations, and second-breakdown energy. The turn-off energy of the switch must not

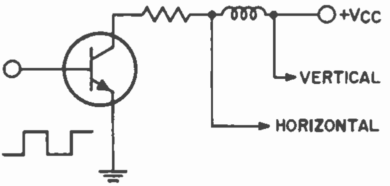


Figure 120. Simple test circuit for analysis of a load line.

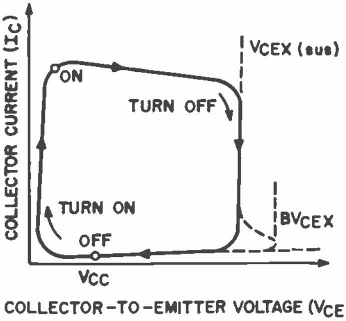


Figure 121. Typical load line for circuit shown in Figure 120.

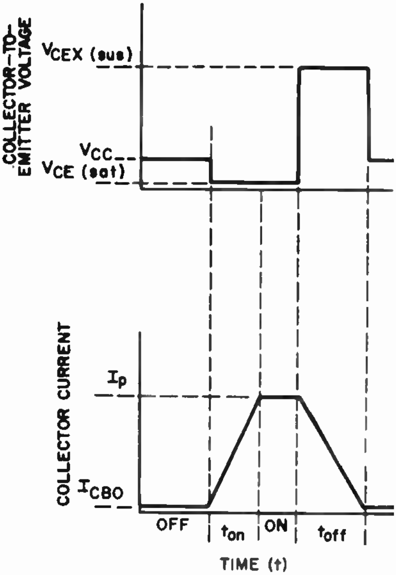
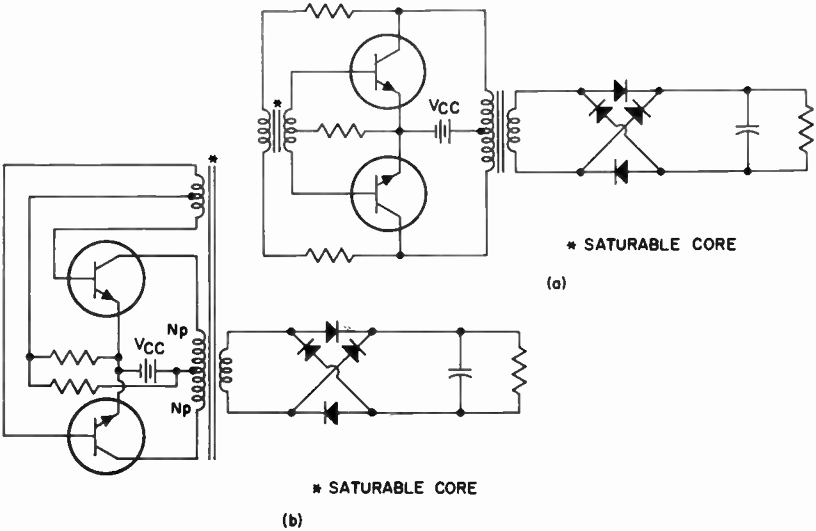


Figure 122. Typical voltage and current waveforms for switch shown in Figure 120.

exceed the second-breakdown voltage rating for the transistor used.

In many cases, the dc voltage required to operate electronic equipment is different from the available dc supply. The circuit used to convert direct current from one level to another is called a **converter.** Fig. 123 shows two simple converter circuits which can be used in place of the conventional vibrator-type converter in automobile radios. The switching drive to the two transistors is supplied by a separate, small, saturable transformer in the circuit of Fig. 123a, and by an additional center-tapped drive winding on a single saturable transformer in Fig. 123b. The characteristic hysteresis loop of the auto-transformer used in the circuit of Fig. 123b is shown in Fig. 124. Transformer parameters such as frequency, number of turns, and size and type of core material are determined by the operating requirements for the circuit. Once the transformer has been established, a change in supply voltage results in a change in the operating frequency.

Switching is accomplished as a result of the saturation of the transformer. When the slope of the hysteresis loop shown in Fig. 124 is small, the magnetizing inductance is small and the magnetizing current



* SATURABLE CORE

(a)

* SATURABLE CORE

(b)

Figure 123. Simple converter circuits that can be used in place of vibrator-type converters in automobile radios.

increases rapidly. This situation exists as the loop is traversed in a counter-clockwise manner from point 1 to point 2. From point 2 to point 3, the magnetizing current increases very slowly because the magnetizing inductance is high. At point 3, the core is in saturation, and the magnetizing current again increases rapidly. As the current continues to increase (between points 3 and 4), the ON transistor comes out of saturation. When point 4 has been reached, the voltages across the primary windings of the transformer have dropped to zero, and the battery voltage is applied across the collector-to-emitter terminals of each transistor. The magnetizing current then begins to decay, and voltages of opposite polarity are induced across the transformer. At point 5, the magnetizing current has been reduced to zero, the second transistor is in saturation, and the first transistor has twice the battery voltage across its emitter-to-collector junction. This sequence of events is repeated during each half-cycle of the operation of the circuit, except for a reversal of polarity.

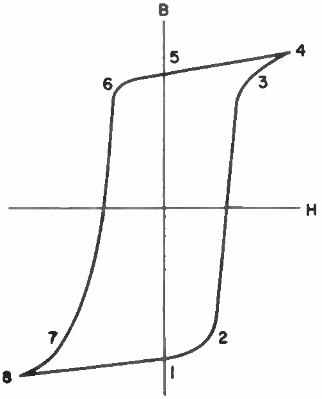


Figure 124. Characteristic hysteresis loop of auto-transformer used in circuit of Figure 123b.

The approximate load line of the converter circuit of Fig. 123b is shown in Fig. 125. Many of the important transistor ratings can be determined from this curve. For example, the collector-to-emitter sustaining voltage under reverse-bias conditions, $V_{CEV}(sus)$, is given by

$$V_{CEV}(sus) \geq 2V_{CC} + \Delta V_{CC}$$

where V_{CC} is the collector-supply voltage and ΔV_{CC} is the magnitude of the supply variations or "spikes". The second-breakdown voltage limit $E_{S/B}$ for the transistor is given by

$$E_{S/B} \geq \frac{1}{2}(\beta I_B)^2 Ll$$

where β is the common-emitter forward transfer-current ratio, I_B is the base current, and Ll is the total series inductance of the transformer and the load reflected to the input.

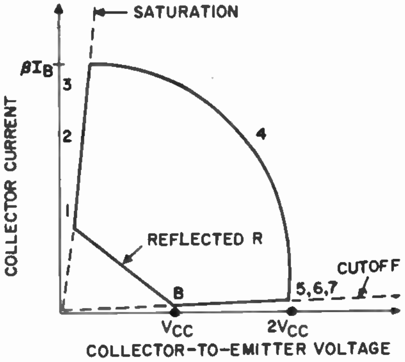


Figure 125. Approximate load line for converter circuit shown in Figure 123b.

As mentioned previously, the collector-to-emitter saturation voltage $V_{CE}(sat)$ of the transistor should be low.

The change in frequency of operation of a converter with supply voltage is not usually important because the ac voltage is rectified and filtered. In an inverter circuit, however, the frequency may be very important and is generally controlled by adjustment of the supply voltage. Typically, the dc supply voltage is controlled by means of a voltage regulator inserted ahead of the converter to stabilize the input voltage and a power amplifier following the converter to isolate the converter from the effects of a varying load.

Fig. 126 shows a block diagram

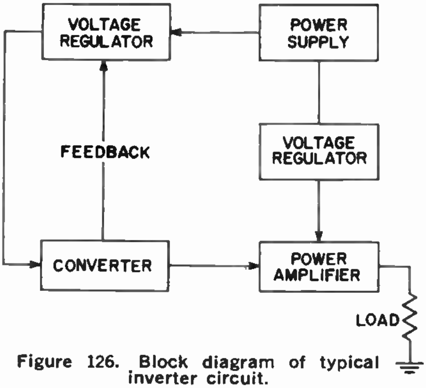


Figure 126. Block diagram of typical inverter circuit.

of a typical inverter circuit. The output frequency is directly dependent on the induced voltage of the converter transformer. The feedback shown samples this induced voltage and adjusts the output of the voltage regulator to maintain a constant induced voltage in the converter and thus a constant output frequency. If a regulated output voltage is not required, the second voltage regulator is omitted.

In the operation of a regulator circuit, the difference between a reference input (e.g., the supply voltage) and some portion of the output voltage (e.g., a feedback signal) is used to supply an actuating error signal to the control elements. The amplified error signal is applied in a manner that tends to reduce this difference to zero. Regulators are designed to provide a constant output voltage very nearly equal to the desired value in the presence of varying input voltage and output load.

A switching regulator provides at least three major advantages over conventional series-type regulators: (1) higher efficiency (lower power dissipation, smaller physical size); (2) use of fewer, more economical transistors; (3) higher power-output capabilities. In the typical switching regulator shown in Fig. 127, the series regulator transistor is pulse-duration modulated by the signal supplied from the multivibrator. The ON time of the multivibrator is in turn controlled by a dc comparison between a reference voltage developed across the zener diode D_1 and the output. The pulsed output from the series transistor is integrated by the low-pass filter. When the transistor is conducting, current is delivered to the load from the input source. In the OFF condition, diode D_2 conducts and the energy stored in the reactive elements supplies current to the load.

When a step-down regulator is required (e.g., 100 volts down to 28 volts), the efficiency of a switching regulator is considerably higher than that of a conventional series regulator. If very precise regulation is required, the switching regulator can be used as a pre-regulator followed by a conventional regulator circuit; this configuration optimizes the advantages of both types of regulators. Over-all efficiency for such a combination circuit is typically about 80 to 85 per cent, as compared to values of 25 to 30 per cent for a conventional series-type step-down regulator. In addition, total power dissipation is reduced from several hundreds of watts to less than 50 watts.

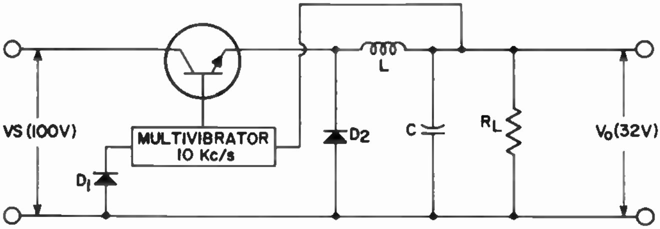


Figure 127. Typical switching regulator.

MOS Field-Effect Transistors

Field-effect transistors combine the inherent advantages of solid-state devices (small size, low power consumption, and mechanical ruggedness) with a very high input impedance and a square-law transfer characteristic that is especially desirable for low cross-modulation in rf amplifiers. Unlike the other transistors described in this Manual, which are **bipolar** devices (i.e., performance depends on the interaction of two types of charge carriers, holes and electrons), field-effect transistors are **unipolar** devices (i.e., operation is basically a function of only one type of charge carrier, holes in p-channel devices and electrons in n-channel devices).

Early models of field-effect transistors used a reverse-biased semiconductor junction for the control electrode. In MOS (metal-oxide-semiconductor) field-effect transistors, a metal control "gate" is separated from the semiconductor "channel" by an insulating oxide layer. One of the major features of the metal-oxide-semiconductor structure is that the very high input resistance of MOS transistors (unlike that of junction-gate-type field-effect transistors) is not affected by the polarity of the bias on the control (gate) electrode. In addition, the leakage currents associated with the insulated control electrode are relatively unaffected by changes in ambient temperature. Because of their unique properties, MOS field-effect transistors are particularly well suited for use in such applications as voltage amplifiers, rf amplifiers, and voltage-controlled attenuators.

THEORY OF OPERATION

The operation of field-effect devices can be explained in terms of a charge-control concept. The metal control electrode, which is called a **gate**, acts as a charge-storage or control element. A charge placed on the gate induces an equal but opposite charge in the semiconductor layer, or **channel**, located beneath the gate. The charge induced in the channel can then be used to control the conduction between two ohmic contacts, called the **source** and the **drain**, made to opposite ends of the channel.

In the junction-gate type of field-effect transistor, a p-n junction is used for the gate or control electrode, as shown in Fig. 128. When this junction is reverse-biased, it functions as a charge-control electrode. Under steady-state condi-

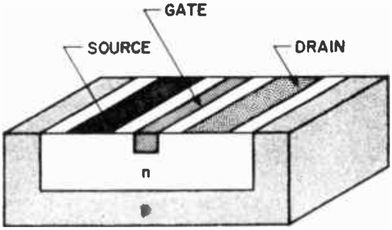


Figure 128. Structure of p-n junction field-effect transistor.

tions, only leakage currents flow in the gate circuit and thus the device has a high input resistance. When the junction gate is forward-biased, however, the input resistance drops sharply, there is appreciable input current, and power gain decreases significantly.

The MOS type of field-effect transistor uses a metal gate electrode separated from the semiconductor material by an insulator, as shown in Fig. 129. Like the p-n junction, this insulated-gate electrode can deplete the source-to-drain channel of active carriers when suitable bias voltages are applied. However, the insulated-gate electrode can also increase the conductivity of the channel without increasing steady-state input current or reducing power gain.

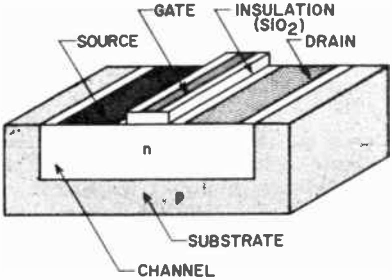


Figure 129. Structure of an MOS field-effect transistor.

The two basic types of MOS field-effect transistors are the depletion type and the enhancement type. In the depletion type, charge carriers are present in the channel when no bias voltage is applied to the gate. A reverse gate voltage is one which depletes this charge and thereby reduces the channel conductivity. A forward gate voltage draws more charge carriers into the channel and thus increases the channel conductivity. In the enhancement type, the gate must be forward-biased to produce active carriers and permit conduction through the channel. No useful channel conductivity exists at either zero or reverse gate bias.

Because MOS transistors can be made to utilize either electron conduction (n-channel) or hole conduction (p-channel), four distinct types of MOS field-effect transistors are possible. As shown in Fig. 130, the schematic symbol for an MOS transistor indicates whether it is n-channel or p-channel, depletion-type or enhancement-type. The direction of the arrowhead in the symbol identifies the n-channel device (arrow pointing toward the channel) or the p-channel device (arrow pointing away from the channel). The channel line itself is made solid to identify the "normally ON" depletion-type, or is interrupted to identify the "normally OFF" enhancement type.

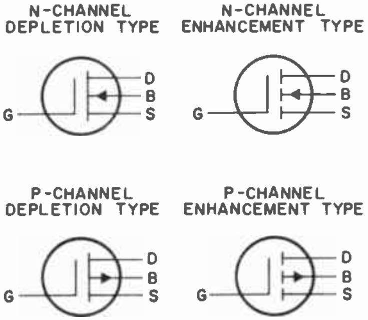


Figure 130. Schematic symbols for MOS transistors (G = gate, D = drain, B = active bulk, S = source).

Fig. 131 shows a cross-section view of an n-channel enhancement-type MOS transistor (reversal of n-type and p-type regions would produce a p-channel enhancement-type transistor). This type of transistor is normally non-conducting until a sufficient voltage of the correct

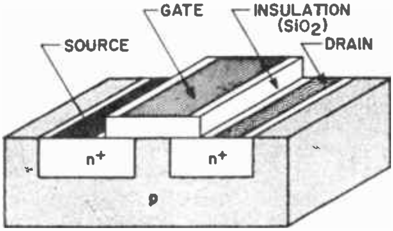


Figure 131. Structure of n-channel enhancement-type MOS transistor.

polarity is applied to the gate electrode. When a positive bias voltage is applied to the gate of an n-channel enhancement transistor, electrons are drawn into the channel region beneath the gate. If sufficient voltage is applied, this channel region changes from p-type to n-type and provides a conduction path between the n-type source and the n-type drain regions. (In a p-channel enhancement transistor, the application of negative bias voltage draws holes into the region below the gate so that this channel region changes from n-type to p-type and again provides a source-to-drain conduction path.) Effectively, the increase in gate voltage causes the forward transfer characteristic to shift along the gate-voltage axis. Because of this feature, enhancement-type MOS transistors are particularly suitable for switching applications.

In a depletion-type MOS transistor, the channel region between the source and the drain is made of material of the same conductivity type as both the source and drain, as was shown in Fig. 129. This structure can provide substantial drain current even when no gate bias voltage is applied.

In enhancement-type transistors, the gate electrode must cover the entire region between the source and the drain so that the applied gate voltage can induce a conductive channel between them. In depletion-type transistors, however, the gate can be "offset" from the drain region to achieve a substantial reduction in feedback capacitance and an over-all improvement in amplifier circuit stability.

FABRICATION

The fabrication techniques used to produce MOS transistors are similar to those used for modern high-speed silicon bipolar transistors. The starting material for an n-channel transistor is a lightly doped p-type silicon wafer. (Reversal of p-type and n-type materials referred to in this description produces a p-channel transistor.) After the wafer is polished on one side and oxidized in a furnace, photolithographic techniques are used to etch away the oxide coating and expose bare silicon in the source and drain regions. The source and drain regions are then formed by diffusion in a furnace containing an n-type impurity (such as phosphorus). If the transistor is to be an enhancement-type device, no channel diffusion is required. If a depletion-type transistor is desired, an n-type channel is formed to bridge the space between the diffused source and drain.

The wafer is then oxidized again to cover the bare silicon regions, and a second photolithographic and etching step is performed to remove the oxide in the contact regions. After metal is evaporated over the entire wafer, another photolithographic and etching step removes all metal not needed for the ohmic contacts to the source, drain, and gate. The individual transistor chips are then mechanically separated and mounted on individual headers, connector wires are bonded to the metalized regions, and each unit is hermetically sealed in its case in an inert atmosphere. After testing, the external leads of each device are physically shorted together to prevent electrostatic damage to the gate insulation during branding and shipping.

ELECTRICAL CHARACTERISTICS

The basic current-voltage relationship for a depletion-type MOS transistor operating in the common-source configuration is shown in Fig. 132. At low drain-to-source potentials and with the gate returned to the source ($V_G = 0$), the resistance of the channel is essentially constant and current varies linearly with voltage, as illustrated in region A-B. As the drain current is increased beyond point B, the voltage (IR) drop in the channel produces a progressively greater voltage difference between the gate and points in the channel successively closer to the drain. As this potential difference between gate and channel increases, the channel is depleted of carriers (becomes "constricted") and drain current increases much more slowly with further increases in drain-to-source voltage, as shown in region B-C. Further increases in drain-to-source voltage beyond point C produce no change in gate current until point D is reached. This condition leads to the description of region B-D as the "pinch-off" region. Beyond point D, the transistor enters the "breakdown" region, and the drain current may increase excessively. (The upper curve in Fig. 132 also applies to enhancement-type transistors provided the gate voltage V_G is large enough to produce channel conduction.)

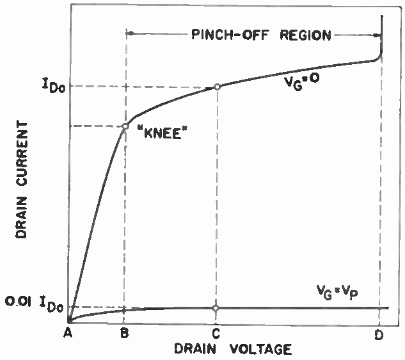


Figure 132. Basic current-voltage relationship for a depletion-type MOS transistor.

The channel of an MOS transistor may achieve self pinch-off as a result of the intrinsic IR drop alone, or it may be pinched off by a combination of intrinsic IR drop and an external voltage applied to the gate, or by an external gate voltage alone which has the same magnitude as the self pinch-off IR drop V_P. In any case, channel pinch-off occurs when the sum of the intrinsic IR drop and the extrinsic gate voltage reaches V_P. The **pinch-off voltage** V_P is usually defined as the gate cutoff voltage V_G(off) that reduces the drain current to one per cent of its zero-gate-voltage value at a specified drain-to-source voltage (which must be the "knee" voltage, point B in Fig. 132, of the zero-gate-voltage output characteristic).

The pinch-off region between points B and D in Fig. 132 is the region in which MOS transistors are especially useful as high-impedance voltage amplifiers. In the ohmic region between points A and B, the linear variation in channel resistance makes the device useful in voltage-controlled resistor applications such as the chopper unit at the input of some dc amplifiers.

Typical output-characteristic curves for n-channel MOS transistors are shown in Fig. 133. (For p-

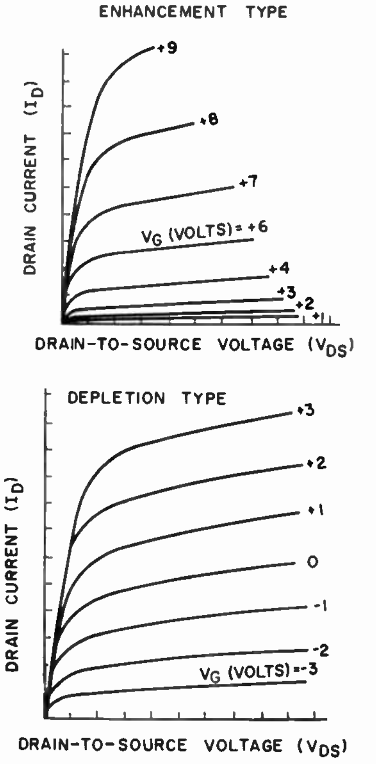


Figure 133. Typical output-characteristic curves for n-channel MOS transistors.

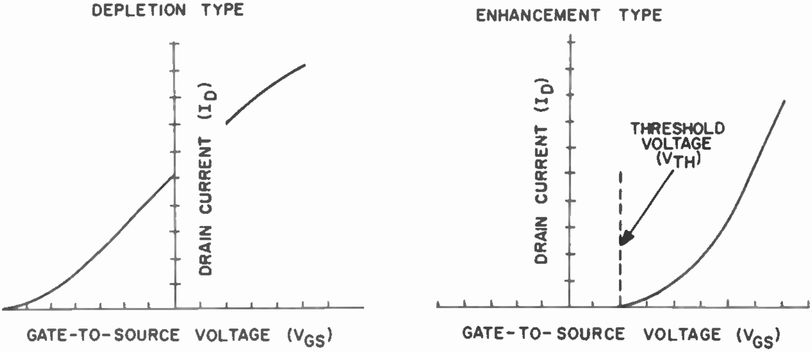


Figure 134. Typical transfer characteristics for n-channel MOS transistors.

channel transistors, the polarity of the voltages and currents is reversed.) In the pinch-off region, the dynamic output resistance r_{os} of the transistor may be approximated from the slope of the output-characteristic curve at any given set of conditions.

Typical transfer characteristics for n-channel MOS transistors are shown in Fig. 134. (Again, polarities would be reversed for p-channel devices.) The threshold voltage shown in Fig. 134 is an important parameter for enhancement-type transistors because it provides a desirable region of noise immunity for switching applications.

GENERAL CIRCUIT CONFIGURATIONS

There are three basic single-stage amplifier configurations for MOS transistors: common-source, common-gate, and common-drain. Each of these configurations provides certain advantages in particular applications.

The **common-source** arrangement, shown in Fig. 135, is most frequently used. This configuration provides a high input impedance, medium to high output impedance, and voltage gain greater than unity. The input signal is applied between gate and source, and the output signal is taken between drain and source. The voltage gain without feedback, A, for the common-source circuit may be determined as follows:

$$A = \frac{g_{fs}\, r_{os}\, R_L}{r_{os} + R_L}$$

where g_{fs} is the gate-to-drain forward transconductance of the transistor, r_{os} is the common-source output resistance, and R_L is the effective load resistance. The addition of an unbypassed source resistor to the circuit of Fig. 135 produces negative voltage feedback proportional to the output current. The voltage gain with feedback, A′, for a common-source circuit is given by

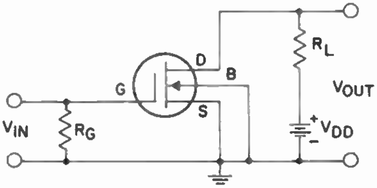


Figure 135. Basic common-source circuit for MOS field-effect transistors.

$$A' = \frac{g_{fs}\, r_{os}\, R_L}{r_{os} + (g_{fs}\, r_{os} + 1)\, R_S + R_L}$$

where R_S is the total unbypassed source resistance in series with the source terminal. The common-source output impedance with feedback, Z_o, is increased by the unbypassed source resistor as follows:

$$Z_o = r_{os} + (g_{fs}\, r_{os} + 1)\, R_S$$

The **common-drain** arrangement, shown in Fig. 136, is also frequently referred to as a **source-follower.** In this configuration, the input impedance is higher than in the common-source configuration, the output impedance is low, there is no polarity reversal between input and output, the voltage gain is always less than unity, and distortion is low. The source-follower is used in applications which require reduced input-circuit capacitance, downward impedance transformation, or increased input-signal-handling capability. The input signal is effectively injected between gate and drain, and the output is taken between source and drain. The circuit inherently has 100-per-cent negative voltage feedback; its gain A′ is given by

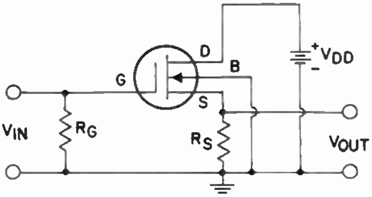


Figure 136. Basic common-drain (or source-follower) circuit for MOS transistors.

$$A' = \frac{R_S}{\frac{\mu + 1}{\mu} R_S + \frac{1}{g_{fs}}}$$

Because the amplification factor (μ) of an MOS transistor is usually much greater than unity, the equation for gain in the source-follower can be simplified as follows:

$$A' = \frac{g_{fs} R_S}{1 + g_{fs} R_S}$$

For example, if it is assumed that the gate-to-drain forward transconductance g_{fs} is 2000 micromhos (2×10^{-3} mho) and the unbypassed source resistance R_S is 500 ohms, the stage gain A′ is 0.5. If the same source resistance is used with a transistor having a transconductance of 10,000 micromhos (1×10^{-2} mho), the stage gain increases to 0.83.

When the resistor R_G is returned to ground, as shown in Fig. 136, the input resistance R_i of the source-follower is equal to R_G. If R_G is returned to the source terminal, however, the effective input resistance R_i' is given by

$$R_i' = \frac{R_G}{1 - A'}$$

where A′ is the voltage amplification of the stage with feedback. For example, if R_G is one megohm and A′ is 9.5, the effective resistance R_i' is two megohms.

If the load is resistive, the effective input capacitance C_i' of the source-follower is reduced by the inherent voltage feedback and is given by

$$C_i' = c_{gd} + (1 - A')\, c_{gs}$$

where c_{gd} and c_{gs} are the intrinsic gate-to-drain and gate-to-source capacitances, respectively, of the MOS transistor. For example, if a typical 3N99 transistor having a c_{gd} of 0.3 picofarad and a c_{gs} of 5 picofarads is used, and if A′ is equal to 0.5, then C_i' is reduced to 2.8 picofarads.

The effective output resistance R_o' of the source-follower stage is given by

$$R_o' = \frac{r_{os} R_S}{(g_{fs} r_{os} + 1) R_S + r_{os}}$$

where r_{os} is the transistor common-source output resistance in ohms. For example, if a 3N99 having a gate-to-drain forward transconductance g_{fs} of 2000 micromhos and a common-source output resistance r_{os} of 7500 ohms is used in a source-follower stage with an unbypassed source resistance R_S of 500 ohms, the effective output resistance R_o' of the source-follower stage is 241 ohms.

The source-follower output capacitance C_o' may be expressed as follows:

$$C_o' = c_{ds} + c_{gs} \left(\frac{1 - A'}{A'}\right)$$

where c_{ds} and c_{gs} are the intrinsic drain-to-source and gate-to-source capacitances, respectively, of the MOS transistor. If A′ is equal to 0.5 (as assumed for the sample input-circuit calculations), C_o' is reduced to the sum of c_{ds} and c_{gs}.

The common-gate circuit, shown in Fig. 137, is used to transform from a low input impedance to a high output impedance. The input impedance of this configuration has approximately the same value as the output impedance of the source-follower circuit. The common-gate circuit is also a desirable configuration for high-frequency applications because its relatively low voltage gain makes neutralization unnecessary in most cases. The common-gate voltage gain, A, is given by

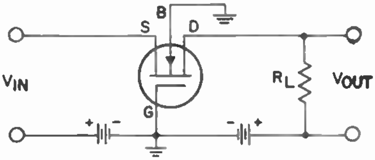


Figure 137. Basic common-gate circuit for MOS transistors.

$$A = \frac{(g_{fs}\, r_{os} + 1)\, R_L}{(g_{fs}\, r_{os} + 1)\, R_G + r_{os} + R_L}$$

where R_G is the resistance of the input-signal source. For a typical 3N99 MOS transistor ($g_{fs} = 2000$ micromhos, $r_{os} = 7500$ ohms) and with $R_L = 2000$ ohms and $R_G = 500$ ohms, the common-gate voltage gain is 1.8. If the value of R_G is doubled, the voltage gain is reduced to 1.25.

APPLICATIONS

MOS field-effect transistors have been used experimentally to perform every low-power function in broadcast-band receivers, including rf amplification, conversion, 455-kilocycle if amplification, and first-stage audio amplification. In addition, they have been used in FM receivers as rf and if amplifiers and limiters. They have performed as synchronous detectors, oscillators, frequency multipliers, and phase splitters. They have been used as choppers, pulse stretchers, current limiters, voltage-controlled attenuators, and electrometer amplifiers. MOS transistors have an advantage over bipolar transistors and vacuum tubes in some of these applications, but are less suitable in others. As improvements are made in transconductance, frequency response, and noise figure, MOS transistors should become competitive in more applications.

At their present state of development, MOS transistors have an equivalent input noise resistance which is typically in the range between 200,000 ohms and 10 megohms at a signal frequency of 1000 cycles per second. Although this level of noise resistance is usually no problem when MOS transistors are used with high-impedance transducers, it can be a definite disadvantage during operation from low-impedance (1000 ohms or less) voltage generators. In such applications, low-noise bipolar transistors are still the logical choice.

Direct-Current Amplifiers

A direct-current (dc) amplifier can amplify signals having a frequency of zero cycles per second. The upper frequency limit of such an amplifier may range from a few hundred cycles per second in general-purpose electrometer applications to several megacycles per second in other applications. In general, dc amplifiers are used to amplify the output of transducers which produce quantitative information relative to heat, vibration, pressure, speed, and distance.

DC amplifiers may take several different forms, including single-ended input to single-ended output, differential input to single-ended output, and differential input to differential output. Normally, dc amplifiers require direct coupling of all stages (no coupling capacitors). In some versions of dc amplifiers, this requirement is circumvented by conversion of the low- or zero-frequency input signal into a modulated ac signal, amplification of this signal by means of capacitor-coupled stages, and then demodulation of the amplified signal to restore it to the original dc form. The necessary modulation may be accomplished by a number of different techniques, including electrically actuated mechanical switches, electronic switches, photo-optical switches, magnetic modulators, and diode bridge modulators. Input devices which function as switches are generally referred to as "choppers" because they divide the input signal into segments in the form of square waves or pulses having an amplitude proportional to the amplitude of the input signal.

Single-ended dc amplifiers which do not employ "choppers" have a continuous ohmic current path between the input and the output as the result of direct coupling of all stages (i.e., the omission of all capacitive or inductive forms of coupling). In this configuration, the steady-state voltage at the output of one stage appears at the input of the next stage. In a typical cascade arrangement using MOS field-effect transistors, the signal progresses from the drain of the first unit to the gate of the next and so on to the last stage, as shown in Fig. 138.

In general, the ideal MOS transistor for use in a single-ended dc amplifier circuit has an optimum zero-signal operating point which is obtained at a gate voltage having the same magnitude as the optimum drain voltage and also the same polarity. Because enhancement-type MOS transistors automatically meet the latter requirement and can be designed to meet the former requirement, they are generally the logical choice for most direct-coupled circuits. If other device considerations (such as gain, input impedance, temperature coefficient, or noise) require the use of depletion-type transistors, such transistors can be direct-coupled by the use of level shifting, as shown in Fig. 139. In this circuit configuration, the source terminal is generally placed at a potential equal to or greater than the drain-to-source voltage of the preceding stage and of an opposite polarity. In the arrangement of Fig. 139, the gate is at a net zero voltage or is reverse-biased relative to the source.

Although the 3N98 and 3N99 MOS transistors are not optimized for direct-coupled applications, they can be used in such circuits because they have low gate leakage current (typically fractions of a picoampere), total input capacitance of about 5 picofarads, and an appreciable value of forward transconductance. In addition, tight production control limits the spread of drain current between individual transistors to a variation

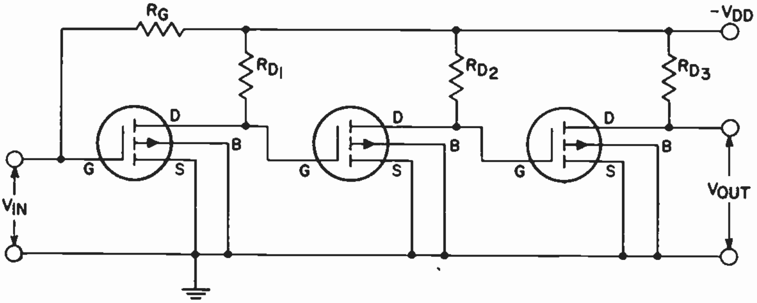


Figure 138. Typical single-ended dc amplifier using n-channel enhancement-type MOS transistors.

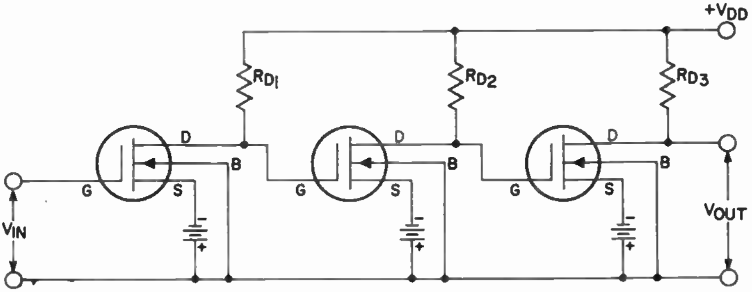


Figure 139. DC amplifier circuit in which p-channel depletion-type MOS transistors are direct-coupled by use of level shifting.

of approximately two to one for a high degree of interchangeability.

For a fixed value of supply voltage, there are only three ways to increase the stage voltage gain A in a single-ended amplifier: (1) use of a transistor having a higher ratio of gate-to-drain forward transconductance g_{fs} to drain current I_D; (2) use of a higher value of load resistance R_L (if R_L is less than the common-source output resistance r_{os}); and (3) use of a transistor having a higher value of r_{os}. The load resistance R_L can only be increased to the point where the product of I_D and R_L is equal to approximately one-half the supply voltage. In general, the ratio of transconductance to drain current increases as drain current is decreased by negative gate bias. As a result, the stage voltage gain may be increased and power consumption decreased at the same time.

The increased voltage gain of an MOS transistor at reduced values of drain current may be accompanied by a relatively large drift in the operating point if there are wide excursions in ambient temperature. Many field-effect transistors have a point on their forward-transfer characteristic which is relatively insensitive to temperature variations. If this point does not coincide with the operating point which provides the desired voltage gain, a design compromise is required. As shown in Fig. 140, the zero-temperature-

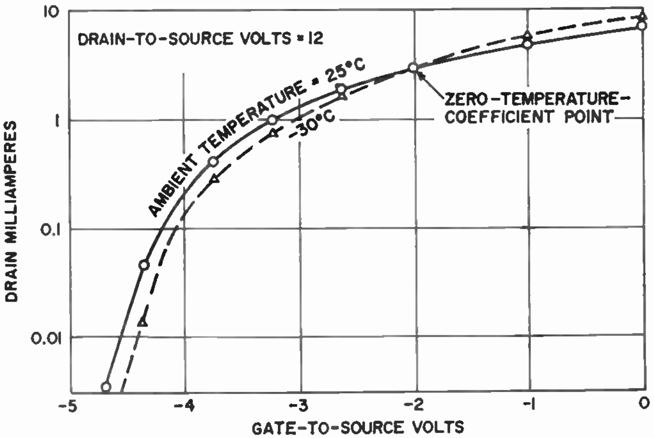


Figure 140. Forward-transfer characteristics of MOS transistor at 25°C and −30°C; intersection indicates zero-temperature-coefficient operating point.

coefficient point may be identified by measurement of the forward-transfer characteristic at different ambient temperatures.

AC Amplifiers

In most ac amplifiers, coupling between stages is accomplished by the use of transformers or capacitors with chokes or resistors serving as the load impedances. Because no ohmic path exists between stages in such amplifiers, variations in the dc operating point of one stage are not transferred to, and amplified by, the succeeding stage. This property is a primary advantage of ac amplifiers for instrumentation work, and is the basis for the chopper amplifier described earlier, in which a dc signal is converted to ac prior to amplification.

MOS transistors such as the 3N98 and 3N99 perform very well as ac voltage amplifiers because of their inherently low feedback capacitance, which maintains the total effective input capacitance at a relatively low value. The Circuits section at the back of the Manual includes an ac-voltmeter circuit that illustrates the type of ac-amplifier performance which can be achieved with the 3N99 MOS transistor.

Voltage-Controlled Attenuators

Because the drain current-voltage characteristic of MOS transistors remains linear at low drain-to-source voltages, these devices can be used as low-distortion voltage-controlled attenuators. The principal advantages of MOS transistors in this application are negligible gate-power requirements and large dynamic range.

Fig. 141 shows drain resistance as a function of gate-to-source voltage for a typical n-channel depletion-type insulated-gate transistor such as the 3N98 or 3N99. Transistors having higher pinch-off voltages accept correspondingly greater peak signal-voltage swings before waveshape distortion occurs. However, the higher-pinch-off-voltage transistors require higher gate-voltage excursions to cover the resistance range from minimum to maximum. A typical 3N99 MOS transistor produces total harmonic distortion of less than two per cent in a 100-millivolt 400-cycle-per-second sine wave. Fig. 142 shows an attenuator circuit using the 3N99 and the output signal of the circuit as a function of gate-to-source voltage.

Figs. 143 to 145 show several possible attenuator circuit configurations which use MOS transistors as

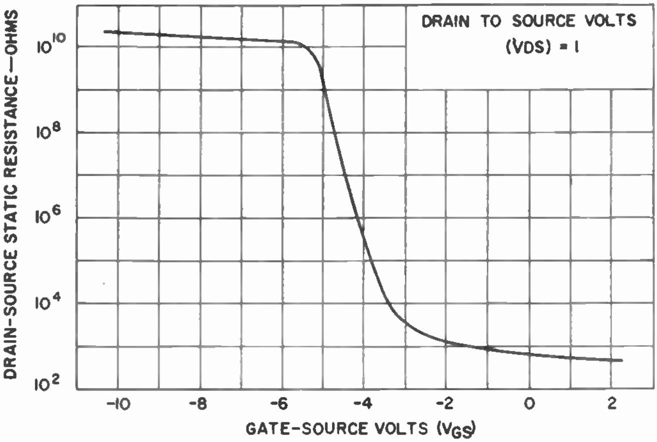


Figure 141. Drain resistance as a function of gate voltage for typical n-channel depletion-type MOS transistor.

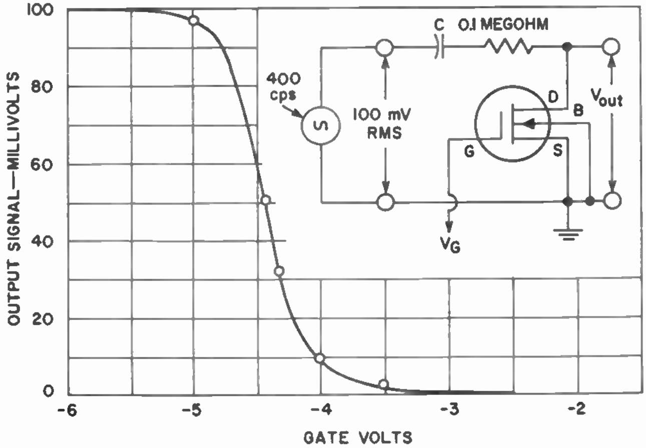


Figure 142. Output signal as a function of gate voltage for 3N99 MOS transistor in circuit shown.

voltage-variable resistors. The circuit in Fig. 143 is desirable for use at high signal levels because at such levels the thermal noise of the one-megohm series resistor does not degrade the signal-to-noise ratio of the system to an objectionable degree. This circuit is a simple L-pad configuration in which the transistor serves as the variable-resistive element in the low side of the attenuator. The maximum attenuation obtainable is generally between 60 and 70 dB; minimum attenuation is 1 to 2 dB. This circuit must be followed by a high-impedance load such as a common-source amplifier stage.

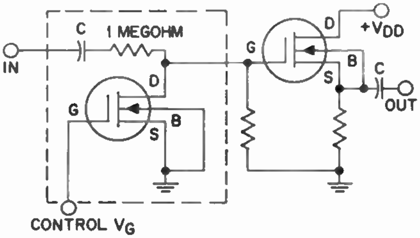


Figure 143. Attenuator circuit in which MOS transistor serves as variable-resistive element in low side.

The circuit shown in Fig. 144 is the inverse of that in Fig. 143; i.e., the transistor serves as the variable-resistive element in the high side of the attenuator. Maximum attenuation in this circuit is also between 60 and 70 dB; minimum attenuation is between 1 and 6 dB. This circuit is usually followed by a low-impedance load such as a common-emitter bipolar transistor amplifier stage.

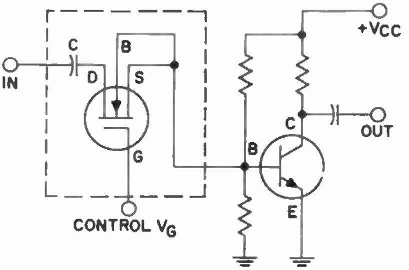


Figure 144. Attenuator circuit in which MOS transistor serves as variable-resistive element in high side.

Fig. 145 shows a method which controls both arms of an L-pad attenuator simultaneously. In this circuit, a p-channel enhancement-type MOS transistor is used in the upper arm and an n-channel depletion-type MOS transistor is used in the lower arm. When negative voltage is applied to the gates, the resistance of the n-channel unit increases at the same time that the resistance of the p-channel unit decreases. When the gate control is at zero volts, the drain resistance of Q_2 is about 500 ohms and that of Q_1 is about 10 megohms. Under these conditions, a maximum attenuation of approximately 86 dB is obtained. When the gate control is at −6 volts, the drain resistance of Q_2 is about 10 megohms and that of Q_1 is about 500 ohms. Under these conditions, the attenuation is essentially zero. This circuit must work into a high-impedance load.

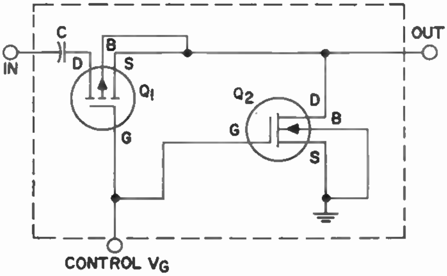


Figure 145. L-pad attenuator circuit using two MOS transistors.

The following design considerations are important for effective use of MOS field-effect transistors as linear attenuators:

(a) The gate(s) must be adequately decoupled to prevent the introduction of unwanted signals.

(b) The transistor attenuator must be inserted at a point in the system where the signal level is as high as the transistor can accept without excessive distortion.

(c) In ac systems, the direct-current flow through the transistor must be minimized by the use of suitable blocking capacitors.

(d) In ac systems, proper layout must be used to minimize stray shunt capacitance.

(e) In ac systems, the effects of the capacitive elements of the transistor must be considered.

Chopper Amplifiers

Chopper amplifiers consist of three basic sections. The first section converts the low-level input signal into a modulated ac signal, the second section amplifies this ac signal, and the third section demodulates the amplified signal.

The first section of a chopper amplifier is fundamentally a continuously operated ON-OFF switch. Ideally, this switch would have zero ON resistance, infinite OFF resistance, zero shunt capacitance, and zero switching time. It would also require no driving power and have infinite life. In actual practice, it is possible to achieve satisfactory performance with a switch that does not have these ideal characteristics.

The two basic circuit configurations for chopping are the series chopper and the shunt chopper. The shunt chopper is the more popular of the two because it can be capacitively coupled to an ac amplifier without the need for either a choke or a transformer. The series chopper has the disadvantage that it requires a dc return path for the input current. This path can be provided by an additional resistor at the expense of over-all circuit efficiency.

The basic series chopper circuit using an MOS transistor is shown in Fig. 146. This circuit has the characteristics of a simple L-pad attenuator in which the transistor is the variable series resistor. In the ON condition, the value of the dc return resistance R_s must be large compared to the load resistance R_L to minimize resistive losses; R_L, in turn, must be large compared to the intrinsic drain resistance r_d(ON) so that the voltage V_L across the load approaches the value of the dc input

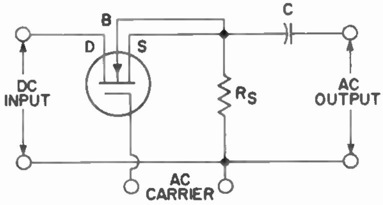


Figure 146. Basic series chopper circuit using an MOS transistor.

voltage V_G. In the OFF condition, the dc return resistance R_S must be small compared to r_d(OFF). Because of these restrictions, the series chopper is seldom used except when the fixed resistance R_S can be made variable by replacing it with a shunt chopper arranged to be OFF when the series chopper is ON, and vice versa.

Fig. 147 shows a shunt chopper circuit using an MOS transistor. In this circuit, the intrinsic drain resistance r_d of the transistor must be small compared to the load resistance R_L in the ON condition, but must be large compared to the fixed series resistance R_D in the OFF condition. The requirement for r_d(ON) to have a very small value is minimized if R_L is the high input impedance of an MOS transistor amplifier stage. Because of their high ON-to-OFF resistance ratio, negligible gate-leakage currents, and low feedthrough capacitance, MOS transistors such as the 3N98 and 3N99 considerably improve the level of solid-state chopper performance.

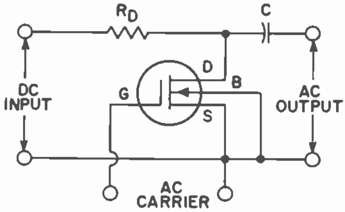


Figure 147. Basic shunt chopper circuit using an MOS transistor.

RF Amplifiers

The important parameters of devices for rf-amplifier applications include noise figure, power gain, and cross-modulation, among others.

In communication receivers, the noise figure of the rf stage determines the absolute selectivity of the receiver and is, therefore, one of the most important characteristics of the device used in the rf stage. In practical rf-amplifier circuits using MOS transistors, the best possible noise figures are obtained when the input impedance of the transistor is slightly mismatched to that of the source. With this technique, noise figures as low as 1.9 dB have been obtained.

Fig. 148 shows the input noise resistance R_N of typical MOS transistors as a function of frequency. In the region where the curves differ, the noise for n-channel MOS units closely resembles "shot noise", i.e., the equivalent noise current I_{eq} increases linearly with direct current, rather than with the square root of the direct current as in the case of thermal noise. Noise figures of 2 to 4 dB appear practical for MOS transistors operating in the vhf range.

The power gain of an rf transistor must be sufficient to overcome the noise level of preceding stages. Al-

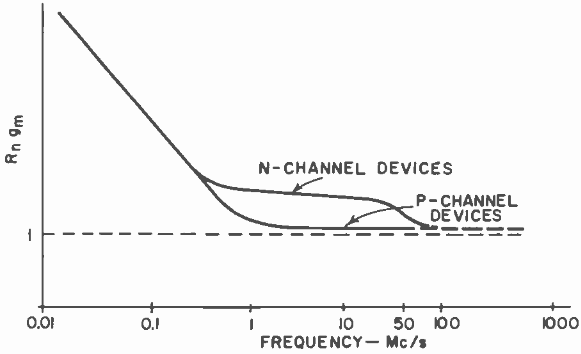


Figure 148. Input noise resistance R_N of MOS transistors as a function of frequency.

though maximum theoretical power gain cannot be achieved in practical circuits, the gain of MOS transistors at high frequencies closely approximates the theoretical limit except for some losses in the input and output matching circuits.

Power gain is essentially independent of channel width, which is a determining factor in the size of MOS transistors. For example, if the width of the transistor is reduced by one half (and the dc drain current is similarly reduced to maintain a constant current density in the device), power gain remains the same because the transconductance, the input conductance, and the output conductance are all reduced by one half. Consequently, the frequency capability of MOS transistors can be increased by a reduction in their size. Size control can also be used to facilitate impedance matching at both input and output terminals in practical circuits.

Cross-modulation distortion is produced when an undesired signal within the pass band of the receiver input circuit modulates the carrier of the desired signal. Such distortion occurs when third- and higher-odd-order nonlinearities are present in an rf-amplifier stage. To measure cross-modulation distortion, it is necessary to determine the amplitude of the undesired signal which transfers one per cent of its modulation to the desired signal. In most cases, a value of 100 millivolts or more over the complete agc range is considered good. The cross-modulation characteristics of MOS transistors are as good as those of bipolar transistors in the high-attenuation region, and are as much as ten times better in the low-attenuation region (when the incoming signal is weak). This low cross-modulation distortion should ultimately lead to extensive use of MOS transistors in the rf stages of all types of communications receivers.

Another feature of MOS transistors for rf applications is their **burn-out protection.** Because of their insulated gate, MOS units can be designed to withstand 50 to 100 volts at the input and still maintain excellent frequency response. In addition, MOS transistors designed for forward-bias operation have a remote cutoff characteristic and therefore have improved **dynamic** range.

There are three areas that must be considered in the design of rf circuits using MOS transistors: (1) output selectivity, (2) input and output matching, and (3) rf-stage neutralization. The first two areas are filter-design problems to which there are numerous solutions. The **neutralization** requirement can also be satisfied in many ways. Some of the more popular circuit techniques are shown in Fig. 149.

In the circuit of Fig. 149a, capacitor C_f represents the internal feedback capacitance of the MOS transistor amplifier A. An inverted output signal from the secondary of the transformer is fed back through a neutralization capacitance C_n. This feedback signal cancels the signal feedback through the internal path C_f.

The circuits in Fig. 149b, c, and d are best explained by bridge-type circuit models. In Fig. 149b, the additional capacitors C_n and C_x form a capacitance bridge with C_f and the output (drain) capacitance C_D. Thus, when the bridge is balanced so that C_nC_D equals C_xC_f, zero signal appears at the input for any value of E_o at the output, i.e., the amplifier is neutralized. In Fig. 149c, a capacitive bridge can be formed by use of the input (gate) capacitance instead of the output capacitance; C_n and C_x are added to form a bridge with C_f and C_G. In the balanced state, C_nC_G equals C_fC_x and the amplifier is neutralized. An inductance-capacitance bridge can be formed by inductors L_1 and L_2 in Fig. 149d. When L_1C_D equals L_2C_f, the amplifier is neutralized.

A typical neutralized rf amplifier

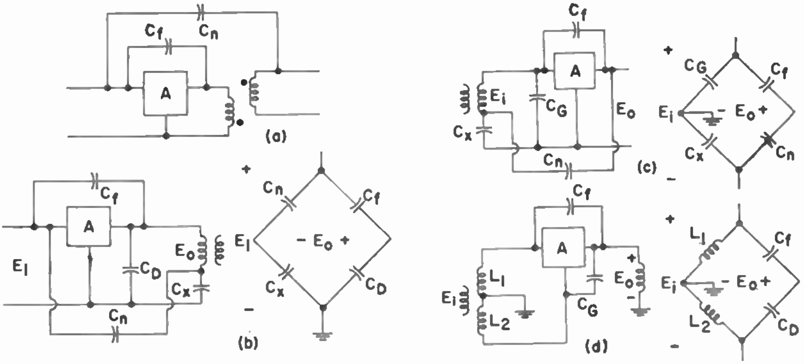


Figure 149. Some suitable neutralizing techniques for MOS rf circuits.

circuit using the 3N99 MOS transistor is shown in Fig. 150. The 3N99 is intended for operation at frequencies up to 60 megacycles per second, although it has useful response well beyond this value. Typically its forward transconductance g_{fs} does not drop 3 dB until approximately 150 megacycles per second. The stage shown in Fig. 150 has a typical power gain of 10 to 18 dB at 60 megacycles per second. Cross-modulation typically is less than one per cent for interfering signal voltages up to 200 millivolts.

Logic Circuits

Enhancement-type MOS transistors are well suited for digital-type logic-circuit applications because direct-coupled signal inversion is possible without the need for level shifting between stages. An important consideration for MOS logic circuits is the relationship between the saturation voltage V_D(sat) and the threshold voltage V_{TH} of the transistor. For direct coupling, V_D(sat) must be smaller than V_{TH}. It is relatively easy to design enhancement-type MOS transistors which meet this requirement.

Fig. 151 shows a simple NOR logic gate consisting of two MOS transistors and a single load resistor. The inputs X and Y are considered to be LOW if the voltage is less than V_{TH}, and HIGH if the voltage

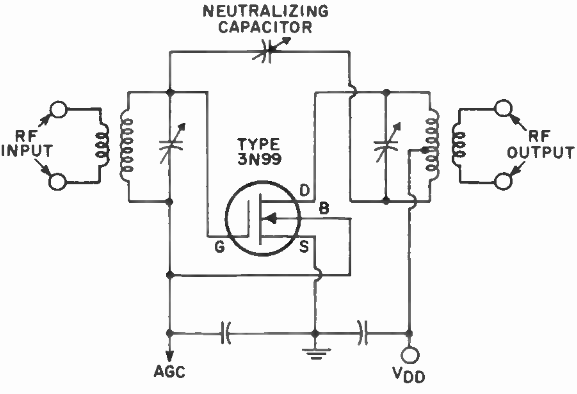


Figure 150. Typical 60-Mc/s rf-amplifier stage using 3N99 transistor.

is greater than V_{GO}. If both inputs are LOW, both MOS transistors are cut off and the output voltage is HIGH (essentially the supply voltage V) because there is negligible current in the load resistor R_L. If either or both inputs are HIGH, the current produced causes the output voltage to drop to the level of $V_D(sat)$, and the output is LOW. If a binary "1" is assigned to the HIGH level and a binary "0" to the LOW level, the gate performs the NOR function.

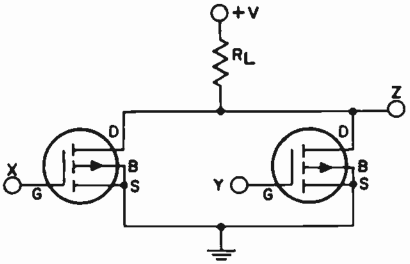


Figure 151. Simple NOR logic gate using MOS transistors.

If all the conductivity types in an MOS transistor are reversed, the resulting device is "complementary" in characteristics to the original device. Thus, n-channel MOS devices are related to p-channel MOS devices in the same way that p-n-p transistors are related to n-p-n transistors. Circuits using both types of MOS devices have demonstrated many performance advantages.

Fig. 152 shows a simple complementary inverter circuit using p-channel and n-channel MOS transistors. When the input voltage to the circuit is zero, the n-channel unit is cut off and the p-channel unit is forward-biased by V volts. The p-channel unit is capable of supplying several milliamperes of current. The n-channel unit, however, will draw only its channel leakage current, which is typically a few microamperes. Because the load for the circuit is assumed to be other MOS gates, which have a high input impedance and require negligible driving current, there is no dc load current under these conditions.

When the input voltage is V volts, however, the situation is reversed; the p-channel unit is cut off and the n-channel unit is forward-biased by V volts. The n-channel unit is then capable of drawing a current of several milliamperes. However, because the only source available is the leakage current of the p-channel unit, the current drawn by the n-channel unit is still negligible. In either of its stable states, therefore, the inverter draws only a leakage current from the supply. On any transition, however, the circuit can provide a current of several milliamperes to charge or discharge capacitive loads such as those presented by MOS gates and wiring. Fig. 153 shows in graphical form the operation of the inverter circuit in its two dc states.

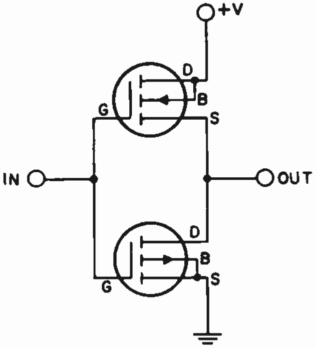


Figure 152. Complementary inverter circuit using MOS transistors.

HANDLING CONSIDERATIONS

Performance of MOS transistors depends on the relative perfection of a very thin insulating layer between the control electrode (gate) and the active channel. If this layer is punctured by inadvertent application of excess voltage to the external gate connection, the damage is irreversible. If the damaged area is small enough, the additional leakage may not be noticed in most

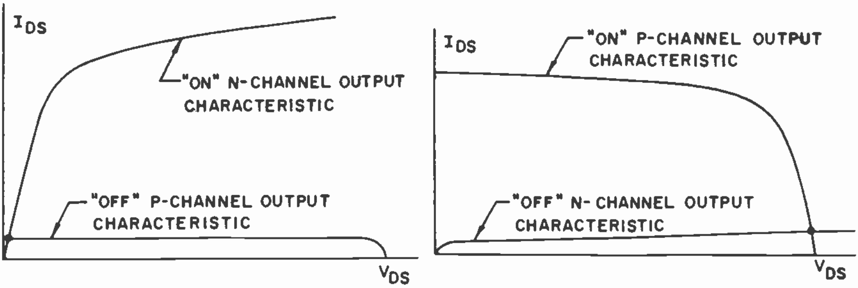


Figure 153. Characteristics of inverter circuit of Figure 152 in its two stable states.

applications. However, greater damage may degrade the device to the leakage levels associated with junction-gate-type field-effect transistors. It is very important, therefore, that appropriate precautions be taken to insure that MOS transistor gate-voltage ratings are not exceeded.

Static electricity represents the greatest threat to the gate insulation in MOS transistors. A large electrostatic charge can accumulate on the gate electrode if the transistor is allowed to slide around in plastic containers or if the leads are brushed against fabrics such as silk or nylon. This type of charge accumulation can be avoided completely by wrapping the leads in conductive foils, by use of conductive containers, or by otherwise electrically interconnecting the leads when the transistors are being transported.

A second cause of electrostatic charge damage to the gate insulation can be traced to the people who handle the transistors. At relative humidity levels of 35 per cent, a person may accumulate an electrostatic potential of 300 volts. If such a "charged" person grasps an MOS transistor by the case and plugs it into a piece of test equipment, or in any other way causes the gate lead to contact "ground" before the other leads, there is a good chance that the accumulated electrostatic charge may break down the gate insulation. The best way to prevent this type of damage is to use a simple electrostatic grounding strap during all handling of MOS transistors. Such a grounding strap may have an impedance to ground of several megohms and still accomplish the primary purpose of "leaking off" static electricity.

In most applications, associated circuit impedances are low enough to prevent any accumulation of electrostatic charge. Thus, although the gate insulation may be damaged by improper handling of MOS transistors before they are connected into actual circuits, thousands of hours of operation under practical circuit conditions have shown that the gate insulation is quite reliable under long-term stress within published ratings.

Transistor Mounting, Testing, and Reliability

THIS section covers installation suggestions and precautions which are generally applicable to all types of transistors. Careful observance of these suggestions will help experimenters and technicians to obtain the best results from semiconductor devices and circuits.

ELECTRICAL CONNECTIONS

The collector, base, and emitter terminals of transistors can be connected to associated circuit elements by means of sockets, clips, or solder connections to the leads or pins. If connections are soldered close to the lead or pin seals, care must be taken to conduct excessive heat away from the seals, otherwise the heat of the soldering operation may crack the glass seals and damage the transistor. When dip soldering is employed in the assembly of printed circuits using transistors, the temperature of the solder should be limited to about 225 to 250 degrees centigrade for a maximum immersion period of 10 seconds. Furthermore, the leads should not be dip-soldered too close to the transistor case. Under no circumstances should the mounting flange of a transistor be soldered to a heat sink because the heat of the soldering operation may permanently damage the transistor.

When the metal case of a transistor is connected internally to the collector, the case operates at the collector voltage. If the case is to operate at a voltage appreciably above or below ground potential, consideration must be given to the possibility of shock hazard and suitable precautionary measures taken.

TESTING

A quick check can be made of transistors prior to their installation in a circuit by resistance measurements with an electronic voltmeter (such as a VoltOhmyst*). Resistance between any two electrodes should be very high (more than 10,000 ohms) in one direction, and considerably lower in the other direction (100 ohms or less between emitter and base or collector and base; about 1000 ohms between emitter and collector). It is very important to limit the amount of voltage used in such tests (particularly between emitter and base) so that the breakdown voltages of the transistor will not be exceeded; otherwise the transistor may be damaged by excessive currents.

TRANSIENT EFFECTS

Unlike other active and passive components, transistors are sometimes extremely sensitive to even small changes in their surroundings. As a result, it is necessary to protect these devices from such effects as static charges, temperature variations, and rf fields both during shelf storage and in actual operation.

The generation of static charge in

---

*Trade Mark Reg. U.S. Pat. Off.

dry weather is harmful to all transistors, and can cause permanent damage or catastrophic failure in the case of high-speed devices and MOS field-effect transistors. The most obvious precaution against such damage is humidity control in storage and operating areas. In addition, it is desirable that transistors be stored and transported in metal trays rather than in polystyrene foam "snow". During testing and installation, both the equipment and the operator should be grounded, and all power should be turned off when the device is inserted into the socket. Grounded plates may also be used for stockpiling of transistors prior to or after testing, or for use in testing ovens or on operating life racks. Further protection against static charges can be provided by use of partially conducting floor planes and non-insulating footwear for all personnel.

Environmental temperature also affects performance. Variations of as little as 5 per cent can cause changes of as much as 50 per cent in the saturation current of a transistor. Some test operators can cause marked changes in measurements of saturation current because the heat of their hands affects the transistors they work on. Precautions against temperature effects include air-conditioning systems, use of finger cots in handling of transistors (or use of pliers or "plug-in boards" to eliminate handling), and accurate monitoring and control of temperature near the devices. Prior to testing, it is also desirable to allow sufficient time (about 5 minutes) for a transistor to stabilize if it has been subjected to temperature much higher or lower than normal room temperature (25°C).

Although transient rf fields are not usually of sufficient magnitude to cause permanent damage to transistors, they can interfere with accurate measurement of characteristics at very low signal levels or at high frequencies. For this reason, it is desirable to check for such radiation periodically and to eliminate its causes. In addition, sensitive measurements should be made in shielded screen rooms if possible. Care must also be taken to avoid the exposure of transistors to other ac or magnetic fields.

Many transistor characteristics are sensitive to variations in temperature, and may change enough at high operating temperatures to affect circuit performance. Fig. 154 illustrates the effect of increasing temperature on the common-emitter forward current-transfer ratio (beta), the dc collector-cutoff current, and the input and output impedances. To avoid undesired changes in circuit operation, it is recommended that transistors be located away from heat sources in equipment, and also that provisions be made for adequate heat dissipation and, if necessary, for temperature compensation.

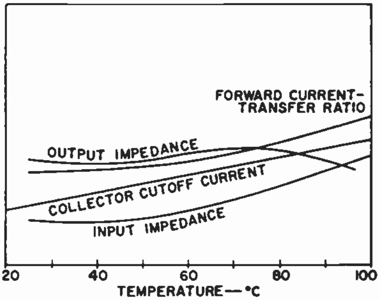


Figure 154. Variation of transistor characteristics with temperature.

HEAT SINKS

In some transistors, the collector electrode is connected internally to the metal case to improve heat-dissipation capabilities. More efficient cooling of the collector junction in these transistors can be accomplished by connection of the case to a heat sink. Direct connection of the case to a metal surface is practical only when a grounded-collector circuit is used. For other configurations, the collector is electrically isolated from the chassis or heat sink by means of an insulator that has good thermal conductivity.

For small general-purpose transistors such as the 2N2102, which use a JEDEC TO-5 package, a good thermal method of isolating the collector from a metal chassis or printed circuit board is by means of a beryllium oxide washer. The use of a zinc-oxide-filled silicone compound between the washer and the chassis, together with a moderate amount of pressure from the top of the transistor, helps to improve thermal dissipation. If the transistor is mounted within a heat sink, a beryllium cup should also be used between the device and the heat sink. Fig. 155 illustrates both types of mounting. Fin-type heat sinks, which are commercially available, are also suitable, especially when transistors are mounted in Teflon sockets which provide no thermal conduction to the chassis or printed circuit board.

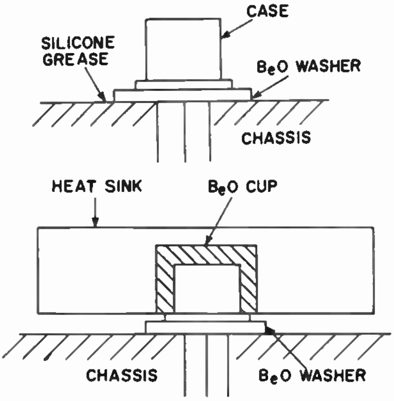


Figure 155. Suggested mounting arrangements for transistors having a JEDEC TO-5 package.

For power transistors which use a JEDEC TO-8 package, such as the 2N1483, it is recommended that a 0.002-inch mica insulator or an anodized aluminum insulator having high thermal conductivity be used between the transistor base and the heat sink or chassis. The insulator should extend beyond the mounting clamp, as shown in Fig. 156. It should be drilled or punched to provide both the two mounting holes and the clearance holes for the collector, emitter, and base pins. Burrs should be removed from both the insulator and the holes in the chassis so that the insulating layer will not be destroyed during mounting. It is also recommended that a fiber washer be used between the mounting bolt and the chassis, as shown in Fig. 156, to prevent a short circuit between them.

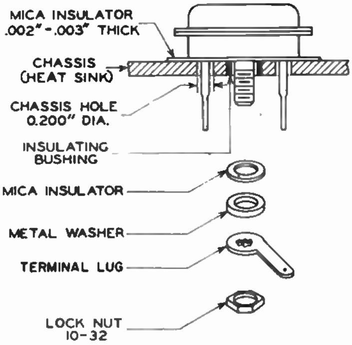


Figure 156. Suggested mounting arrangement for power transistors.

For large power transistors such as the 2N2876 which use a double-ended stud package, connection to the chassis or heat sink should be made at the flat surface of the transistor perpendicular to the threaded stud. A large mating surface should be provided to avoid hot spots and high thermal drop. The hole for the stud should be only as large as necessary for clearance, and should contain no burrs or ridges on its perimeter. As mentioned above, the use of a silicon grease between the heat sink and the transistor improves thermal contact. The transistor can be screwed directly into the heat sink or can be fastened by means of a nut. In either case, care must be taken to avoid the application of too much torque lest the transistor semiconductor junction be damaged. Although the studs are made of relatively soft copper to provide high thermal conductivity, the threads should not be relied upon to provide a mating surface. The actual heat transfer must take place on the underside of the hexagonal part of the package.

Mounting hardware is supplied with many RCA semiconductor devices. A listing of such hardware is included at the end of the **Outlines** section.

The use of an external resistance in the emitter or collector circuit of a transistor is an effective deterrent to damage which might be caused by thermal runaway. The minimum value of this resistance for low-level stages may be obtained from the following equation:

$$R_{min} = \frac{E^2}{4\left(P_0 + \frac{25}{K}\right)}$$

where E is the dc collector supply voltage in volts, P_0 is the product of the collector-to-emitter voltage and the collector current at the desired operating point in watts, and K is the thermal resistance of the transistor and heat sink in degrees centigrade per watt.

SHIELDING

In high-frequency stages having high gain, undesired feedback may occur and produce harmful effects on circuit performance unless shielding is used. The output circuit of each stage is usually shielded from the input of the stage, and each high-frequency stage is usually shielded from other high-frequency stages. It is also desirable to shield separately each unit of the high-frequency stages. For example, each if and rf coil in a superheterodyne receiver may be mounted in a separate shield can. Baffle plates may be mounted on the ganged tuning capacitor to shield each section of the capacitor from the other section.

The shielding precautions required in a circuit depend on the design of the circuit and the layout of the parts. When the metal case of a transistor is grounded at the socket terminal, the grounding connection should be as short as possible to minimize lead inductance. Many transistors have a separate lead connected to the case and used as a ground lead; where present, these leads are indicated in the outline diagrams.

HIGH-FREQUENCY CONSIDERATIONS

At frequencies of 100 megacycles per second or more, the effects of stray capacitances and inductances, ground paths, and feedback coupling have a pronounced effect on the gain and power-output capabilities of transistors. As a result, physical aspects such as layout, type of chassis, shielding, and heat-sink considerations are important in the design of high-frequency amplifiers and oscillators.

In general, high-frequency circuits are constructed on material such as brass or aluminum which is either silver-plated or machined to increase conductivity. The input and output circuits are "compartmentalized" by use of a milling operation. Copper-clad laminated or printed circuit boards facilitate soldering operations, and have been used satisfactorily at frequencies up to 400 megacycles per second when the entire copper surface was kept intact and used for the ground plane.

Because even a short lead provides a large impedance at high frequencies, it is necessary to keep all high-frequency leads as short as possible. This precaution is especially important for ground connections and for all connections to bypass capacitors and high-frequency filter capacitors. It is recommended that a common ground return be used for each stage, and that short, direct connections be made to the common ground point. The emitter lead especially should be kept as short as possible.

In many cases, problems of oscillation and regenerative feedback are caused by unwanted ground currents (i.e., ground-circuit feedback currents). An effective solution is to isolate the ac signal path from the dc path so that the signal does not pass through the power supply by way of the power leads. In a multistage amplifier, the power leads should enter the circuit at the highest power stage to minimize the amount of signal on the common power path. Lower-frequency oscillations can be minimized by use of a large capacitor across the power-supply terminals. High-quality feed-through capacitors should also be used as the power-lead connections.

Particular care should be taken with the lead dress of the input and output circuits of high-frequency stages so that the possibility of stray coupling is minimized. Unshielded leads connected to shielded components should be dressed close to the chassis. (In high-gain audio amplifiers, these same precautions should be taken to minimize the possibility of self-oscillation.)

FILTERS

Feedback effects may occur in radio or television receivers as a result of coupling between stages through common voltage-supply circuits. Filters find an important use in minimizing such effects. They should be placed in voltage-supply leads to each transistor to provide isolation between stages.

Capacitors used in transistor rf circuits, particularly at high frequencies, should be mica or ceramic. For audio bypassing, electrolytic capacitors are required.

Interpretation of Data

THE technical data for RCA transistors given in the following section include ratings, characteristics, typical operation values, and characteristic curves. Unless otherwise specified, voltages and currents are dc values, and values are obtained at an ambient temperature of 25°C.

Ratings are established for semiconductor devices to help equipment designers utilize the performance and service capabilities of each type to the best advantage. These ratings are based on careful study and extensive testing, and indicate limits within which the specified characteristics must be maintained to ensure satisfactory performance. The maximum ratings given for the semiconductor devices included in this Manual are based on the Absolute Maximum system. This system has been defined by the Joint Electron Device Engineering Council (JEDEC) and standardized by the National Electrical Manufacturers Association (NEMA) and the Electronic Industries Association (EIA).

Absolute-maximum ratings are limiting values of operating and environmental conditions which should not be exceeded by any device of a specified type under any condition of operation. Effective use of these ratings requires close control of supply-voltage variations, component variations, equipment-control adjustment, load variations, signal variations, and environmental conditions.

Electrode voltage and current ratings for transistors are in general self-explanatory, but a brief explanation of some ratings will aid in the understanding and interpretation of transistor data.

Voltage ratings are established with reference to a specified electrode (e.g., collector-to-emitter voltage), and indicate the maximum potential which can be placed across the two given electrodes before crystal breakdown occurs. These ratings may be specified with the third electrode open, or with specific bias voltages or external resistances.

Transistor dissipation is the power dissipated in the form of heat by the collector. It is the difference between the power supplied to the collector and the power delivered by the transistor to the load. Because of the sensitivity of semiconductor materials to variations in thermal conditions, maximum dissipation ratings are usually given for specific temperature conditions.

For many types, the maximum value of transistor dissipation is specified for ambient, case, or mounting-flange temperatures up to 25 degrees centigrade, and must be reduced linearly for higher temperatures. For such types, Fig. 157 can be used to determine maximum permissible dissipation values at particular temperature conditions above 25 degrees centigrade. (This figure cannot be assumed to apply to types other than those for which it is specified in the data section.) The curves show the permissible percentage of the maximum dissipation ratings as a function of ambient or case temperature. Individual curves are plotted for maximum operating temperatures of 50, 55, 71, 80, 85, 100, 125, 175, and 200 degrees centigrade. If the maximum operating temperature of a transistor type is some other value, a new curve can be drawn from point A in the figure to the desired temperature value on the abscissa.

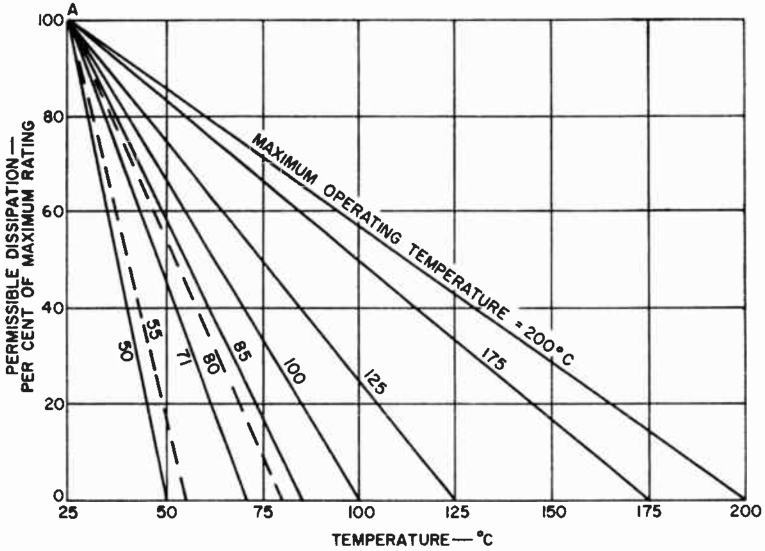


Figure 157. Chart showing maximum permissible percentage of maximum rated dissipation as a function of temperature.

To use the chart, it is necessary to know the maximum dissipation rating and the maximum operating temperature for a given transistor. The calculation involves only two steps:

1. A vertical line is drawn at the desired operating temperature value on the abscissa to intersect the curve representing the maximum operating temperature for the transistor.

2. A horizontal line drawn from this intersection point to the ordinate establishes the permissible percentage of the maximum dissipation at the given temperature.

The following example illustrates the calculation of the maximum permissible dissipation for transistor type 2N1490 at a case temperature of 100 degrees centigrade. This type has a maximum dissipation rating of 75 watts at a case temperature of 25 degrees centigrade, and a maximum permissible case-temperature rating of 200 degrees centigrade.

1. A perpendicular line is drawn from the 100-degree point on the abscissa to the 200-degree curve.

2. Projection of this point to the ordinate shows a percentage of 57.5. Therefore, the maximum permissible dissipation for the 2N1490 at a case temperature of 100 degrees centigrade is 0.575 times 75, or approximately 43 watts.

Semiconductor devices require close control of thermal variations not only during operation, but also during storage. For this reason, the maximum ratings for transistors usually include a maximum permissible storage temperature, as well as a maximum operating temperature.

Characteristics are covered in the **Transistor Characteristics** section, and such data should be interpreted in accordance with the definitions given in that section. Characteristic curves represent the characteristics of an average transistor. Individual transistors, like any manufactured product, may have characteristics that range above or below the values given in the characteristic curves. Although some curves are extended beyond the maximum ratings of the transistor, this extension has been made only for convenience in calculations; no transistor should be operated outside of its maximum ratings.

Transistor Symbols

Although transistor symbols have not yet been standardized throughout the industry, many symbols have become fairly well established by common usage. The transistor symbols used in this Manual are listed and defined in this section.

GENERAL SEMICONDUCTOR SYMBOLS

df	duty factor
η	efficiency (eta)
NF	noise figure
T	temperature
T_A	ambient temperature
T_C	case temperature
T_J	junction temperature
T_{MF}	mounting-flange temperature
T_{STG}	storage temperature
Θ	thermal resistance
Θ_{J-A}	thermal resistance, junction-to-ambient
Θ_{J-C}	thermal resistance, junction-to-case
Θ_{J-MF}	thermal resistance, junction-to-mounting-flange
t_d	delay time
$t_d + t_r$	turn-on time
t_f	fall time
t_p	pulse time
t_r	rise time
t_s	storage time
$t_s + t_f$	turn-off time
τ	time constant (tau)
τ_S	saturation stored-charge time constant

TRANSISTOR SYMBOLS

$C_{b'c}$	collector-to-base feedback capacitance
C_c	collector-to-case capacitance
C_{cb}	collector-to-base feedback capacitance
C_{ibo}	input capacitance, open circuit (common base)
C_{ieo}	input capacitance, open circuit (common emitter)
C_{obo}	output capacitance, open circuit (common base)
C_{oeo}	output capacitance, open circuit (common emitter)
$E_{S/b}$	second-breakdown energy
f_c	cutoff frequency
f_{hfb}	small-signal forward-current transfer-ratio cutoff frequency, short-circuit (common base)
f_{hfe}	small-signal forward-current transfer-ratio cutoff frequency, short-circuit (common emitter)
f_T	gain-bandwidth product (frequency at which small-signal forward-current transfer ratio, common emitter, extrapolates to unity)
g_{me}	small-signal transconductance (common emitter)
G_{PB}	large-signal average power gain (common base)
G_{pb}	small-signal average power gain (common base)
G_{PE}	large-signal average power gain (common emitter)
G_{pe}	small-signal average power gain (common emitter)
h_{FB}	static forward-current transfer ratio (common base)

h_{fb}	small-signal forward-current transfer ratio, short circuit (common base)
h_{FE}	static forward-current transfer ratio (common emitter)
h_{fe}	small-signal forward-current transfer ratio, short circuit (common emitter)
h_{ib}	small-signal input impedance, short circuit (common base)
h_{IE}	static input resistance (common emitter)
h_{ie}	small-signal input impedance, short circuit (common emitter)
h_{ob}	small-signal output impedance, open circuit (common base)
h_{oe}	small-signal output impedance, open circuit (common emitter)
h_{rb}	small-signal reverse-voltage transfer ratio, open circuit (common base)
h_{re}	small-signal reverse-voltage transfer ratio, open circuit (common emitter)
I_B	base current
I_{B1}	turn-on current
I_{B2}	turn-off current
I_C	collector current
i_C	collector current, instantaneous value
I_{CB}	collector-cutoff current
I_{CBO}	collector-cutoff current, emitter open
I_{CEO}	collector-cutoff current, base open
I_{CER}	collector-cutoff current, specified resistance between base and emitter
I_{CES}	collector-cutoff current, base short-circuited to emitter
I_{CEV}	collector-cutoff current, specified voltage between base and emitter
I_{CEX}	collector-cutoff current, specified circuit between base and emitter

I_{CS}	switching current (at minimum h_{FE} per specification)
I_E	emitter current
I_{EBO}	emitter-cutoff current, collector open
$I_{S/b}$	second-breakdown collector current
MAG	maximum available amplifier gain
MAG_c	maximum available conversion gain
MUG	maximum usable amplifier gain
P_{BE}	total dc or average power input to base (common emitter)
p_{BE}	total instantaneous power input to base (common emitter)
P_{CB}	total dc or average power input to collector (common base)
p_{CB}	total instantaneous power input to collector (common base)
P_{CE}	total dc or average power input to collector (common emitter)
p_{CE}	total instantaneous power input to collector (common emitter)
P	total dc or average power input to emitter (common base)
p_{EB}	total instantaneous power input to emitter (common base)
P_{IB}	large-signal input power (common base)
P_{ib}	small-signal input power (common base)
P_{IE}	large-signal input power (common emitter)
P_{ie}	small-signal input power (common emitter)
P_{OB}	large-signal output power (common base)
P_{ob}	small-signal output power (common base)
P_{OE}	large-signal output power (common emitter)
P_{oe}	small-signal output power (common emitter)
Q_s	stored base charge

r_{CE}(sat)	collector-to-emitter saturation resistance
Re(h_{ie})	real part of small-signal input impedance, short circuit (common emitter)
R_G	generator resistance
R_{ie}	input resistance (common emitter)
R_L	load resistance
R_{oe}	output resistance (common emitter)
R_S	source resistance
V_{BB}	base-supply voltage
V_{BC}	base-to-collector voltage
V_{BE}	base-to-emitter voltage
$V_{(BR)CBO}$	collector-to-base breakdown voltage, emitter open
$V_{(BR)CEO}$	collector-to-emitter breakdown voltage, base open
$V_{(BR)CER}$	collector-to-emitter breakdown voltage, specified resistance between base and emitter
$V_{(BR)CES}$	collector-to-emitter breakdown voltage, base short-circuited to emitter
$V_{(BR)CEV}$	collector-to-emitter breakdown voltage, specified voltage between base and emitter
$V_{(BR)EBO}$	emitter-to-base breakdown voltage, collector open
V_{CB}	collector-to-base voltage
V_{CB}(fl)	dc open-circuit voltage between collector and base (floating potential), emitter biased with respect to base
V_{CE}(fl)	dc open-circuit voltage between collector and emitter (floating potential), base biased with respect to emitter
V_{CBO}	collector-to-base voltage (emitter open)
V_{CBV}	collector-to-base voltage, specified voltage between emitter and base
V_{CC}	collector-supply voltage
V_{CE}	collector-to-emitter voltage
V_{CEO}	collector-to-emitter voltage, base open
V_{CER}	collector-to-emitter voltage, specified resistance between base and emitter
V_{CES}	collector-to-emitter voltage, base short-circuited to emitter
V_{CEV}	collector-to-emitter voltage, specified voltage between base and emitter
V_{CE}(sat)	collector-to-emitter saturation voltage
V_{EB}	emitter-to-base voltage
V_{EB}(fl)	dc open-circuit voltage between emitter and base (floating potential), collector biased with respect to base
V_{EBO}	emitter-to-base voltage, collector open
V_{EE}	emitter-supply voltage
V_{RT}	reach-through voltage
Y_{fe}	forward transconductance
Y_{ie}	input admittance
Y_{oe}	output admittance
Y_{re}	reverse transconductance

MOS FIELD-EFFECT TRANSISTOR SYMBOLS

A	voltage amplification ($= Y_{fs}/Y_{os} + Y_L$)
B_{os}	$= c_{ds}$
c_c	intrinsic channel capacitance
c_{ds}	drain-to-source capacitance (includes approximately 1-pF drain-to-case and interlead capacitance)
c_{gd}	gate-to-drain capacitance (includes 0.1-pF interlead capacitance)
c_{gs}	gate-to-source interlead and case capacitance
C_{iss}	small-signal input capacitance, short circuit
C_{rss}	small-signal reverse transfer capacitance, short circuit
g_{fs}	forward transconductance

g_{is}	input conductance
g_{os}	output conductance
I_D	dc drain current
I_{DS}(OFF)	drain-to-source OFF current
I_{GSS}	gate leakage current
NF	spot noise figure (generator resistance R_G = 1 megohm)
r_e	effective gate series resistance
r_d	active channel resistance
r_d'	unmodulated channel resistance
r_{DS}(ON)	drain-to-source ON resistance
r_{gd}	gate-to-drain leakage resistance
r_{gs}	gate-to-source leakage resistance
V_{DB}	drain-to-substrate voltage
V_{DS}	drain-to-source voltage
V_{GB}	dc gate-to-substrate voltage
v_{GB}	peak gate-to-substrate voltage
V_{GS}	dc gate-to-source voltage
v_{GS}	peak gate-to-source voltage
V_{GS}(OFF)	gate-to-source cutoff voltage
Y_{fs}	forward transadmittance $\approx g_{fs}$
Y_{os}	output admittance $= g_{os} + jB_{os}$, $B_{os} = \omega C_{ds}$
Y_L	load admittance $= g_L + jB_L$

RCA Military—Specification Transistors

TYPE	MIL-S-19500/
JAN-2N174	13B
JAN-2N220	1
JAN-2N274	26 (Sig C)
JAN-2N384	27D
JAN-2N388	65A
JAN-2N396A	64C
JAN-2N398	174 (Navy)
JAN-2N404	20B
JAN-2N706	120A
JAN-2N962	258 (Navy)
JAN-2N964	258 (Navy)
JAN-2N1183	143A (EL)
JAN-2N1183A	143A (EL)
JAN-2N1183B	143A (EL)
JAN-2N1184	143A (EL)
JAN-2N1184A	143A (EL)
JAN-2N1184B	143A (EL)
JAN-2N1224	189 (Sig C)
JAN-2N1225	189 (Sig C)
JAN-2N1302	126B
JAN-2N1303	126B
JAN-2N1304	126B
JAN-2N1305	126B
JAN-2N1306	126B
JAN-2N1307	126B
JAN-2N1308	126B
JAN-2N1309	126B
JAN-2N1412	76B (Navy)
JAN-2N1479	207A (EL)
JAN-2N1480	207A (EL)
JAN-2N1481	207A (EL)
JAN-2N1482	207A (EL)
JAN-2N1483	108A (EL)
JAN-2N1484	180A (EL)
JAN-2N1485	180A (EL)
JAN-2N1486	180A (EL)
JAN-2N1487	208A (EL)
JAN-2N1488	208A (EL)
JAN-2N1489	208A (EL)
JAN-2N1490	208A (EL)
JAN-2N1493	247 (EL)
JAN-2N1853	171A (Navy)
JAN-2N1854	172A (Navy)
JAN-2N2015	248A (EL)
JAN-2N2016	248A (EL)
JAN-2N2273	244A (Sig C)
JAN-2N2708	302 (EL)

Copies of transistor specification sheets may be obtained by directing requests to *Specifications* Division, Naval Supply Depot, 5801 Tabor Avenue, Philadelphia 20, Pa., Attn: CDS

Transistor Selection Charts

The accompanying charts classify RCA transistors by function, by material, and by performance level. These charts are particularly useful for an initial selection of suitable transistors for a specific application. More complete data on these devices, given in the Technical Data section, should then be consulted to determine the most suitable type. Data charts for rectifiers, silicon controlled rectifiers (SCR's), and semiconductor diodes are given later (see Table of Contents).

Audio-Frequency Applications

SMALL SIGNAL—CLASS A

Germanium n-p-n

2N1010

Germanium p-n-p

2N2613
2N2614
40263

Silicon n-p-n

2N718A
2N720A
2N2102
2N2270
2N2405
2N2895
2N2896
2N2897
2N3241
2N3242
3N98▲
3N99▲
40084
40231
40232
40233
40234
40366○

LARGE-SIGNAL POWER AMPLIFIER—CLASS A and CLASS B

Germanium n-p-n

2N647
2N649

Germanium p-n-p

Dissipations up to 50 W

2N1183
2N1183A
2N1183B
2N1184
2N1184A
2N1184B
2N2147▪
2N2148▪
2N2869•
2N2870•
2N2953
40022•
40050•
40051•
40253
40254•
40239
40395
40396

Dissipations of 50 W or More

2N173
2N174
2N277
2N278
2N441
2N442
2N443
2N1099
2N1100
2N1358
2N1412
2N1905
2N1906

Silicon p-n-p

40319
40362
40406
40410

Silicon n-p-n

Dissipations up to 5 W

2N1479
2N1480
2N1481
2N1482
2N1700
2N1711
2N3585
40084
40264•
40309
40311
40314
40315
40317
40320
40321
40323
40326
40327
40347
40347V1*
40347V2
40348
40348V1*
40348V2
40349
40349V1*
40349V2
40360
40361
40367○
40407
40408
40409

Dissipations of 5 W to 50 W

2N1483
2N1484
2N1485
2N1486
2N1701
2N3054
2N3583
2N3584
2N3878
2N3879
40250
40250V1*
40251
40310
40312
40313
40316
40318
40322
40324
40328
40364
40368
40372*
40374*
40375*

Dissipations of 50 W or More

2N1487
2N1488
2N1489
2N1490
2N1702
2N1703
2N2015
2N2016
2N2338
2N3055
2N3263
2N3264
2N3265
2N3266
2N3442
2N3771
2N3772
2N3773
40251
40325
40363
40369○
40411

* For printed-circuit-board applications.
• High-fidelity power-amplifier type.
▪ High-power extended-frequency-range type.
▲ N-channel depletion type.
○ High-reliability type.

Radio-Frequency Applications

SMALL SIGNAL, UHF and VHF

Germanium n-p-n

2N2482

Germanium p-n-p

2N384
2N1023
2N1066
2N1177
2N1178
2N1179
2N1225
2N1396
2N1397

Silicon n-p-n

2N917
2N918
2N2708
2N2857
2N3053
2N3478
2N3600
2N3932
2N3933
2N4036
2N4037
40242
40294
40295
40296
40404
40405
40391
40392
40394

LARGE SIGNAL, UHF and VHF

Silicon n-p-n

2N699
2N1491
2N1492
2N1493
2N2631
2N2876
2N3229
2N3375†
2N3553†
2N3632†
2N3733†
2N3866†
2N4012†‡
40279†
40280†
40281†
40282†
40290†
40291†
40292†
40305†
40306†
40307†
40340†
40341†

HIGH FREQUENCY

Germanium p-n-p

2N274
2N370
2N384
2N1023
2N1066
2N1224
2N1225
2N1226
2N1283
2N1395
2N1396
2N1397
2N1631
2N1632
2N1637
2N2273

Silicon n-p-n

40080
40081
40082
40243
40244
40245
40246

MIXER, OSCILLATOR, and CONVERTER

Germanium p-n-p

2N274
2N374
2N384
2N1023
2N1066
2N1178
2N1179
2N1224
2N1225
2N1226
2N1395
2N1396
2N1397
2N1426
2N1526
2N1527
2N1639
40261

Silicon n-p-n

40243
40244

IF AMPLIFIER

Germanium p-n-p

2N139
2N218
2N274
2N384
2N409
2N410
2N1023
2N1066
2N1180
2N1224
2N1225
2N1226
2N1395
2N1396
2N1397
2N1524
2N1525
2N1638
40262

Silicon n-p-n

40080
40081
40082
40243
40244
40245
40246

VIDEO AMPLIFIER

Germanium p-n-p

2N274
2N384
2N699
2N1023
2N1066
2N1224
2N1225
2N1226
2N1395
2N1396
2N1397

Silicon n-p-n

2N1491
2N1492
2N1493
2N2102
2N2708
2N2857
2N3118
40245
40246

Television Applications

TV DEFLECTION

Germanium p-n-p

2N3730
2N3731
2N3732

TV TUNER

Silicon n-p-n

40235
40236
40237
40350

TV VIDEO OUTPUT

Silicon n-p-n

40354
40355

TV IF AMPLIFIER

Silicon n-p-n

40238
40239
40240
40351
40352

Power Switching

Dissipations up to 5 W

Silicon n-p-n (Medium Voltage, up to 100V)

2N697
2N718A
2N1613
2N3119

Silicon n-p-n (High Voltage, above 100V)

2N720A
2N1893

---

† Overlay type.

‡ Frequency-multiplier type.

Dissipations from 5 W to 50 W

Germanium p-n-p (Medium Voltage, up to 100V)

2N1183
2N1183A
2N1183B
2N1184
2N1184A
2N1184B
2N2869
2N2870

Silicon n-p-n (Medium Voltage, up to 100V)

2N1479
2N1481
2N1483
2N1485
2N1700
2N1701
2N2270
2N3053
2N3054
2N3230
40082
40250
40278
40347
40348

Silicon n-p-n (High Voltage, above 100V)

2N1480
2N1482
2N1484
2N1486
2N2102
2N2405
2N3231
2N3262
2N3441
2N3878
2N3879
40346
40349
40366○
40367○
40368○
40373*
40375*

Silicon n-p-n (Very High Voltage, above 250V)

2N3439
2N3440
2N3583
2N3584
2N3585
40255
40256
40374*

Dissipations of 50 W or More

Germanium p-n-p (Medium Voltage, up to 100V)

2N173
2N174
2N277
2N278
2N441
2N442
2N443
2N1099
2N1100
2N1358
2N1412
2N1905

Germanium p-n-p (High Voltage, above 100V)

2N1906

Silicon n-p-n (Medium Voltage, up to 100V)

2N1487
2N1488
2N1489
2N1490
2N1702
2N1703
2N2015
2N2338
2N3055
2N3771
2N3772
40251

Silicon n-p-n (High Voltage, above 100V)

2N2016
2N3263
2N3264
2N3265
2N3266
2N3442
2N3773

DC-TO-DC CONVERTERS, INVERTERS, CHOPPERS, RELAY CONTOLS, VOLTAGE and CURRENT REGULATORS, SERVO AMPLIFIERS

Germanium p-n-p

2N173
2N174
2N277
2N278
2N441
2N442
2N443
2N1099
2N1100
2N1183
2N1183A
2N1183B
2N1184
2N1184A
2N1184B
2N1358
2N1412

Silicon n-p-n

2N1487
2N1488
2N1489
2N1490
2N1700
2N1701
2N1702
2N1703
2N2015
2N2016
2N2338
2N3054
2N3055
2N3263
2N3264
2N3265
2N3266
2N3439
2N3440
2N3441
2N3442
2N3583
2N3584
2N3585
3N98▲
3N99▲
40255
40256
40369○
40389*
40390*

DIFFERENTIAL and OPERATIONAL AMPLIFIERS

Silicon n-p-n

2N1613
2N2102
2N2270
2N3439
2N3440
3N98▲
3N99▲
40255
40256
40346
40366○

Computer Applications

MEMORY DRIVERS

Germanium p-n-p

2N1384

Silicon n-p-n

2N2476
2N2477
2N3261
2N3262
2N3512
40283

LOGIC CIRCUITS

Germanium p-n-p (Low and Medium Speed)

2N404
2N404A
2N414
2N1300
2N1301
2N1303
2N1305
2N1307
2N1309
2N1384
2N1683
40269

Germanium n-p-n (Low and Medium Speed)

2N585
2N1090
2N1091
2N1302
2N1304
2N1306
2N1308
2N1605
2N1605A

Silicon n-p-n (High Speed)

2N706
2N706A
2N708
2N709
2N834
2N914
2N2205
2N2369A
2N2475
2N2938
2N3011
2N3261
40217
40218
40219
40220
40221
40222

DIRECT ON-OFF CONTROL (NEON OR INCANDESCENT-LAMP INDICATORS, RELAYS, COUNTERS, and OTHER HIGH-VOLTAGE CIRCUITS)

2N398
2N398A
2N398B

▲ N-channel depletion type.
○ High-reliability type.
* For printed-circuit-board applications.

Technical Data for RCA Transitors

This section contains detailed technical data for all current RCA transistors. Types are listed according to the numerical-alphabetical-numerical sequence of their type designations. Tabular data for RCA discontinued transistors are given at the end of the section. Tabular data for silicon rectifiers, silicon controlled rectifiers (SCR's), and semiconductor diodes are given later in the Manual, as are outline drawings and information on mounting hardware for all RCA semiconductor devices (see Table of Contents).

2N104 TRANSISTOR

Ge **p-n-p alloy-junction** type used in low-power audio-frequency service. JEDEC TO-40, **Outline** No.13. **Terminals:** 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	–30	V
Collector Current	I_C	–50	mA
Emitter Current	I_E	50	mA
Transistor Dissipation:			
At T_A up to 25°C	P_T	150	mW
At T_A = 50°C	P_T	80	mW
At T_A = 70°C	P_T	30	mW
Temperature Range:			
Operating (Ambient)	T_A (opr)	–65 to 70	°C
Storage	T_{STG}	–65 to 85	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = –20 μA, I_E = 0)	$V_{(BR)CBO}$	–30 min	V
Collector-Cutoff Current (V_{CB} = –12 V, I_E = 0)	I_{CBO}	–10 max	μA
Emitter-Cutoff Current (V_{EB} = –12 V, I_C = 0)	I_{EBO}	–10 max	μA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = –6 V, I_C = –1 mA)	h_{fe}	44	
Small-Signal Forward-Current Transfer Ratio Cutoff Frequency (V_{CB} = –3 V, I_C = –0.2 mA)	f_{hfb}	0.7	Mc/s
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	0.4	°C/mW

2N109 TRANSISTOR

Ge **p-n-p alloy-junction** type used in low-power, small-signal and large-signal audio applications in consumer-product equipment. JEDEC TO-40, **Outline** No.13. **Terminals:** 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	–35	V
Collector-to-Emitter Voltage	V_{CEO}	–25	V
Emitter-to-Base Voltage	V_{EBO}	–12	V
Collector Current	I_C	–150	mA

MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_A up to 25°C	P_T	165	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 85	°C
Storage	T_{STG}	−65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −50 μA, I_E = 0)	$V_{(BR)CBO}$	−35 min	V
Collector-to-Emitter Breakdown Voltage (I_C = −1 mA, I_B = 0)	$V_{(BR)CEO}$	−25 min	V
Emitter-to-Base Breakdown Voltage (I_E = −7 μA, I_C = 0)	$V_{(BR)EBO}$	−12 min	V
Collector-to-Emitter Saturation Voltage (I_C = −50 mA, I_B = −5 mA)	V_{CE} (sat)	−0.15 max	V
Base-to-Emitter Voltage (V_{CE} = −1 V, I_C = −50 mA)	V_{BE}	0.2 to 0.4	V
Collector-Cutoff Current (V_{CB} = −30 V, I_E = 0)	I_{CBO}	−7 max	μA
Emitter-Cutoff Current (V_{EB} = −12 V, I_C = 0)	I_{EBO}	−7 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = −1 V, I_C = −50 mA)	h_{FE}	65 to 115	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_E = −1 mA, f = 1 kc/s)	h_{fe}	50 to 150	
Small-Signal Input Impedance (V_{CE} = −6 V, I_E = −1 mA, f = 1 kc/s)	h_{ie}	1000 to 4000	Ω
Output Capacitance (V_{CB} = −6 V, I_C = −1 mA, f = 0.5 Mc/s)	C_{obo}	20 to 60	pF

TRANSISTOR 2N139

Ge p-n-p alloy-junction type used primarily in 455-kilocycle intermediate-frequency amplifier service in battery-operated portable radio receivers and automobile radio receivers operating from either a 6-volt or a 12-volt supply. JEDEC TO-40, Outline No.13. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−16	V
Emitter-to-Base Voltage	V_{EBO}	−12	V
Collector Current	I_C	−15	mA
Emitter Current	I_E	15	mA
Transistor Dissipation:			
T_A = 25°C	P_T	80	mW
T_A = 71°C	P_T	10	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	to 71	°C
Storage	T_{STG}	to 85	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −10 μA, I_E = 0)	$V_{(BR)CBO}$	−16 min	V
Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−6 max	μA
Emitter-Cutoff Current (V_{EB} = −12 V, I_C = 0)	I_{EBO}	−40 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = −9 V, I_C = −0.6 mA)	h_{FE}	48	
Gain-Bandwidth Product (V_{CE} = −9 V, I_C = −1 mA)	f_T	14	Mc/s

TYPICAL OPERATION IN 455-kc/s IF-AMPLIFIER CIRCUIT

DC Collector-to-Emitter Voltage	V_{CE}	−9	−9	V
DC Collector Current	I_C	−0.5	−1	mA
Input Resistance (approx.)	R_S	1000	500	Ω
Output Resistance (approx.)	R_L	70000	30000	Ω
Maximum Power Gain (approx.)	MAG	38	37	dB
Useful Power Gain (approx.)	MUG	27.6	30.4	dB
Spot Noise Figure (approx.)	NF	4.5	4.5	dB

2N140 TRANSISTOR

Ge p-n-p alloy-junction type used primarily in converter and mixer-oscillator service in AM battery-operated portable radio receivers and automobile radio receivers operating from either a 6-volt or a 12-volt supply. JEDEC TO-40, Outline No.13. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−16	V
Emitter-to-Base Voltage	V_{EBO}	−0.5	V
Collector Current	I_C	−15	mA
Emitter Current	I_E	15	mA
Transistor Dissipation:			
$T_A = 25°C$	P_T	80	mW
$T_A = 71°C$	P_T	10	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 71	°C
Storage	T_{STG}	−65 to 85	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage ($I_C = -10$ μA, $I_E = 0$)	$V_{(BR)CBO}$	−16 min	V
Collector-Cutoff Current ($V_{CB} = -12$ V, $I_E = 0$)	I_{CBO}	−6 max	μA
Emitter-Cutoff Current ($V_{EB} = -0.5$ V, $I_C = 0$)	I_{EBO}	−12	μA
Static Forward-Current Transfer Ratio ($V_{CE} = -9$ V, $I_C = -0.6$ mA)	h_{FE}	48	
Gain-Bandwidth Product ($V_{CE} = -9$ V, $I_C = -0.6$ mA)	f_T	16.5	Mc/s

TYPICAL OPERATION AT 1 Mc/s IN SELF-EXCITED CONVERTER CIRCUIT

DC Collector-to-Emitter Voltage	V_{CE}	−9	V
DC Collector Current	I_C	−0.6	mA
Input Resistance (approx.)	R_S	700	Ω
Output Resistance (approx.)	R_L	75000	Ω
RMS Base-to-Emitter Oscillator Injection Voltage (approx.)		100	mV
Useful Conversion Power Gain (approx.)	MUG_c	32	dB

2N173 POWER TRANSISTOR

Ge p-n-p alloy-junction type used in a wide variety of switching and amplifier applications in equipment having high voltage, current, and dissipation requirements. It is used in power switching, voltage- and current-regulating, dc-to-dc converter, inverter, power-supply, and relay- and solenoid-actuating circuits; and in low-frequency oscillator and audio-amplifier service. JEDEC TO-36, Outline No.11. Terminals: Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage ($V_{BE} = 1.5$ V)	V_{CBV}	−60	V
Emitter-to-Base Voltage	V_{EBO}	−40	V
Collector Current	I_C	−15	A
Emitter Current	I_E	15	A
Base Current	I_B	−4	A
Transistor Dissipation:			
T_C up to 25°C	P_T	150	W
T_C above 25°C	P_T	See curve page	112
Temperature Range:			
Operating (T_C) and Storage (T_{STG})		−65 to 100	°C

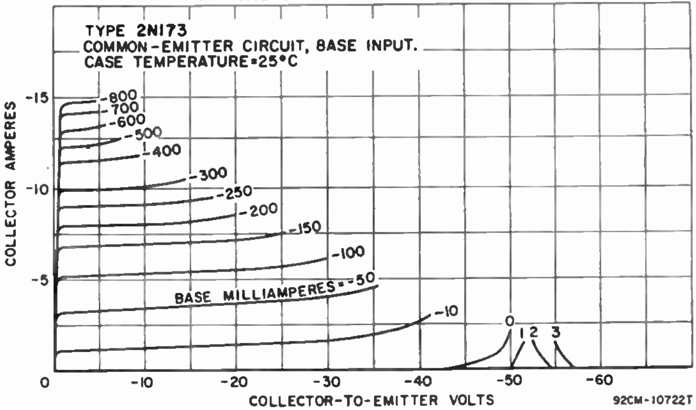
CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage:			
$I_C = -0.3$ A, $R_{BE} = 0$	$V_{(BR)CES}$	−50 min	V
$I_C = -1$ A, $I_B = 0$	$V_{(BR)CEO}$	−45 min	V
Collector-to-Emitter Saturation Voltage:			
$I_C = -12$ A, $I_B = -2$ A	V_{CE}(sat)	−0.7 max	V
$I_C = -12$ A, $I_B = -2$ A	V_{CE}(sat)	−0.3 typ	V
Base-to-Emitter Voltage ($I_C = -5$ A, $V_{CE} = -2$ V)	V_{BE}	−0.65	V
Emitter-to-Base Voltage ($V_{CB} = -80$ V, $I_E = 0$)	V_{EB}	−1 max	V

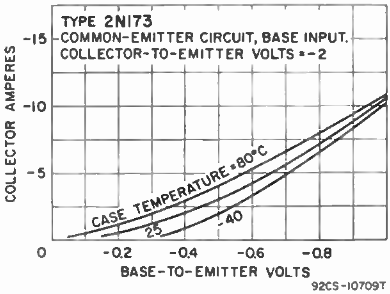
CHARACTERISTICS (cont'd)

Collector-to-Emitter Reach-Through Voltage	V_{RT}	—60 min	V
Collector-Cutoff Current:			
$V_{CB} = -2$ V, $I_E = 0$, $T_C = 25$°C	I_{CBO}	—100	μA
$V_{CB} = -60$ V, $I_E = 0$, $T_C = 25$°C	I_{CBO}	—4 max	mA
$V_{CB} = -60$ V, $I_E = 0$, $T_C = 71$°C	I_{CBO}	—15 max	mA
Emitter-Cutoff Current:			
$V_{EB} = -40$ V, $I_C = 0$	I_{EBO}	—1 typ	mA
$V_{EB} = -40$ V, $I_C = 0$	I_{EBO}	—4 max	mA
Static Forward-Current Transfer Ratio:			
$V_{CE} = -2$ V, $I_C = -5$ A	h_{FE}	35 to 70	
$V_{CE} = -2$ V, $I_C = -12$ A	h_{FE}	25	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CE} = -6$ V, $I_C = -5$ A)	f_{hfe}	10	kc/s
Thermal Resistance, Junction-to-Case	Θ_{J-C}	0.5 max	°C/W

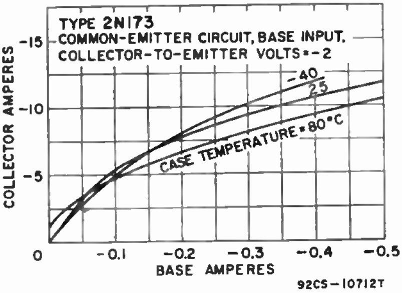
TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



POWER TRANSISTOR 2N174

Ge p-n-p alloy-junction type used in a wide variety of switching and amplifier applications in equipment having high voltage, current, and dissipation requirements. It is used in power switching, voltage- and current-regulating, dc-to-dc converter, inverter, power-supply, and relay- and solenoid-actuating circuits; and in low-frequency oscillator and audio-amplifier service. JEDEC **TO-36, Outline No.11. Terminals:** Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case.

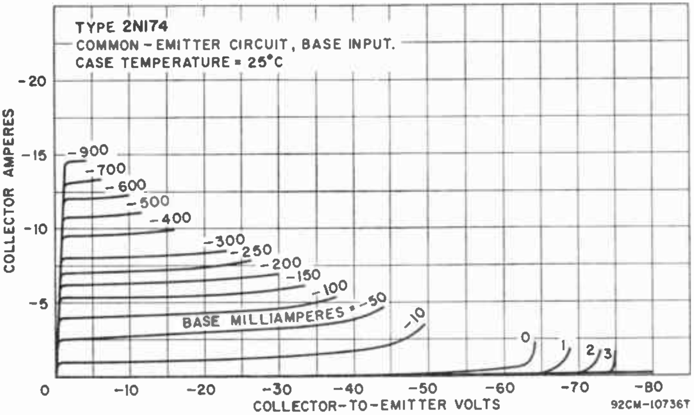
MAXIMUM RATINGS

Collector-to-Base Voltage (V_{BE} = 1.5V)	V_{CBV}	—80	V
Emitter-to-Base Voltage	V_{EBO}	—60	V
Collector Current	I_C	—15	A
Emitter Current	I_E	15	A
Base Current	I_B	—4	A
Transistor Dissipation:			
T_C up to 25°C	P_T	150	W
T_C above 25°C	P_T	See curve page 112	
Case Temperature Range:			
Operating (T_C) and Storage (T_{STG})		—65 to 100	°C

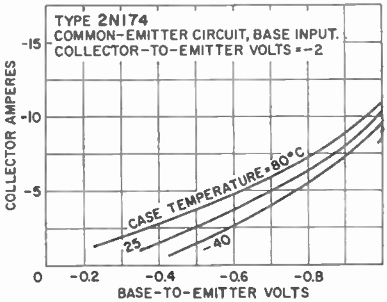
CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage:			
I_C = —0.3 A, R_{BE} = 0	$V_{(BR)CES}$	—70 min	V
I_C = —1 A, I_B = 0)	$V_{(BR)CEO}$	—55 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = —12 A, I_B = —2 A	V_{CE}(sat)	—0.7 max	V
I_C = —12 A, I_B = —2 A	V_{CE}(sat)	—0.3 typ	V
Emitter to Base Voltage (V_{CB} = —80 V, I_E = 0)	V_{EB}	—1 max	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	—80 min	V
Base-to-Emitter Voltage:			
V_{CE} = —2 V, I_C = —5 A	V_{BE}	—0.65 typ	V
V_{CE} = —2 V, I_C = —5 A	V_{BE}	—0.9 max	V
Collector-Cutoff Current:			
V_{CB} = —2 V, I_E = 0, T_C = 25°C	I_{CBO}	—100	µA
V_{CB} = —80 V, I_E = 0, T_C = 25°C	I_{CBO}	—4 max	mA
V_{CB} = —80 V, I_E = 0, T_C = 71°C	I_{CBO}	—15 max	mA
Emitter-Cutoff Current:			
V_{EB} = —60 V, I_C = 0	I_{EBO}	—1 typ	mA
V_{EB} = —60 V, I_C = 0	I_{EBO}	—4 max	mA

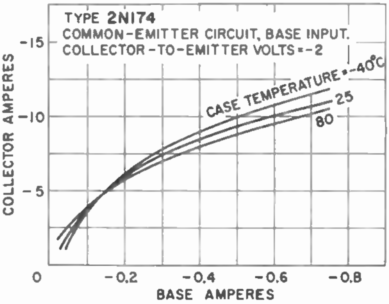
TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



CHARACTERISTICS (cont'd)

Static Forward-Current Transfer Ratio:			
$V_{CE} = -2$ V, $I_C = -5$ A	h_{FE}	25 to 50	
$V_{CE} = -2$ V, $I_C = -12$ A	h_{FE}	20	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CE} = -6$ V, $I_C = -5$ A)	f_{hfe}	10	kc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	0.5 max	°C/W

TRANSISTOR 2N175

Ge p-n-p alloy-junction type used in small-signal af amplifier applications in hearing aids, microphone preamplifiers, recorders, and other low-power applications. JEDEC TO-40, Outline No.13. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−10	V
Emitter-to-Base Voltage	V_{EBO}	−10	V
Collector Current	I_C	−2	mA
Emitter Current	I_E	2	mA
Transistor Dissipation:			
T_A at 25°C	P_T	50	mW
T_A at 71°C	P_T	10	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	71	°C
Storage	T_{STG}	−65 to 85	°C

CHARACTERISTICS

Collector-Cutoff Current ($V_{CB} = -25$ V, $I_E = 0$)	I_{CBO}	−12 max	μA
Emitter-Cutoff Current ($V_{EB} = -12$ V, $I_C = 0$)	I_{EBO}	−12 max	μA
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = -4$ V, $I_C = -0.5$ mA)	f_{hfb}	0.85	Mc/s
Noise Figure ($V_{CE} = -4$ V, $I_C = -0.5$ mA, $R_{ie} = 1000\ \Omega$, $R_{oe} = 20000\ \Omega$)	NF	6 max	dB

POWER TRANSISTOR 2N176

Ge p-n-p alloy-junction type used in large-signal af amplifiers in class A power-output stages and class B push-pull amplifier stages in automobile radio receivers. JEDEC TO-3, Outline No.2. Terminals: 1 - base, 2 - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−40	V
Collector Current	I_C	−3	A
Emitter Current	I_E	3	A
Transistor Dissipation:			
T_{MF} up to 80°C	P_T	10	W
T_{MF} above 80°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_{MF}) and Storage (T_{STG})		−65 to 90	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage ($I_C = -330$ mA, $R_{BE} = 0$)	$V_{(BR)CES}$	−30 min	V
Collector-Cutoff Current ($V_{CB} = -30$ V, $I_E = 0$)	I_{CBO}	−3 max	mA
Emitter-Cutoff Current ($V_{EB} = -10$ V, $I_C = 0$)	I_{EBO}	−2 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = -2$ V, $I_C = -0.5$ A)	h_{FE}	63	
Small-Signal Forward-Current Transfer Ratio ($f = 1$ kc/s, $V_{CE} = -2$ V, $I_C = -0.5$ A)	h_{fe}	45	
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	1 max	°C/W

TYPICAL OPERATION IN CLASS A POWER-AMPLIFIER CIRCUIT

DC Collector-Supply Voltage	V_{CC}	−14.4	V
DC Collector-to-Emitter Voltage	V_{CE}	−13.7	V
DC Base-to-Emitter Voltage	V_{BE}	−0.24	V

TYPICAL OPERATION (cont'd)

Peak Collector Current	$i_{C(peak)}$	—1	A
Zero-Signal Collector Current		—0.5	A
Emitter Resistance		1	Ω
Load Impedance	R_L	25	Ω
Signal Frequency		1	kc/s
Signal-Source Impedance	R_S	10	Ω
Power Gain	G_{PE}	35.5	dB
Total Harmonic Distortion		4	%
Zero-Signal Collector Dissipation		6.83	W
Maximum-Signal Power Output	P_{OE}	2	W

2N215 TRANSISTOR

Ge p-n-p alloy-junction type used in low-power audio-frequency amplifier applications. JEDEC TO-1, **Outline** No.1. **Terminals**: 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N104.

2N217 TRANSISTOR

Ge p-n-p alloy-junction type used in low-power, small-signal and large-signal audio applications in consumer-product equipment. JEDEC TO-1, **Outline** No.1. **Terminals**: 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N109.

2N218 TRANSISTOR

Ge p-n-p alloy-junction type used primarily in 455-kilocycle intermediate-frequency amplifier service in battery-operated portable radio receivers and automobile radio receivers operating from either a 6-volt or a 12-volt supply. JEDEC TO-1, **Outline** No.1. **Terminals**: 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N139.

2N219 TRANSISTOR

Ge p-n-p alloy-junction type used primarily in converter and mixer-oscillator service in AM battery-operated portable radio receivers and automobile radio receivers operating from either a 6-volt or a 12-volt supply. JEDEC TO-1, **Outline** No.1. **Terminals**: 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N140.

2N220 TRANSISTOR

Ge p-n-p alloy-junction type used in small-signal af amplifier applications in hearing aids, microphone preamplifiers, recorders, and other low-power applications. JEDEC TO-1, **Outline** No.1. **Terminals**: 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N175.

2N270 TRANSISTOR

Ge p-n-p alloy-junction type used in large-signal applications in class A driver stages and af amplifiers, and class B push-pull line- and battery-operated af amplifiers. Similar to JEDEC TO-7 (3-lead type), **Outline** No.4. **Terminals**: 1 - emitter, 2 - base, 3 - no connection, 4 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−25	V
Emitter-to-Base Voltage	V_{EBO}	−12	V
Collector Current	I_C	−75	mA
Emitter Current	I_E	75	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	250	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 71	°C
Storage	T_{STG}	−65 to 85	°C

CHARACTERISTICS

Collector-to-Emitter Voltage	V_{CEO}	−25	V
Collector-Cutoff Current (V_{CB} = −25 V, I_E = 0)	I_{CBO}	−16 max	μA
Emitter-Cutoff Current (V_{EB} = −12 V, I_C = 0)	I_{EBO}	−12 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = −1 V, I_C = −150 mA)	h_{FE}	70	
Gain-Bandwidth Product	f_T	1	Mc/s
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	0.24 max	°C/mW

TYPICAL OPERATION IN CLASS A POWER-AMPLIFIER CIRCUIT

DC Collector-Supply Voltage	V_{CC}	−9	V
DC Collector-to-Emitter Voltage	V_{CE}	−6.7	V
DC Base-to-Emitter Voltage	V_{BE}	−0.19	V
DC Collector Current	I_C	−19	mA
Emitter Resistance		400	Ω
Load Impedance	R_L	400	Ω
Signal Frequency		1	kc/s
Power Gain	G_{PE}	35	dB
Zero-Signal Transistor Dissipation		128	mW
Maximum-Signal Power Output	P_{OE}	60	mW
Total Harmonic Distortion:			
At power output = 60 mW		10 max	%
At power output = 10 mW		4 max	%

TRANSISTOR 2N274

Ge p-n-p alloy drift-field type used in rf and if amplifier, oscillator, mixer, and converter circuits, and in low-level video-amplifier circuits in industrial and military equipment. JEDEC TO-44, Outline No.14. Terminals: 1 - emitter, 2 - base, 3 - collector, Center Lead - interlead shield and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−40	V
Collector-to-Emitter Voltage (V_{BE} = 0.5 V)	V_{CEV}	−40	V
Emitter-to-Base Voltage	V_{EBO}	−0.5	mA
Collector Current	I_C	−10	mA
Emitter Current	I_E	10	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	120	mW
T_A above 25°C	P_T	See curve page 112	
T_A = 25°C (with heat sink)	P_T	240	mW
T_A above 25°C (with heat sink)	P_T	See curve page 112	
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 100	°C

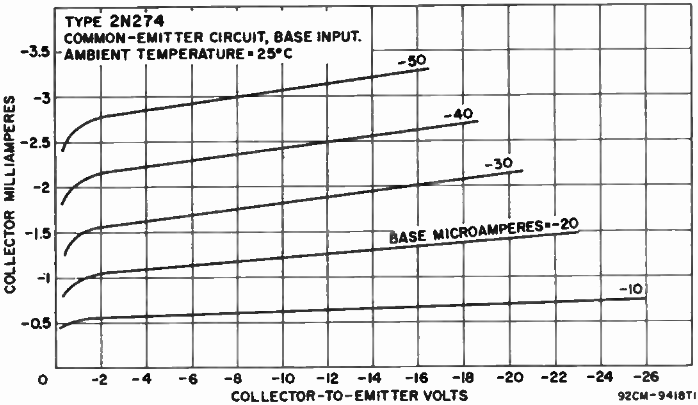
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −50 μA, I_E = 0)	$V_{(BR)CBO}$	−40 min	V
Collector-to-Base Reach-Through Voltage (V_{EB} = −0.5 V)	V_{RT}	−40 min	V
Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−12 max	μA
Emitter-Cutoff Current (V_{EB} = −0.5 V, I_C = 0)	I_{EBO}	−12 max	μA
Small-Signal Forward-Current Transfer Ratio (f = 1 kc/s, V_{CE} = −12 V, I_E = 1.5 mA)	h_{fe}	20 to 175	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −12 V, I_E = 1.5 mA)	f_{hfb}	30	Mc/s
Output Capacitance (V_{CB} = −12 V, I_E = 0)	C_{obo}	3 max	pF
Input Resistance:			
V_{CE} = −12 V, I_E = 1.5 mA, f = 12.5 Mc/s	R_{ie}	150	Ω
V_{CE} = −12 V, I_E = 1.5 mA, f = 1.5 Mc/s	R_{ie}	1350	Ω

CHARACTERISTICS (cont'd)

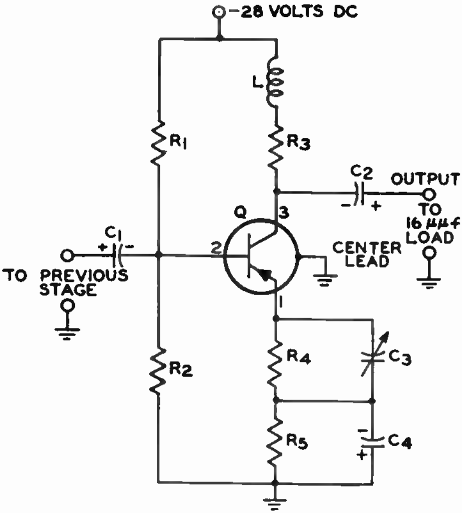
Output Resistance:			
V_{CE} = —12 V, I_E = 1.5 mA, f = 12.5 Mc/s	R_{oe}	4000	Ω
V_{CE} = —12 V, I_E = 1.5 mA, f = 1.5 Mc/s	R_{oe}	70000	Ω
Power Gain:			
V_{CE} = —12 V, I_E = 1.5 mA, f = 12.5 Mc/s	G_{pe}	17 to 27	dB
V_{CE} = —12 V, I_E = 1.5 mA, f = 1.5 Mc/s	G_{pe}	40 to 50	dB
Thermal Resistance, Junction-to-Case	θ_{J-C}	0.31 max	°C/mW
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	0.62 max	°C/mW

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL OPERATION IN VIDEO-AMPLIFIER CIRCUIT

DC Collector-to-Emitter Voltage	V_{CE}	—12	V
DC Emitter Current	I_E	5.8	mA
Source Impedance	R_S	150	Ω
Capacitive Load		16	pF
Frequency Response		20 c/s to 9	Mc/s
Pulse-Rise Time	t_r	0.039	μs
Voltage Gain		26	dB
Maximum Peak-to-Peak Output Voltage		20	V



C_1 = 25 μF, 12 volts
C_2 = 25 μF, 25 volts
C_3 = 100 to 300 pF (variable)
C_4 = 100 μF, 12 volts
L = 30 μH
R_1 = 20000 ohms, 0.25 watt
R_2 = 3600 ohms, 0.25 watt
R_3 = 2000 ohms, 0.25 watt
R_4 = 62 ohms, 0.25 watt
R_5 = 620 ohms, 0.25 watt

POWER TRANSISTOR 2N277

Ge **p-n-p alloy-junction** type used in a wide variety of switching and amplifier applications in industrial and military equipment requiring transistors having high voltage, current, and dissipation values. It is used in power-switching, voltage- and current-regulating, dc-to-dc converter, inverter, power-supply, and relay- and solenoid-actuating circuit; and in low-frequency oscillator and audio-amplifier service. JEDEC TO-36, **Outline** No.11. Terminals: Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case. This type is identical with type 2N173 except for the following items:

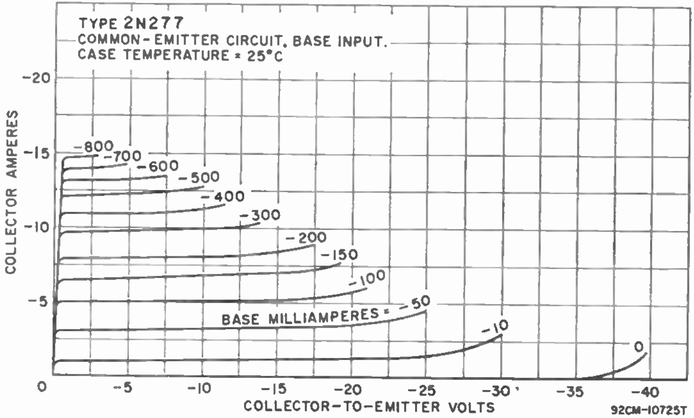
MAXIMUM RATINGS

Collector-to-Base Voltage (V_{BE} = 1.5 V)	V_{CBV}	−40	V
Emitter-to-Base Voltage	V_{EBO}	−20	V

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage:			
I_C = −0.3 A, R_{BE} = 0	$V_{(BR)CES}$	−40 min	V
I_C = −1 A, I_B = 0	$V_{(BR)CEO}$	−25 min	V
Collector-to-Emitter Saturation Voltage (I_C = −12 A, I_B = −2 A)	V_{CE}(sat)	−0.3	V
Emitter-to-Base Voltage (V_{CB} = −40 V, I_E = 0)	V_{EB}	−1 max	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−40 min	V
Collector-Cutoff Current:			
V_{CB} = −40 V, I_E = 0, T_C = 25°C	I_{CBO}	−4 max	mA
V_{CB} = −40 V, I_E = 0, T_C = 71°C	I_{CBO}	−15 max	mA
Emitter-Cutoff Current:			
V_{EB} = −20 V, I_C = 0	I_{EBO}	−1 typ	mA
V_{EB} = −20 V, I_C = 0	I_{EBO}	−4 max	mA

TYPICAL COLLECTOR CHARACTERISTICS



POWER TRANSISTOR 2N278

Ge **p-n-p alloy-junction** type used in a wide variety of switching and amplifier applications in industrial and military equipment requiring transistors having high voltage, current, and dissipation values. It is used in power-switching, voltage- and current-regulating, dc-to-dc converter, inverter, power-switching, and relay- and solenoid-actuating circuits; and in low-frequency oscillator and audio-amplifier service. JEDEC TO-36, **Outline** No.11. Terminals: Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case. This type is identical with type 2N173 except for the following items:

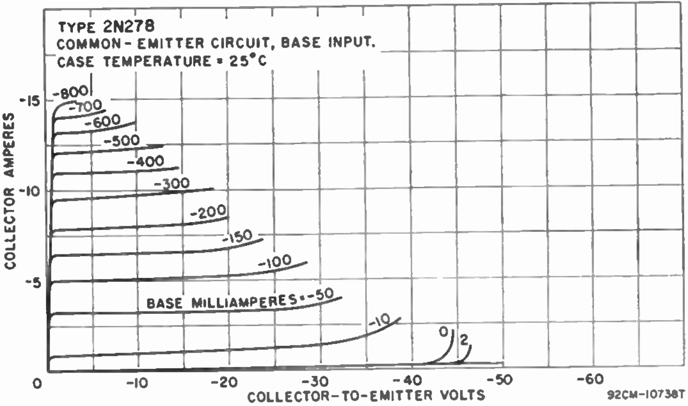
MAXIMUM RATINGS

Collector-to-Base Voltage (V_{BE} = 1.5 V)	V_{CBV}	−50	V
Emitter-to-Base Voltage	V_{EBO}	−30	V

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage:			
$I_C = -0.3$ A	$V_{(BR)CES}$	—45 min	V
$I_C = -1$ A, $I_B = 0$	$V_{(BR)CEO}$	—30 min	V
Emitter-to-Base Voltage ($V_{CB} = -50$ V, $I_E = 0$)	V_{EB}	—1 max	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	—50 min	V
Collector-Cutoff Current:			
$V_{CB} = -50$ V, $I_E = 0$, $T_C = 71°C$	I_{CBO}	—4 max	mA
$V_{CB} = -50$ V, $I_E = 0$, $T_C = 25°C$	I_{CBO}	—15 max	mA
Emitter-Cutoff Current:			
$V_{EB} = -30$ V, $I_C = 0$	I_{EBO}	—1 typ	mA
$V_{EB} = -30$ V, $I_C = 0$	I_{EBO}	—4 max	mA

TYPICAL COLLECTOR CHARACTERISTICS



2N351 POWER TRANSISTOR

Ge **p-n-p alloy-junction** type used in large-signal af amplifiers in class A power-output stages and class B push-pull amplifier stages in automobile radio receivers. JEDEC TO-3, **Outline No.2. Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N176 except for the following items:

CHARACTERISTICS

Static Forward-Current Transfer Ratio ($V_{CE} = -2$ V, $I_C = -0.7$ A)	h_{FE}	65
Small-Signal Forward-Current Transfer Ratio (f = 1 kc/s, $V_{CE} = -2$ V, $I_C = -0.7$ A)	h_{fe}	45

TYPICAL OPERATION IN CLASS A POWER-AMPLIFIER CIRCUIT

DC Collector-Supply Voltage	V_{CC}	—14.4	V
DC Collector-to-Emitter Voltage	V_{CE}	—13.2	V
DC Base-to-Emitter Voltage	V_{BE}	—0.3	V
Peak Collector Current	i_C(peak)	—1.4	A
Zero-Signal Collector Current	I_C	—0.7	A
Emitter Resistance		1	Ω
Load Impedance	R_L	15	Ω
Signal Frequency		1	kc/s
Signal-Source Impedance	R_S	10	Ω
Power Gain	MUG	33.5	dB
Total Harmonic Distortion ($P_{oe} = 4$ W)		5	%
Zero-Signal Collector Dissipation		9.25	W
Maximum-Signal Power Output	P_{OE}	4	W

2N370 TRANSISTOR

Ge **p-n-p alloy-junction drift-field** type used in rf-amplifier service in AM broadcast-band portable radio receivers and short-wave receivers. JEDEC

TO-7, Outline No.4. Terminals: 1 - emitter, 2 - base, 3 - interlead shield and case, 4 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−24	V
Emitter-to-Base Voltage	V_{EBO}	−0.5	V
Collector Current	I_C	−10	mA
Emitter Current	I_E	10	mA
Transistor Dissipation:			
T_A = 25°C	P_T	80	mW
T_A = 55°C	P_T	40	mW
T_A = 71°C	P_T	20	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 71	°C
Storage	T_{STG}	−65 to 85	°C

CHARACTERISTICS

Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−10 max	µA
Emitter-Cutoff Current (V_{EB} = −0.5 V, I_C = 0)	I_{EBO}	−12 max	µA
Static Forward-Current Transfer Ratio* (V_{CE} = −12 V, I_C = −1 mA)	h_{FE}	60	typ
Gain-Bandwidth Product (V_{CE} = −12 V, I_C = −1 mA)	f_T	132	Mc/s

TYPICAL OPERATION

Frequency	f	1.5	20	Mc/s
DC Collector-to-Emitter Voltage	V_{CE}	−12	−12	V
DC Collector Current	I_C	1	1	mA
Input Resistance	R_S	1750	100	Ω
Output Resistance	R_L	180000	11000	Ω
Maximum Power Gain	MAG	50.5	17	dB
Maximum Useful Power Gain (unneutralized)	MUG	31	12.5	dB
Intrinsic Transconductance	g_m	37800	13700	µmhos
Collector Transition Capacitance		1.7	1.7	pF

* This characteristic does not apply to type 2N371

TRANSISTOR 2N371

Ge **p-n-p alloy-junction drift-field** type used in rf-oscillator applications in AM broadcast-band battery-operated portable radio receivers and short-wave receivers. JEDEC TO-7, **Outline** No.4. **Terminals:** 1 - emitter, 2 - base, 3 - interlead shield and case, 4 - collector. This type is identical with type 2N370 except for the following items:

TYPICAL OPERATION AS AN RF OSCILLATOR

The 2N371 produces an oscillator-injection voltage for optimum mixing in an rf tuner circuit. If the collector supply voltage drops from −12 to −8 volts at a frequency of 22 Mc/s, the frequency provided by the oscillator stage will deviate from 22 Mc/s by less than 7 kc/s.

TRANSISTOR 2N372

Ge **p-n-p alloy-junction drift-field** type for use as an rf mixer in AM broadcast-band portable radio receivers and short-wave receivers. JEDEC TO-7, **Outline** No.4. **Terminals:** 1 - emitter, 2 - base, 3 - interlead shield and case, 4 - collector. This type is identical with type 2N370.

POWER TRANSISTOR 2N376

Ge **p-n-p alloy-junction** type used in large-signal af amplifiers in class A power-output stages and class B push-pull amplifier stages in automobile radio receivers. JEDEC TO-3, **Outline** No.2. **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N176 except for the following items:

CHARACTERISTICS

Static Forward-Current Transfer Ratio (V_{CE} = −2 V, I_C = −0.7 A)	h_{FE}	78	
Small-Signal Forward-Current Transfer Ratio (f = 1 kc/s, V_{CE} = −2 V, I_C = −0.7 A)	h_{fe}	60	

TYPICAL OPERATION IN CLASS A POWER-AMPLIFIER CIRCUIT (T_{MF} = 80°C)

DC Collector-Supply Voltage	V_{CC}	−14.4	V
DC Collector-to-Emitter Voltage	V_{CE}	−13.2	V
DC Base-to-Emitter Voltage	V_{BE}	−0.3	V
Peak Collector Current	i_C(peak)	−1.4	A
Zero-Signal Collector Current	I_C	−0.7	A
Emitter Resistance		1	Ω
Load Impedance	R_L	15	Ω
Signal Frequency		1	kc/s
Signal-Source Impedance	R_S	10	Ω
Power Gain	G_{PE}	35	dB
Total Harmonic Distortion		5	%
Zero-Signal Collector Dissipation		9.25	W
Maximum-Signal Power Output	P_{OE}	4	W

2N384 TRANSISTOR

Ge **p-n-p alloy-junction drift-field** type used in rf and if amplifier, oscillator, mixer, and converter circuits, and low-level video-amplifier circuits in industrial and military equipment. JEDEC TO-44, **Outline No.14. Terminals:** 1 - emitter, 2 - base, 3 - collector, Center Lead - interlead shield and case. For collector-characteristics curves and video-amplifier circuit, refer to type 2N274.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−40	V
Collector-to-Emitter Voltage (V_{BE} = 0.5 V)	V_{CEV}	−40	V
Emitter-to-Base Voltage	V_{EBO}	−0.5	V
Collector Current	I_C	−10	mA
Emitter Current	I_E	10	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	120	mW
T_A above 25°C	P_T	See curve page 112	
T_C = 25°C (with heat sink)	P_T	240	mW
T_C above 25°C (with heat sink)	P_T	See curve page 112	
Ambient-Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 100	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −50 μA, I_E = 0)	$V_{(BR)CBO}$	−40 min	V
Collector-to-Base Reach-Through (V_{EB} = −0.5 V)	V_{RT}	−40 min	V
Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−12 max	μA
Emitter-Cutoff Current (V_{EB} = −0.5 V, I_C = 0)	I_{EBO}	−12 max	μA
Small-Signal Forward-Current Transfer Ratio (V_{CB} = −12 V, I_E = 1.5 mA)	h_{fe}	20 to 175	
Small-Signal Forward-Current Transfer Ratio Cutoff Frequency (V_{CB} = −12 V, I_E = 1.5 mA)	f_{hfb}	100	Mc/s
Input Resistance:			
V_{CE} = −12 V, I_E = 1.5 mA, f = 50 Mc/s	R_{ie}	30	Ω
V_{CE} = −12 V, I_E = 1.5 mA, f = 12.5 Mc/s	R_{ie}	250	Ω
Output Resistance:			
V_{CE} = −12 V, I_E = 1.5 mA, f = 50 Mc/s	R_{oe}	5000	Ω
V_{CE} = −12 V, I_E = 1.5 mA, f = 12.5 Mc/s	R_{oe}	16000	Ω
Output Capacitance (V_{CB} = −12 V, I_E = 0)	C_{obo}	3 max	pF
Power Gain:			
V_{CE} = −12 V, I_E = 1.5 mA, f = 50 Mc/s	G_{pe}	15 to 21	dB
V_{CE} = −12 V, I_E = 1.5 mA, f = 12.5 Mc/s	G_{pe}	24 to 32	dB
Thermal Resistance, Junction-to-Case	θ_{J-C}	0.31 max	°C/mW
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	0.62 max	°C/mW

TYPICAL OPERATION IN VIDEO-AMPLIFIER CIRCUIT

DC Collector-to-Emitter Voltage	V_{CE}	−12	V
DC Emitter Current	I_E	5.8	mA
Source Impedance	R_S	150	Ω
Capacitive Load		16	pF
Frequency Response		20 c/s to 10 Mc/s	
Pulse-Rise Time	t_r	0.035	μs
Voltage Gain		26	dB
Maximum Peak-to-Peak Output Voltage		20	V

COMPUTER TRANSISTORS

2N388
2N388A

Ge n-p-n alloy-junction types used in switching applications in data-processing equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base and case, 3 - collector.

MAXIMUM RATINGS

		2N388	*2N388A*	
Collector-to-Base Voltage	V_{CBO}	25	40	V
Collector-to-Emitter Voltage:				
$V_{BE} = -0.5$ V	V_{CEV}	—	40	V
$R_{BE} = 10000\ \Omega$	V_{CER}	20	—	V
Emitter-to-Base Voltage	V_{EBO}	15	15	V
Collector Current	I_C	200	200	mA
Transistor Dissipation:				
T_A up to 25°C	P_T	150	150	mW
T_A above 25°C	P_T	See curve page 112		
Temperature Range:				
Operating (Junction)	T_J(opr)	100	100	°C
Storage	T_{STG}	−65 to 100		°C
Lead-Soldering Temperature (10 s max)	T_L	235	235	°C

CHARACTERISTICS

		2N388	*2N388A*	
Base-to-Emitter Voltage:				
$I_B = 10$ mA, $I_C = 200$ mA	V_{BE}	1.5	1.5 max	V
$I_B = 4$ mA, $I_C = 100$ mA	V_{BE}	0.8	0.8 max	V
Collector-Cutoff Current:				
$V_{CE} = 20$ V, $R_{BE} = 10000\ \Omega$	I_{CER}	50	50 max	µA
$V_{CE} = 40$ V, $V_{BE} = -0.5$ V	I_{CEV}	—	50 max	µA
$V_{CB} = 40$ V, $I_E = 0$	I_{CBO}	—	40 max	µA
$V_{CB} = 25$ V, $I_E = 0$	I_{CBO}	10	10 max	µA
$V_{CB} = 1$ V, $I_E = 0$	I_{CBO}	5	5 max	µA
Emitter-Cutoff Current:				
$V_{EB} = 15$ V, $I_C = 0$	I_{EBO}	10	10 max	µA
$V_{EB} = 1$ V, $I_C = 0$	I_{EBO}	5	5 max	µA
Static Forward-Current Transfer Ratio:				
$V_{CE} = 0.75$ V, $I_C = 200$ mA	h_{FE}	30	30 min	
$V_{CE} = 0.5$ V, $I_C = 30$ mA	h_{FE}	60 to 180		
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = 6$ V, $I_C = 1$ mA)	f_{hfb}	5	5 min	Mc/s
Output Capacitance ($V_{CB} = 6$ V, $I_C = 1$ mA)	C_{obo}	20	20 max	pF
Turn-On Time ($V_{CC} = 20$ V, $I_{B1} = 10$ mA, $I_{B2} = -10$ mA, $I_C = 0.2$ A, $R_C = 100\ \Omega$)	$t_d + t_r$	1	1 max	µs
Storage Time ($V_{CC} = 20$ V, $I_{B1} = 10$ mA, $I_{B2} = -10$ mA, $I_C = 0.2$ A, $R_C = 100\ \Omega$)	t_s	0.7	0.7 max	µs
Fall Time ($V_{CC} = 20$ V, $I_{B1} = 10$ mA, $I_{B2} = -10$ mA, $I_C = 0.2$ A, $R_C = 100\ \Omega$)	t_f	0.7	0.7 max	µs

COMPUTER TRANSISTOR

2N395

Ge p-n-p alloy-junction type used in switching applications in data-processing equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base and case, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−30	V
Collector-to-Emitter Voltage ($R_{BE} = 10000\ \Omega$)	V_{CER}	−15	V
Emitter-to-Base Voltage	V_{EBO}	−20	V
Collector Current	I_C	−0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	150	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 85	°C
Storage	T_{STG}	−65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage ($I_C = -0.1$ mA, $I_E = 0$)	$V_{(BR)CBO}$	−30 min	V

CHARACTERISTICS (cont'd)

Emitter-to-Base Breakdown Voltage (I_E = −0.1 mA, I_C = 0)	$V_{(BR)EBO}$	−20 min	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−15 min	V
Collector-to-Emitter Saturation Voltage (I_B = −5 mA, I_C = −50 mA)	V_{CE}(sat)	−0.2 max	V
Collector-Cutoff Current (V_{CB} = −15 V, I_E = 0)	I_{CBO}	−6 max	µA
Emitter-Cutoff Current (V_{EB} = −10 V, I_C = 0)	I_{EBO}	−6 max	µA
Static Forward-Current Transfer Ratio:			
V_{CE} = −1 V, I_C = −10 mA	h_{FE}	20 to 150	
V_{CE} = −0.35 V, I_C = −200 mA	h_{FE}	10 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −5 V, I_E = 1 mA)	f_{hfb}	3 min	Mc/s
Output Capacitance (V_{CB} = −5 V, I_C = −1 mA, f = 1 Mc/s)	C_{obo}	20	pF

2N396
2N396A

COMPUTER TRANSISTORS

Ge **p-n-p alloy-junction** types used in switching applications in data-processing equipment. JEDEC **TO-5, Outline** No.3. **Terminals:** 1 - emitter, 2 - base and case, 3 - collector. This type is identical with type 2N395 except for the following items:

MAXIMUM RATINGS

		2N396	*2N396A*	
Collector-to-Emitter Voltage:				
R_{BE} = 1000 Ω	V_{CER}	−20	—	V
Base open	V_{CEO}	—	−20	V
Transistor Dissipation:				
T_A up to 25°C	P_T	—	200	mW
T_A above 25°C	P_T	See curve page 112		

CHARACTERISTICS

		2N396	*2N396A*	
Collector-to-Emitter Breakdown Voltage (I_C = −0.6 mA, I_B = 0)	$V_{(BR)CEO}$	—	−20 min	V
Collector-to-Emitter Saturation Voltage (I_B = −3.3 mA, I_C = −50 mA)	V_{CE}(sat)	−0.2	−0.2 max	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−20	−20 min	V
Collector-Cutoff Current:				
V_{CB} = −20 V, I_E = 0, T_A = 25°C	I_{CBO}	−6	−6 max	µA
V_{CB} = −20 V, I_E = 0, T_A = 71°C	I_{CBO}	—	−120 max	µA
Static Forward-Current Transfer Ratio:				
V_{CE} = −1 V, I_C = −10 mA, T_A = 25°C	h_{FE}	30 to 150		
V_{CE} = −0.35 V, I_C = −200 mA, T_A = 25°C	h_{FE}	15	15 min	
V_{CE} = −1 V, I_C = −10 mA, T_A = 55°C	h_{FE}	—	20 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −5 V, I_E = 1 mA)	f_{hfb}	5	5 min	Mc/s
Delay Time (V_{CC} = −10 V, I_C = −10 mA, I_{B1} = 1 mA, I_{B2} = −1 mA)	t_d	—	0.1 to 0.2	µs
Rise Time (V_{CC} = −10 V, I_C = −10 mA, I_{B1} = 1 mA, I_{B2} = −1 mA)	t_r	—	0.2 to 0.65	µs
Storage Time (V_{CC} = −10 V, I_C = −10 mA, I_{B1} = 1 mA, I_{B2} = −1 mA)	t_s	—	0.25 to 0.8	µs
Fall Time (V_{CC} = −10 V, I_C = −10 mA, I_{B1} = 1 mA, I_{B2} = −1 mA)	t_f	—	0.2 to 0.4	µs

2N397

COMPUTER TRANSISTOR

Ge **p-n-p alloy-junction** type used in switching applications in data-processing equipment. JEDEC **TO-5, Outline** No.3. **Terminals:** 1 - emitter, 2 - base and case, 3 - collector. This type is identical with type 2N395 except for the following items:

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage (I_B = −2.5 mA, I_C = −50 mA)	V_{CE}(sat)	−0.2 max	V
Static Forward-Current Transfer Ratio (V_{CE} = −1 V, I_C = −10 mA)	h_{FE}	40 to 150	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −5 V, I_E = 1 mA)	f_{hfb}	10 min	Mc/s

TRANSISTORS

2N398
2N398A
2N398B

Ge p-n-p alloy-junction types used for direct "on-off" control of high-voltage, low-power devices such as neon indicators, relays, incandescent-lamp indicators, indicator counters of electronic computers, and similar applications in critical industrial and military equipment. Designed to meet MIL specifications, including mechanical, environmental, and life tests. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

		2N398	*2N398A*	*2N398B*	
Collector-to-Base Voltage	V_{CBO}	−105	−105	−105	V
Collector-to-Emitter ($R_{BE} = 0$)	V_{CES}	−105	−105	−105	V
Emitter-to-Base Voltage	V_{EBO}	−50	−50	−75	V
Collector Current	I_C	−100	−200	−200	mA
Emitter Current	I_E	100	200	200	mA
Transistor Dissipation:					
T_A up to 25°C	P_T	50	150	250	mW
T_A above 25°C	P_T	See curve page 112			
Temperature Range:					
Operating (Ambient)	T_A(opr)	−65 to 55	−65 to 100		°C
Storage	T_{STG}	−65 to 85	−65 to 100		°C
Lead-Soldering Temperature:					
10 seconds max	T_L	230	—	250	°C
3 seconds max	T_L	—	250	—	°C

CHARACTERISTICS

		2N398	*2N398A*	*2N398B*	
Collector-to-Base Breakdown Voltage:					
$I_C = -0.025$ mA, $I_E = 0$	$V_{(BR)CBO}$	—	—	−105 min	V
$I_C = -0.05$ mA, $I_E = 0$	$V_{(BR)CBO}$	−105	−105	— min	V
Emitter-to-Base Breakdown Voltage ($I_E = -0.05$ mA, $I_C = 0$)	$V_{(BR)EBO}$	−50	−50	−75 min	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−105	−105	−105 min	V
Collector-to-Emitter Saturation Voltage ($I_C = -5$ mA, $I_B = -0.25$ mA)	V_{CE}(sat)	−0.35	−0.35	−0.25 max	V
Base-to-Emitter Saturation Voltage ($I_C = -5$ mA, $I_B = -0.25$ mA)	V_{BE}(sat)	−0.4	−0.4	−0.3 max	V
Collector-Cutoff Current:					
$V_{CE} = -105$ V, $R_{BE} = 0$, $T_A = 25°C$	I_{CES}	−600	−600	−300 max	µA
$V_{CE} = -55$ V, $R_{BE} = 1000\ \Omega$, $T_A = 25°C$	I_{CEB}	—	—	−300 max	µA
$V_{CB} = -2.5$ V, $I_E = 0$, $T_A = 25°C$	I_{CBO}	−14	−14	−6 max	µA
$V_{CB} = -105$ V, $I_E = 0$, $T_A = 25°C$	I_{CBO}	−50	−50	−25 max	µA
$V_{CB} = -105$ V, $I_E = 0$, $T_A = 71°C$	I_{CBO}	—	—	−300 max	µA
Emitter-Cutoff Current:					
$V_{EB} = -2.5$ V, $I_C = 0$	I_{EBO}	—	—	−6 max	µA
$V_{EB} = -50$ V, $I_C = 0$	I_{EBO}	−50	−50	— max	µA
$V_{EB} = -50$ V, $I_C = 0$	I_{EBO}	—	—	−50 max	µA
Static Forward-Current Transfer Ratio:					
$V_{CE} = -0.25$ V, $I_C = -5$ mA	h_{FE}	—	—	20 min	
$V_{CE} = -0.35$ V, $I_C = -5$ mA	h_{FE}	20	20	— min	
Small-Signal Forward-Current Transfer Ratio ($V_{CE} = -6$ V, $I_C = -1$ mA, f = 1 kc/s)	h_{fe}	—	20	40 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = -6$ V, $I_E = 1$ mA)	f_{hfb}	—	—	1 max	Mc/s
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	—	0.5	0.3 max	°C/W

COMPUTER TRANSISTORS

2N404
2N404A

Ge p-n-p alloy-junction types used in switching applications in data-processing equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

		2N404	2N404A	
Collector-to-Base Voltage	V_{CBO}	−25	−40	V
Collector-to-Emitter Voltage (V_{BE} = 1 V)	V_{CEV}	−24	−35	V
Emitter-to-Base Voltage	V_{EBO}	−12	−25	V
Collector Current	I_C	−100	−150	mA
Emitter Current	I_E	100	150	mA
Transistor Dissipation:				
T_A up to 25°C	P_T	150	150	mW
T_A = 55°C	P_T	75	90	mW
T_A = 71°C	P_T	35	60	mW
Temperature Range:				
Operating (Ambient)	T_A(opr)	−65 to 85	−65 to 100	°C
Storage	T_{STG}	−65 to 100	−65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	255	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −0.02 mA, I_E = 0)	$V_{(BR)CBO}$	−25	−40 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.02 mA, I_C = 0)	$V_{(BR)EBO}$	−12	−25 min	V
Base-to-Emitter Saturation Voltage:				
I_C = −12 mA, I_B = −0.4 mA	V_{BE}(sat)	−0.35	−0.35 max	V
I_C = −24 mA, I_B = −1 mA	V_{BE}(sat)	−0.4	−0.4 max	V
Collector-to-Emitter Saturation Voltage:				
I_C = −12 mA, I_B = −0.4 mA	V_{CE}(sat)	−0.15	−0.15 max	V
I_C = −24 mA, I_B = −1 mA	V_{CE}(sat)	−0.2	−0.2 max	V
Emitter-to-Base Reach-Through Voltage (V_{EB} = −1 V)	V_{RT}	−24	−35 min	V
Collector-Cutoff Current:				
V_{CB} = −12 V, I_E = 0, T_A = 25°C	I_{CBO}	−5	−5 max	µA
V_{CB} = −12 V, I_E = 0, T_A = 80°C	I_{CBO}	−90*	−90 max	µA
Static Forward-Current Transfer Ratio:				
V_{CE} = −0.2 V, I_C = −24 mA	h_{FE}	24	24 min	
V_{CE} = −0.15 V, I_C = −12 mA	h_{FE}	30	30 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −6 V, I_C = −1 mA)	f_{hfb}	4	4 min	Mc/s
Output Capacitance:				
V_{CB} = −6 V, I_E = 0	C_{obo}	20	— max	pF
V_{CB} = −6 V, I_C = −1 mA, f = 2 Mc/s	C_{obo}	—	20 max	pF
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	500	500 max	°C/W
Stored Base Charge (I_C = −10 mA, I_B = −1 mA)	Q_S	1400	1400 max	pC

* This value does not apply to type 2N581.

2N405

TRANSISTOR

Ge p-n-p alloy-junction type used in low-power class A af-amplifier applications in battery-operated portable radio-receivers. JEDEC TO-40, Outline No.13. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−20	V
Collector-to-Emitter Voltage	V_{CEO}	−18	V
Emitter-to-Base Voltage	V_{EBO}	−2.5	V
Collector Current	I_C	−35	mA
Emitter Current	I_E	35	mA
Transistor Dissipation:			
T_A = 25°C	P_T	150	mW
T_A = 55°C	P_T	50	mW
T_A = 71°C	P_T	20	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 71	°C
Storage	T_{STG}	−65 to 85	°C

CHARACTERISTICS

Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−14 max	µA
Emitter-Cutoff Current (V_{EB} = −2.5 V, I_C = 0)	I_{EBO}	−14 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = −6 V, I_E = 1 mA)	h_{FE}	35	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −6 V, I_C = −1 mA)	f_{hfb}	650	kc/s
Intrinsic Transconductance (V_{CE} = −6 V, I_E = 1 mA)	g_m	37500	µmhos
Power Gain (R_{oe} = 8500 Ω, R_{ie} = 750 Ω)	G_{pe}	43	dB

TRANSISTOR 2N406

Ge p-n-p alloy-junction type used in low-power class A af-amplifier applications in battery-operated portable radio receivers. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N405.

TRANSISTOR 2N407

Ge p-n-p alloy-junction type used in class A amplifiers and class B push-pull output stages of battery-operated radio receivers and af amplifiers. JEDEC TO-40, Outline No.13. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−20	V
Collector-to-Emitter Voltage	V_{CEO}	−18	V
Emitter-to-Base Voltage	V_{EBO}	−2.5	V
Collector Current	I_C	−70	mA
Emitter Current	I_E	70	mA
Transistor Dissipation:			
$T_A = 25°C$	P_T	150	mW
$T_A = 55°C$	P_T	50	mW
$T_A = 71°C$	P_T	20	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 71	°C
Storage	T_{STG}	−65 to 85	°C

CHARACTERISTICS

Collector-Cutoff Current ($V_{CB} = -12$ V, $I_E = 0$)	I_{CBO}	−14 max	µA
Emitter-Cutoff Current ($V_{EB} = -2.5$ V, $I_C = 0$)	I_{EBO}	−14 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = -1$ V, $I_C = -50$ mA)	h_{FE}	65	

TYPICAL OPERATION IN CLASS B AF-AMPLIFIER CIRCUIT

(Values Are For Two Transistors Except as Noted)

DC Collector Supply Voltage	V_{CC}	−4.5	−9	V
Base-to-Emitter Voltage	V_{BE}	−0.15	−0.15	V
Peak Collector Current (Approx.) per transistor	i_c(peak)	−35	−40	mA
Maximum-Signal DC Collector Current (Approx.) per transistor	I_C	−11.5	−13	mA
Zero-Signal DC Collector Current (Approx.) per transistor	I_C	−2	−2	mA
Signal Frequency		1	1	kc/s
Signal-Source Impedance per base	R_S	375	375	Ω
Load Impedance per collector	R_L	100	200	Ω
Power Gain	G_{PE}	30	33	dB
Circuit Efficiency	η	60	69	%
Total Harmonic Distortion		10 max	10 max	%
Maximum-Signal Power Output	P_{OE}	75	160	mW

TRANSISTOR 2N408

Ge p-n-p alloy-junction type used in class A amplifiers and class B push-pull output stages of battery-operated radio receivers and af amplifiers. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N407.

TRANSISTOR 2N409

Ge p-n-p alloy-junction type used in 455-kilocycle if-amplifier service in battery-operated portable radio receivers and automobile radio receivers. JEDEC TO-40, Outline No.13. Terminals: 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N410.

2N410 TRANSISTOR

Ge p-n-p alloy-junction type used in 455-kilocycle if-amplifier service in battery-operated portable radio receivers and automobile radio receivers. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	—13	V
Emitter-to-Base Voltage	V_{EBO}	—0.5	V
Collector Current	I_C	—15	mA
Emitter Current	I_E	15	mA
Transistor Dissipation:			
$T_A = 25°C$	P_T	80	mW
$T_A = 55°C$	P_T	35	mW
$T_A = 71°C$	P_T	10	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	—65 to 71	°C
Storage	T_{STG}	—65 to 85	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage ($I_C = -10\ \mu A$, $I_E = 0$)	$V_{(BR)CBO}$	—13 min	V
Emitter-Cutoff Current ($V_{EB} = -0.5$ V, $I_C = 0$)	I_{EBO}	—12 max	μA
Collector-Cutoff Current ($V_{CB} = -13$ V, $I_E = 0$)	I_{CBO}	—10 max	μA
Intrinsic Base-Lead Resistance ($V_{CE} = -9$ V, $I_E = 1$ mA)	r_{bb}	75	Ω
Static Forward-Current Transfer Ratio:			
$V_{CE} = -9$ V, $I_E = 0.5$ mA	h_{FE}	45	
$V_{CE} = -9$ V, $I_E = 1$ mA	h_{FE}	48	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency:			
$V_{CE} = -9$ V, $I_E = 0.5$ mA		6.8	Mc/s
$V_{CE} = -9$ V, $I_E = 1$ mA	f_{hfb}	6.7	Mc/s
Gain-Bandwidth Product ($V_{CE} = -9$ V, $I_E = 1$ mA)	f_T	14	Mc/s

TYPICAL OPERATION IN 455-kc/s IF-AMPLIFIER CIRCUIT

DC Collector-to-Emitter Voltage	V_{CE}	—9.0	—9.0	V
DC Emitter Current	I_E	0.5	1.0	mA
Input Resistance	R_S	1000	500	Ω
Output Resistance	R_L	70000	30000	Ω
Maximum Power Gain (Approx.)	MAG	38.8	37.8	dB
Typical Spot Noise Factor (Approx.)		4.5	4.5	dB
Useful Power Gain (Approx.)	MUG	28.4	31.2	dB

2N411 TRANSISTOR

Ge p-n-p alloy-junction type intended for converter and mixer-oscillator applications in battery-operated portable radio receivers. JEDEC TO-40, Outline No.13. Terminals: 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N412.

2N412 TRANSISTOR

Ge p-n-p alloy-junction type used in converter and mixer-oscillator applications in battery-operated portable radio receivers. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	—13	V
Emitter-to-Base Voltage	V_{EBO}	—0.5	V
Collector Current	I_C	—15	mA
Emitter Current	I_E	15	mA
Transistor Dissipation:			
$T_A = 25°C$	P_T	80	mW
$T_A = 55°C$	P_T	35	mW
$T_A = 71°C$	P_T	10	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	—65 to 71	°C
Storage	T_{STG}	—65 to 85	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage ($I_C = -10$ μA, $I_E = 0$)	$V_{(BR)CBO}$	−13 min	V
Collector-Cutoff Current ($V_{CB} = -13$ V, $I_E = 0$)	I_{CBO}	−10 max	μA
Emitter-Cutoff Current ($V_{EB} = -0.5$ V, $I_C = 0$)	I_{EBO}	−12 max	μA
Static Forward-Current Transfer Ratio ($V_{CE} = -9$ V, $I_C = -0.6$ mA)	h_{FE}	75	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = -9$ V, $I_E = 0.6$ mA)	f_{hfb}	10	Mc/s
Gain-Bandwidth Product ($V_{CE} = -9$ V, $I_E = 0.6$ mA)	f_T	16.5	Mc/s
Intrinsic Base-Lead Resistance ($V_{CE} = -9$ V, $I_E = 0.6$ mA)	r_{bb}	85	Ω

TYPICAL OPERATION IN CONVERTER CIRCUIT

DC Collector-to-Emitter Voltage	V_{CC}	−9	V
DC Collector Current	I_C	−0.6	mA
Input Resistance	R_S	700	Ω
Output Resistance	R_L	75000	Ω
RMS Base-to-Emitter Oscillator-Injection Voltage (Approx.)		100	mV
Signal Frequency		1	Mc/s
Useful Conversion Power Gain (Approx.)	MUG_c	32	dB

COMPUTER TRANSISTOR 2N414

Ge p-n-p alloy-junction type used in switching applications in data-processing equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−30	V
Collector-to-Emitter Voltage:			
$V_{BE} = 1$ V	V_{CEV}	−20	V
Base open	V_{CEO}	−15	V
Emitter-to-Base Voltage	V_{EBO}	−20	V
Collector Current	I_C	−200	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	150	mW
T_A above 25°C	P_T	See curve page 112	
$T_A = 55$°C	P_T	75	mW
Ambient-Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	240	°C

CHARACTERISTICS

Collector-Cutoff Current ($V_{CB} = -12$ V, $I_E = 0$)	I_{CBO}	−5 max	μA
Emitter-Cutoff Current ($V_{EB} = -12$ V, $I_C = 0$)	I_{EBO}	−5 max	μA
Small-Signal Forward-Current Transfer Ratio ($V_{CE} = -6$ V, $I_E = 1$ mA, $f = 1$ kc/s)	h_{fe}	80	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = -6$ V, $I_E = 1$ mA)	f_{hfb}	8	Mc/s
Output Capacitance ($V_{CB} = -6$ V, $I_C = -1$ mA)	C_{obo}	11 max	pF
Small-Signal Short-Circuit Input Impedance ($V_{CB} = -6$ V, $I_E = 1$ mA, $f = 1$ kc/s)	h_{ib}	30	Ω
Small-Signal Open-Circuit Reverse-Voltage Transfer Ratio ($V_{CB} = -6$ V, $I_E = 0$, $f = 1$ kc/s)	h_{rb}	5×10^{-4}	
Noise Figure ($V_{CE} = -6$ V, $I_E = 1$ mA, $f = 1.5$ Mc/s)	NF	6	dB
Power Gain ($V_{CE} = -6$ V, $I_E = 1$ mA, $f = 1.5$ Mc/s)	G_{pe}	16	dB

POWER TRANSISTOR 2N441

Ge p-n-p alloy-junction type used in a wide variety of switching and amplifier applications in industrial and military equipment requiring transistors having high voltage, current, and dissipation values. It is used in power-switching, voltage- and current-regulating, dc-to-dc converter, inverter, power-supply, and relay- and solenoid-actuating circuits; and in low-frequency oscillator and audio-amplifier service. It is stud-mounted to provide positive heat-sink contact. JEDEC TO-36, Outline No.11. Terminals: Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case.

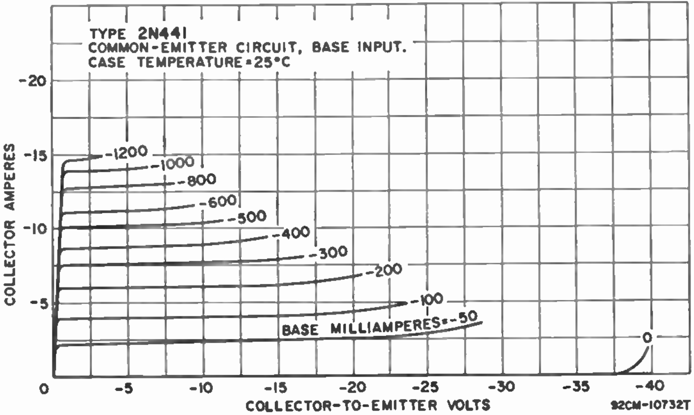
MAXIMUM RATINGS

Collector-to-Base Voltage (V_{BE} = 1.5 V)	V_{CBV}	−40	V
Emitter-to-Base Voltage	V_{EBO}	−20	V
Collector Current	I_C	−15	A
Emitter Current	I_E	15	A
Base Current	I_B	−4	A
Transistor Dissipation:			
T_C up to 25°C	P_T	150	W
T_C above 25°C	P_T	See curve page 112	
Case-Temperature Range:			
Operating (T_C) and Storage (T_{STG})		−65 to 100	°C

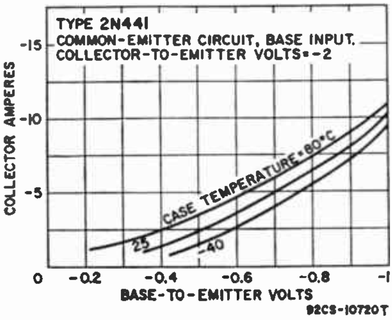
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
I_C = −0.3 A, R_{BE} = 0	$V_{(BR)CES}$	−40 min	V
I_C = −1 A, I_B = 0	$V_{(BR)CEO}$	−25 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = −12 A, I_B = −2 A	V_{CE}(sat)	−0.3	V
Emitter-to-Base Voltage (V_{CB} = −40 V, I_E = 0)	V_{EB}	−1 max	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−40 min	V
Base-to-Emitter Voltage (V_{CE} = −2 V, I_C = −5 A)	V_{BE}	−0.65	V
Collector-Cutoff Current:			
V_{CB} = −2 V, I_E = 0, T_C = 25°C	I_{CBO}	−100	µA
V_{CB} = −40 V, I_E = 0, T_C = 25°C	I_{CBO}	−4 max	mA
V_{CB} = −40 V, I_E = 0, T_C = 71°C	I_{CBO}	−15 max	mA
Emitter-Cutoff Current:			
V_{EB} = −20 V, I_C = 0	I_{EBO}	−1 typ	mA
V_{EB} = −20 V, I_C = 0	I_{EBO}	−4 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = −2 V, I_C = −5 A	h_{FE}	20 to 40	
V_{CE} = −2 V, I_C = −12 A	h_{FE}	20	

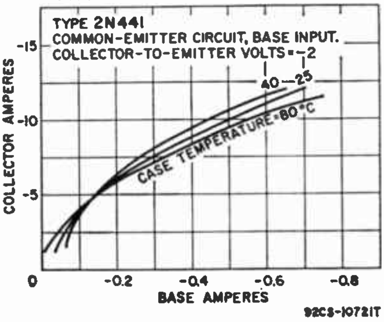
TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



CHARACTERISTICS (cont'd)

Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = −6 V, I_C = −5 A)	f_{hfe}	10	kc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	0.5 max	°C/W

POWER TRANSISTOR 2N442

Ge **p-n-p** alloy-junction type used in a wide variety of switching and amplifier applications in industrial and military equipment requiring transistors having high voltage, current, and dissipation values. It is used in power-switching, voltage- and current-regulating, dc-to-dc converter, inverter, power-supply, and relay- and solenoid-actuating circuits; and in low-frequency oscillator and audio-amplifier service. It is stud-mounted to provide positive heat-sink contact. JEDEC TO-36, Outline No.11. Terminals: Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case. This type is identical with type 2N441 except for the following items:

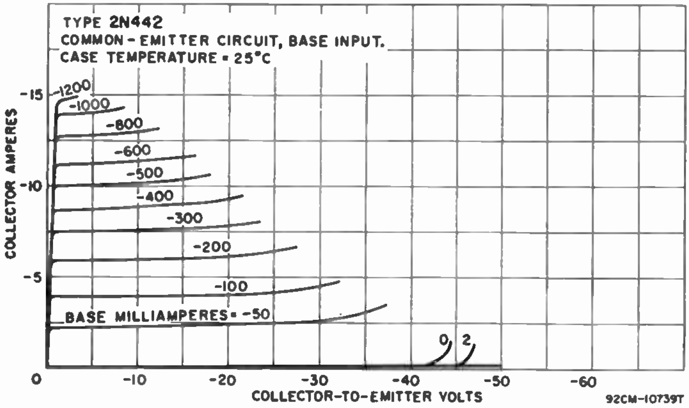
MAXIMUM RATINGS

Collector-to-Base Voltage (V_{BE} = 1.5 V)	V_{CBV}	−50	V
Emitter-to-Base Voltage	V_{EBO}	−30	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
I_C = −0.3 A, R_{BE} = 0	$V_{(BR)CES}$	−45 min	V
I_C = −1 A, I_B = 0	$V_{(BR)CEO}$	−30 min	V
Emitter-to-Base Voltage (V_{CB} = −50 V, I_E = 0)	V_{EB}	−1 max	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−50 min	V
Collector-Cutoff Current:			
V_{CB} = −50 V, I_E = 0, T_C = 25°C	I_{CBO}	−4 max	mA
V_{CB} = −50 V, I_E = 0, T_C = 71°C	I_{CBO}	−15 max	mA
Emitter-Cutoff Current:			
V_{EB} = −30 V, I_C = 0	I_{EBO}	−1 typ	mA
V_{EB} = −30 V, I_C = 0	I_{EBO}	−4 max	mA

TYPICAL COLLECTOR CHARACTERISTICS



POWER TRANSISTOR 2N443

Ge **p-n-p** alloy-junction type used in a wide variety of switching and amplifier applications in industrial and military equipment requiring transistors having high voltage, current, and dissipation values. It is used in power-switching, voltage- and current-regulating, dc-to-dc converter, inverter, power-supply, and relay- and solenoid-actuating circuits; and in low-frequency oscillator and audio-amplifier service. It is stud-mounted to provide positive heat-sink contact. JEDEC TO-36, **Outline** No.11. Terminals: Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case. This type is identical with type 2N441 except for the following items:

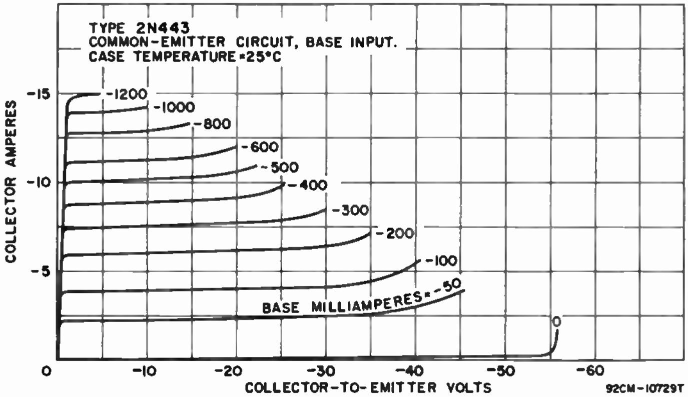
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	—60	V
Emitter-to-Base Voltage	V_{EBO}	—40	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
I_C = —0.3 A, R_{BE} = 0	$V_{(BR)CES}$	—50 min	V
I_C = —1 A, I_B = 0	$V_{(BR)CEO}$	—45 min	V
Collector-to-Emitter Saturation Voltage (I_C = —12 A, I_B = —2 A)	V_{CE}(sat)	—1 max	V
Emitter-to-Base Voltage (V_{CB} = —60 V, I_E = 0)	V_{EB}	—1 max	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	—60 min	V
Base-to-Emitter Voltage (V_{CE} = —2 V, I_C = —5 A)	V_{BE}	—0.9 max	V
Collector-Cutoff Current:			
V_{CB} = —60 V, I_E = 0, T_C = 25°C	I_{CBO}	—4 max	mA
V_{CB} = —60 V, I_E = 0, T_C = 71°C	I_{CBO}	—15 max	mA
Emitter-Cutoff Current:			
V_{EB} = —40 V, I_C = 0	I_{EBO}	—1 typ	mA
V_{EB} = —40 V, I_C = 0	I_{EBO}	—4 max	mA

TYPICAL COLLECTOR CHARACTERISTICS



2N581 COMPUTER TRANSISTOR

Ge **p-n-p alloy-junction** type used in switching applications in data-processing equipment. JEDEC TO-5, **Outline** No.3. Terminals: 1 - emitter, 2 - base, 3 - collector. This type is identical with type 2N404 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	—18	V
Collector-to-Emitter Voltage (V_{BE} = 1 V)	V_{CEV}	—15	V
Emitter-to-Base Voltage	V_{EBO}	—10	V

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = —0.02 mA, I_E = 0)	$V_{(BR)CBO}$	—18 min	V
Emitter-to-Base Breakdown Voltage (I_E = —0.02 mA, I_C = 0)	$V_{(BR)EBO}$	—10 min	V
Collector-to-Emitter Saturation Voltage (I_C = —20 mA, I_B = —1 mA)	V_{CE}(sat)	—0.2 min	V

CHARACTERISTICS (cont'd)

Base-to-Emitter Voltage ($I_C = -20$ mA, $I_B = -1$ mA)	V_{BE}	–0.5 max	V
Emitter-to-Base Reach-Through Voltage (V_{BE} = 1 V)	V_{RT}	–15 min	V
Collector-Cutoff Current:			
$V_{CB} = -12$ V, $I_E = 0$, $T_A = 25$°C	I_{CBO}	–10 max	A
Static Forward-Current Transfer Ratio ($V_{CE} = -0.3$ V, $I_C = -20$ mA)	h_{FE}	20 min	
Stored Base Charge ($I_C = -20$ mA, $I_B = -2$ mA)	Q_S	2400 max	pC

COMPUTER TRANSISTOR

2N582

Ge p-n-p alloy-junction type used in switching applications in data-processing equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector. This type is identical with type 2N404 except for the following items:

MAXIMUM RATINGS

Collector-to-Emitter Voltage (V_{BE} = 1 V)	V_{CEV}	–14	V

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage:			
$I_C = -24$ mA, $I_B = -0.6$ mA	V_{CE}(sat)	–0.2 max	V
$I_C = -100$ mA, $I_B = -5$ mA	V_{CE}(sat)	–0.3 max	V
Base-to-Emitter Voltage:			
$I_C = -24$ mA, $I_B = -0.6$ mA	V_{BE}	–0.4 max	V
$I_C = -100$ mA, $I_B = -5$ mA	V_{BE}	–0.8 max	V
Emitter-to-Base Reach-Through Voltage (V_{BE} = 1 V)	V_{RT}	–14 min	V
Static Forward-Current Transfer Ratio:			V
$V_{CE} = -0.2$ V, $I_C = -24$ mA	h_{FE}	40 min	
$V_{CE} = -0.3$ V, $I_C = -100$ mA	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio Cutoff Frequency ($V_{CB} = -6$ V, $I_C = -1$ mA)	f_{hfb}	14 min	Mc/s
Stored Base Charge ($I_C = -24$ mA, $I_B = -1.2$ mA)	Q_S	1200 max	pC

COMPUTER TRANSISTOR

2N585

Ge n-p-n alloy-junction type used in switching applications in data-processing equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	25	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1$ V	V_{CEV}	24	V
Base open	V_{CEO}	15	V
Emitter-to-Base Voltage	V_{EBO}	20	V
Collector Current	I_C	200	mA
Emitter Current	I_E	–200	mA
Transistor Dissipation:			
T_A = 25°C	P_T	120	mW
T_A = 55°C	P_T	35	mW
T_A = 71°C	P_T	10	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	–65 to 71	°C
Storage	T_{STG}	–65 to 85	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 25 µA, I_E = 0)	$V_{(BR)CBO}$	25 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 600 µA, I_B = 0)	$V_{(BR)CEO}$	15 min	V
Emitter-to-Base Breakdown Voltage (I_E = 25 µA, I_C = 0)	$V_{(BR)EBO}$	20 min	V
Collector-to-Emitter Saturation Voltage (I_C = 20 mA, I_B = 1 mA)	V_{CE}(sat)	0.2 max	V

CHARACTERISTICS (cont'd)

Base-to-Emitter Voltage ($I_C = 20$ mA, $I_B = 1$ mA)	V_{BE}	0.45 max	V
Collector-Cutoff Current:			
$V_{CB} = 0.25$ V, $I_E = 0$	I_{CBO}	6 max	µA
$V_{CB} = 12$ V, $I_E = 0$	I_{CBO}	8 max	µA
Emitter-Cutoff Current ($V_{EB} = 5$ V, $I_C = 0$)	I_{EBO}	5 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = 0.2$ V, $I_C = 20$ mA)	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio Cutoff Frequency ($V_{CB} = 6$ V, $I_E = -1$ mA)	f_{hfb}	3 min	Mc/s
Output Capacitance ($V_{CB} = 6$ V, $I_E = 0$)	C_{obo}	25 max	pF
Stored Base Charge ($I_C = 20$ mA, $I_B = 2$ mA)	Q_S	3000 max	pC

2N586 TRANSISTOR

Ge p-n-p alloy-junction type used in low-speed switching applications in industrial and military equipment. It can also be used in large-signal class A and class B push-pull af amplifiers. Similar to JEDEC TO-7 (3-lead type), **Outline** No.4. **Terminals:** 1 - emitter, 2 - base, 3 - no connection, 4 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−45	V
Emitter-to-Base Voltage	V_{EBO}	−12	V
Collector Current	I_C	−250	mA
Emitter Current	I_E	250	mA
Transistor Dissipation:			
$T_A = 25°C$	P_T	250	mW
$T_A = 55°C$	P_T	125	mW
$T_A = 71°C$	P_T	60	mW
Ambient-Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 85	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage:			
$I_C = -50$ µA, $R_{BE} = 0$	$V_{(BR)CES}$	−45 min	V
$I_C = -1$ mA, $I_B = 0$	$V_{(BR)CEO}$	−25 min	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−45 min	V
Collector-to-Emitter Saturation Voltage ($I_C = -250$ mA, $I_B = -25$ mA)	V_{CE}(sat)	−0.5 max	V
Base-to-Emitter Voltage ($I_C = -250$ mA, $I_B = -7$ mA)	V_{BE}	−1 max	V
Collector-Cutoff Current ($V_{CB} = -45$ V, $I_E = 0$)	I_{CBO}	−16 max	µA
Emitter-Cutoff Current ($V_{EB} = -12$ V, $I_C = 0$)	I_{EBO}	−12 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = -0.5$ V, $I_C = -250$ mA)	h_{FE}	35 min	

2N591 TRANSISTOR

Ge p-n-p alloy-junction type used in large-signal af driver applications in class A stages of automobile radio receivers. JEDEC TO-1, **Outline** No.1. **Terminals:** 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Emitter Voltage	V_{CEO}	−32	V
Collector Current	I_C	−40	mA
Emitter Current	I_E	40	mA
Transistor Dissipation:	*With Heat Sink*	*Without Heat Sink*	
T_A up to 55°C	100	50	mW
$T_A = 71°C$	40	20	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 71	°C
Storage	T_{STG}	−65 to 85	°C

CHARACTERISTICS

Collector-Cutoff Current ($V_{CB} = -1$ V, $I_E = 0$)	I_{CBO}	−7 max	µA
Emitter-Cutoff Current ($V_{EB} = -1$ V, $I_C = 0$)	I_{EBO}	−20 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = -12$ V, $I_E = 2$ mA)	h_{FE}	70	

CHARACTERISTICS (cont'd)

Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = —12 V, I_E = 2 mA)	f_{hfb}	0.7	Mc/s
Thermal Resistance:			
Junction-to-ambient	θ_{J-A}	340 max	°C/W
With heat sink		150 max	°C/W

TYPICAL OPERATION IN CLASS A AF DRIVER-AMPLIFIER CIRCUIT

DC Collector-Supply Voltage	V_{CC}	—14.4	V
DC Collector-to-Emitter Voltage	V_{CE}	—12	V
DC Base-to-Emitter Voltage	V_{BE}	—0.13	V
DC Collector Current	I_C	—2	mA
Input Resistance	R_S	1000	Ω
Output Resistance	R_L	10000	Ω
Signal Frequency		1	kc/s
Power Gain		41	dB
Total Harmonic Distortion		3	%
Transistor Dissipation		25	mW
Power Output	P_{OE}	5	mW

TRANSISTOR 2N647

Ge n-p-n alloy-junction type used in large-signal af-amplifier applications in battery-operated portable radio receivers and phonographs. N-P-N construction permits complementary push-pull operation with a matching p-n-p type, such as the 2N217. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector (red dot).

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	25	V
Collector-to-Emitter Voltage	V_{CEO}	25	V
Emitter-to-Base Voltage	V_{EBO}	12	V
Collector Current	I_C	100	mA
Emitter Current	I_E	—100	mA
Transistor Dissipation:			
T_A = 25°C	P_T	100	mW
T_A = 55°C	P_T	50	mW
T_A = 71°C	P_T	20	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	—65 to 71	°C
Storage	T_{STG}	—65 to 85	°C

CHARACTERISTICS

Collector-Cutoff Current (V_{CB} = 25 V, I_E = 0)	I_{CBO}	14 max	µA
Emitter-Cutoff Current (V_{EB} = 12 V, I_C = 0)	I_{EBO}	14 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 1 V, I_C = 50 mA)	h_{FE}	70	

TYPICAL OPERATION IN CLASS B COMPLEMENTARY-SYMMETRY CIRCUIT

DC Collector-Supply Voltage	V_{CC}	6	V
DC Collector-to-Emitter Voltage for driver stage	V_{CE}	2.3	V
Zero-Signal DC Base-to-Emitter Voltage for output stage	V_{BE}	0.14	V
Peak Collector Current for each transistor in output stage	i_C(peak)	70	mA
Zero-Signal DC Collector Current for each transistor (driver and output stage)	I_C	1.5	mA
Signal Frequency		1	kc/s
Input Resistance	R_S	1100	Ω
Load Resistance	R_L	45	Ω
Power Gain		54	dB
Total Harmonic Distortion		10	%
Power Output (input = 20 mV)	P_{OE}	100	mW

TRANSISTOR 2N649

Ge n-p-n alloy-junction type used in large-signal af-amplifier applications in battery-operated portable radio receivers and phonographs. N-P-N construction permits complementary push-pull operation with a matching p-n-p type, such as the 2N408. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	20	V
Collector-to-Emitter Voltage	V_{CEO}	18	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	100	mA
Emitter Current	I_E	–100	mA
Transistor Dissipation:			
$T_A = 25°C$	P_T	100	mW
$T_A = 55°C$	P_T	50	mW
$T_A = 71°C$	P_T	20	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	–65 to 71	°C
Storage	T_{STG}	–65 to 85	°C

CHARACTERISTICS

Collector-Cutoff Current ($V_{CB} = 12$ V, $I_E = 0$)	I_{CBO}	14 max	µA
Emitter-Cutoff Current ($V_{EB} = 2.5$ V, $I_C = 0$)	I_{EBO}	14 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = 1$ V, $I_C = 50$ mA)	h_{FE}	65	

TYPICAL OPERATION IN CLASS B COMPLEMENTARY-SYMMETRY CIRCUIT

DC Collector Supply Voltage	V_{CC}	6	V
DC Collector-to-Emitter Voltage for driver stage	V_{CE}	2.3	V
Zero-Signal DC Base-to-Emitter Voltage for output stage	V_{BE}	0.14	V
Peak Collector Current for each transistor in output stage	i_C(peak)	70	mA
Zero-Signal DC Collector Current for each transistor (driver and output stage)	I_C	1.5	mA
Signal Frequency		1	kc/s
Input Resistance	R_S	1100	Ω
Load Resistance	R_L	45	Ω
Power Gain		54	dB
Total Harmonic Distortion ($P_{oe} = 100$ mW)		10 max	%
Power Output (input = 20 mV)	P_{OE}	100	mW

2N697 COMPUTER TRANSISTOR

Si **n-p-n planar** triple-diffused-base type used in switching applications in data-processing equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
$R_{BE} = 100\ \Omega$	V_{CER}	40	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	500	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	0.6	W
T_C up to 25°C	P_T	2	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A and T_C) and Storage (T_{STG})		–65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage ($I_C = 0.1$ mA, $I_E = 0$)	$V_{(BR)CBO}$	60 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.1$ mA, $I_C = 0$)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Sustaining Voltage ($I_C = 100$ mA, $t_p \leq 12$ ms, df $\leq 2\%$, $R_{BE} = 10\ \Omega$)	V_{CER}(sus)	40 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 150$ mA, $I_B = 15$ mA)	V_{CE}(sat)	1.5 max	V
Base-to-Emitter Saturation Voltage ($I_C = 150$ mA, $I_B = 15$ mA)	V_{BE}(sat)	1.3 max	V
Collector-Cutoff Current:			
$V_{CB} = 30$ V, $I_E = 0$, $T_A = 25°C$	I_{CBO}	1 max	µA
$V_{CB} = 30$ V, $I_E = 0$, $T_A = 150°C$	I_{CBO}	100 max	µA

CHARACTERISTICS (cont'd)

Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 150 mA, tp $\leqq$ 12 ms, df $\leqq$ 2%)	h_{FE}	120 max	
Small-Signal Forward-Current Transfer Ratio (f = 20 Mc/s, V_{CE} = 10 V, I_C = 50 mA)	h_{fe}	2.5 min	
Gain-Bandwidth Product	f_T	100	Mc/s
Output Capacitance (V_{CB} = 10 V, I_E = 0)	C_{obo}	35 max	pF

TRANSISTOR

2N699

Si **n-p-n** planar triple-diffused-base type used in small-signal and medium-power applications in rf amplifier, mixer, oscillator and converter service and in power applications in small-signal af amplifiers and switching circuits in industrial and military equipment. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	120	V
Collector-to-Emitter Voltage ($R_{BE} \leqq$ 10 Ω)	V_{CER}	80	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Transistor Dissipation:			
T_A up to 25°C	P_T	0.6	W
T_C up to 25°C	P_T	2	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 175	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	120 min	V
Collector-to-Emitter Sustaining Voltage (R_{BE} = 10 Ω, I_C = 100 mA, tp $\leqq$ 300 μs, df $\leqq$ 2%)	V_{CER}(sus)	80 min	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, tp $\leqq$ 300 μs, df $\leqq$ 2%)	V_{CE}(sat)	5 max	V
Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, tp $\leqq$ 300 μs, df $\leqq$ 2%)	V_{BE}(sat)	1.3 max	V
Collector-Cutoff Current (V_{CB} = 60 V, I_E = 0)	I_{CBO}	2 max	μA
Emitter-Cutoff Current (V_{EB} = 2 V, I_C = 0)	I_{EBO}	100 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 150 mA, tp $\leqq$ 300 μs, df $\leqq$ 2%)	h_{FE}	120 max	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{fe}	35 min	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{fe}	45 min	
V_{CE} = 10 V, I_C = 50 mA, f = 20 Mc/s	h_{fe}	2.5 min	
Gain-Bandwidth Product	f_T	50 min	Mc/s
Output Capacitance (V_{CB} = 10 V, I_E = 0)	C_{obo}	20 max	pF
Small-Signal Short-Circuit Impedance:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{ib}	30 max	Ω
V_{CE} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{ib}	10 max	Ω
Voltage-Feedback Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{rb}	2.5×10^{-4} max	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{rb}	3×10^{-4} max	
Output Conductance:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{ob}	0.5 max	μmho
V_{CE} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{ob}	1 max	μmho
Thermal Resistance, Junction-to-Case	Θ_{J-C}	75 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	250 max	°C/W

COMPUTER TRANSISTORS

2N706
2N706A

Si **n-p-n epitaxial planar** types used in high-speed switching applications in data-processing equipment. JEDEC TO-18, **Outline** No.9. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

		2N706	*2N706A*	
Collector-to-Base Voltage	V_{CBO}	25	25	V
Collector-to-Emitter Voltage ($R_{BE} = 10\ \Omega$)	V_{CER}	20	20	V
Emitter-to-Base Voltage	V_{EBO}	5	5	V
Collector Current	I_C	—	50	A
Transistor Dissipation:				
T_A up to 25°C	P_T	0.3	0.3	W
T_C (with heat sink) up to 25°C	P_T	1	1	W
T_A or T_C (with heat sink) above 25°C	P_T	See curve page 112		
Temperature Range:				
Operating (Junction)	T_J(opr)	175	175	°C
Storage	T_{STG}	−65 to 175		°C

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage: ($I_C = 10$ mA, $I_B = 1$ mA)	V_{CE}(sat)	0.6	0.6 max	V
Base-to-Emitter Saturation Voltage: ($I_C = 10$ mA, $I_B = 1$ mA)	V_{BE}(sat)	0.9	0.9 max	V
Collector-Cutoff Current:				
$V_{CB} = 15$ V, $I_E = 0$, $T_A = 25°C$	I_{CBO}	0.5	0.5 max	μA
$V_{CB} = 15$ V, $I_E = 0$, $T_A = 150°C$	I_{CBO}	30	30 max	μA
Static Forward-Current Transfer Ratio:				
$V_{CE} = 1$ V, $I_C = 10$ mA	h_{FE}	—	20 to 60	
$V_{CE} = 1$ V, $I_C = 10$ mA, $t_p \leqq 12$ ms, df $\leqq 2\%$	h_{FE}	20	— min	
Small-Signal Forward-Current Transfer Ratio:				
$V_{CE} = 15$ V, $I_C = 10$ mA, f = 100 Mc/s	h_{fe}	2	— min	
$V_{CE} = 10$ V, $I_C = 10$ mA, f = 100 Mc/s	h_{fe}	—	2 min	
Output Capacitance (f = 0.14 Mc/s, $V_{CB} = 5$ V, $I_E = 0$)	C_{obo}	6	5 max	pF
Turn-On Time ($V_{CC} = 3$ V, $I_C = 10$ mA, $I_{B1} = 3$ mA, $I_{B2} = -1$ mA)	$t_d + t_r$	—	40 max	ns
Turn-Off Time ($V_{CC} = 3$ V, $I_C = 10$ mA, $I_{B1} = 3$ mA, $I_{B2} = -1$ mA)	$t_s + t_f$	—	75 max	ns
Storage Time ($V_{CC} = 10$ V, $I_C = 10$ mA, $I_{B1} = 10$ mA, $I_{B2} = -10$ mA, $R_L = 1000\ \Omega$)	t_s	—	25 max	ns

2N708

COMPUTER TRANSISTOR

Si n-p-n planar double-diffused-junction type used in high-speed switching applications in data-processing equipment. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage:			
$R_{BE} \leqq 10\ \Omega$	V_{CER}	20	V
Base open	V_{CEO}	15	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	Limited by dissipation		
Transistor Dissipation:			
T_A up to 25°C	P_T	0.36	W
T_C up to 25°C	P_T	1.2	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 300	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage ($I_C = 0.001$ mA, $I_E = 0$)	$V_{(BR)CBO}$	40 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.01$ mA, $I_C = 0$)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Sustaining Voltage ($R_{BE} \leqq 10\ \Omega$, $I_C = 30$ mA, $t_r = 1$ ns, $t_p \geqq 300$ ns, df $\leqq 2\%$)	V_{CER}(sus)	20 min	V
Collector-to-Emitter Sustaining Voltage With Base Open ($I_C = 30$ mA, $t_r = 1$ ns, $t_p \geqq 300$ ns, df $\leqq 2\%$)	V_{CEO}(sus)	15 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 10$ mA, $I_B = 1$ mA)	V_{CE}(sat)	0.4 max	V
Base-to-Emitter Saturation Voltage ($I_C = 10$ mA, $I_B = 1$ mA)	V_{BE}(sat)	0.72 to 0.8	V
Collector-Cutoff Current:			
$V_{CB} = 20$ V, $I_E = 0$, $T_A = 25°C$	I_{CBO}	0.025 max	μA
$V_{CB} = 20$ V, $I_E = 0$, $T_A = 150°C$	I_{CBO}	15 max	μA

CHARACTERISTICS (cont'd)

Emitter-Cutoff Current ($V_{EB} = -4$ V, $I_C = 0$)	I_{EBO}	0.08 max	µA
Collector Current for forward bias ($V_{BE} = 0.25$ V, $V_{CB} = 20$ V, $T_A = 125°C$)	I_{CEV}	10 max	µA
Static Forward-Current Transfer Ratio:			
$V_{CE} = 1$ V, $I_C = 0.5$ mA	h_{FE}	15 min	
$V_{CE} = 1$ V, $I_C = 10$ mA	h_{FE}	30 to 120	
Small-Signal Forward-Current Transfer Ratio ($V_{CE} = 10$ V, $I_C = 10$ mA, f = 100 Mc/s)	h_{fe}	3 min	
Output Capacitance ($V_{CB} = 10$ V, $I_E = 0$, f = 0.14 Mc/s)	C_{obo}	6 max	pF
Base Spreading Resistance (f = 300 Mc/s, $V_{CB} = 10$ V, $I_C = 10$ mA)	$r_{bb'}$	50 max	Ω
Storage Time ($V_{CC} = 10$ V, $I_C = 10$ mA, $I_{B1} = 10$ mA, $I_{B2} = -10$ mA, $R_L = 1000$ Ω)	t_s	25 max	ns
Thermal Resistance, Junction-to-Case	θ_{J-C}	145 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	480 max	°C/W

COMPUTER TRANSISTOR 2N709

Si **n-p-n** epitaxial planar type used in switching applications in data-processing equipment. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N2475 except for the following items:

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage ($I_C = 3$ mA, $I_B = 0.15$ mA)	V_{CE}(sat)	0.3 max	V
Base-to-Emitter Saturation Voltage ($I_C = 3$ mA, $I_B = 0.15$ mA)	V_{BE}(sat)	0.85 max	V
Pulsed Static Forward-Current Transfer Ratio:			
$I_C = 10$ mA, $V_{CE} = 0.5$ V, $T_A = 25°C$	h_{FE}(pulsed)	20 to 120	
$I_C = 30$ mA, $V_{CE} = 1$ V, $T_A = 25°C$	h_{FE}(pulsed)	15 min	
$I_C = 10$ mA, $V_{CE} = 0.5$ V, $T_A = -55°C$	h_{FE}(pulsed)	10 min	
Small-Signal Forward-Current Transfer Ratio ($I_C = 5$ mA, $V_{CE} = 4$ V, f = 100 Mc/s)	h_{fe}	6 min	
Input Capacitance ($V_{EB} = 0.5$ V, $I_C = 0$, f = 140 kc/s)	C_{ibo}	2 max	Mc/s
Output Capacitance ($V_{CB} = 5$ V, $I_E = 0$, f = 140 kc/s)	C_{obo}	3 max	pF
Storage Time ($I_C = 5$ mA, $I_{B1} = 5$ mA, $I_{B2} = -5$ mA, $V_{CC} = 3$ V)	t_s	6 max	pF
Turn-On Time ($I_C = 10$ mA, $I_{B1} = 2$ mA, $I_{B2} = -1$ mA, $V_{CC} = 1$ V)	$t_d + t_r$	15 max	ns
Turn-Off Time ($I_C = 10$ mA, $I_{B1} = 2$ mA, $I_{B2} = -1$ mA, $V_{CC} = 1$ V)	$t_s + t_f$	15 max	ns

COMPUTER TRANSISTOR 2N718A

Si **n-p-n** planar triple-diffused-junction type used primarily for small-signal and switching applications in data-processing equipment. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	75	V
Collector-to-Emitter Voltage:			
Base open	V_{CEO}	32	V
$R_{BE} \leq 10$ Ω	V_{CER}	50	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_C up to 25°C	P_T	1.8	W
T_A or T_C above 25°C	P_T	See curve page	112
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C

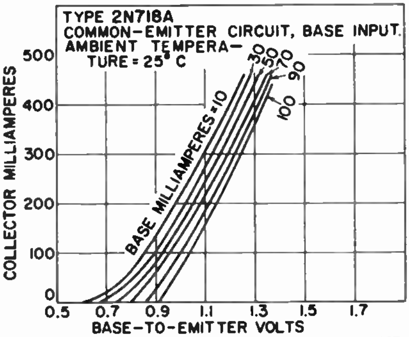
CHARACTERISTICS

Collector-to-Base Breakdown Voltage ($I_C = 0.1$ mA, $I_E = 0$)	$V_{(BR)CBO}$	75 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.1$ mA, $I_C = 0$)	$V_{(BR)EBO}$	7 min	V

CHARACTERISTICS (cont'd)

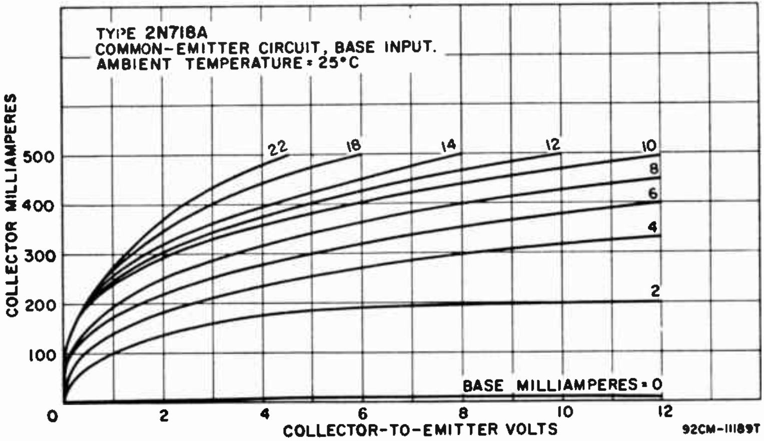
Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0, R_{BE} = 10 Ω)	V_{CER}(sus)	50 min	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p ≦ 300 µs, df ≦ 2%)	V_{CE}(sat)	1.5 max	V
Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p ≦ 300 µs, df ≦ 2%)	V_{BE}(sat)	1.3 max	V
Collector-Cutoff Current:			
V_{CB} = 60 V, I_E = 0, T_A = 25°C	I_{CBO}	0.01 max	µA
V_{CB} = 60 V, I_E = 0, T_A = 150°C	I_{CBO}	10 max	µA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	0.01 max	µA
Pulsed Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 150 mA, t_p ≦ 300 µs, df ≦ 2%	h_{FE}(pulsed)	40 to 120	
V_{CE} = 10 V, I_C = 10 mA, t_p ≦ 300 µs, df ≦ 2%	h_{FE}(pulsed)	35 min	
V_{CE} = 10 V, I_C = 10 mA, T_A = −55°C, t_p ≦ 300 µs, df ≦ 2%	h_{FE}(pulsed)	20 min	
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 0.1 mA)	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{fe}	30 to 100	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{fe}	35 to 150	
V_{CE} = 10 V, I_C = 50 mA, f = 20 Mc/s	h_{fe}	3 min	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0)	C_{ibo}	80 max	pF
Output Capacitance (V_{CB} = 10 V, I_E = 0)	C_{obo}	25 max	pF
Input Resistance:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{ib}	24 to 34	Ω
V_{CE} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{ib}	4 to 8	Ω
Voltage-Feedback Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{rb}	3×10^{-4} max	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{rb}	3×10^{-4} max	

TYPICAL TRANSFER CHARACTERISTICS



92CS-11185T

TYPICAL COLLECTOR CHARACTERISTICS



92CM-11189T

CHARACTERISTICS (cont'd)

Output Conductance:			
$V_{CE} = 5$ V, $I_C = 1$ mA, f = 1 kc/s	h_{ob}	0.5 max	µmhos
$V_{CE} = 10$ V, $I_C = 5$ mA, f = 1 kc/s	h_{ob}	1 max	µmhos
Noise Figure ($V_{CE} = 10$ V, $I_C = 0.3$ mA, f = 1 kc/s)	NF	12 max	dB
Thermal Resistance, Junction-to-Case	θ_{J-C}	97 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	350 max	°C/W

COMPUTER TRANSISTOR

2N720A

Si **n-p-n planar triple-diffused-junction** type used primarily in small-signal and switching applications in data-processing equipment. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case. For collector and transfer curves, refer to type 2N718A.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	120	V
Collector-to-Emitter Voltage:			
$R_{BE} \leqq 10\ \Omega$	V_{CER}	100	V
Base open	V_{CEO}	80	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_C up to 25°C	P_T	1.8	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage ($I_C = 0.1$ mA, $I_E = 0$)	$V_{(BR)CBO}$	120 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.1$ mA, $I_C = 0$)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
$I_C = 100$ mA, $I_B = 0$, $t_p = 300$ µs, df = 2%	V_{CEO}(sus)	80 min	V
$I_C = 100$ mA, $I_B = 0$, $R_{BE} = 10\ \Omega$	V_{CER}(sus)	100 min	V
Collector-to-Emitter Saturation Voltage:			
$I_C = 150$ mA, $I_B = 15$ mA, $t_p \leqq 300$ µs, df $\leqq$ 2%	V_{CE}(sat)	5 max	V
$I_C = 50$ mA, $I_B = 5$ mA	V_{CE}(sat)	1.2 max	V
Base-to-Emitter Saturation Voltage:			
$I_C = 150$ mA, $I_B = 15$ mA, $t_p \leqq 300$ µs, df $\leqq$ 2%	V_{BE}(sat)	1.3 max	V
$I_C = 50$ mA, $I_B = 15$ mA	V_{BE}(sat)	0.9 max	V
Collector-Cutoff Current:			
$V_{CB} = 90$ V, $I_E = 0$, $T_A = 25$°C	I_{CBO}	0.01 max	µA
$V_{CB} = 90$ V, $I_E = 0$, $T_A = 150$°C	I_{CBO}	15 max	µA
Emitter-Cutoff Current ($V_{EB} = 5$ V, $I_C = 0$)	I_{EBO}	0.01 max	µA
Pulsed Static Forward-Current Transfer Ratio:			
$V_{CE} = 10$ V, $I_C = 150$ mA, $t_p \leqq 300$ µs, df $\leqq$ 2%	h_{FE}(pulsed)	40 to 120	
$V_{CE} = 10$ V, $I_C = 10$ mA, $t_p \leqq 300$ µs, df $\leqq$ 2%	h_{FE}(pulsed)	35 min	
$V_{CE} = 10$ V, $I_C = 10$ mA, $T_A = -55$°C, $t_p \leqq 300$ µs, df $\leqq$ 2%	h_{FE}(pulsed)	20 min	
Static Forward-Current Transfer Ratio ($V_{CE} = 10$ V, $I_C = 0.1$ mA)	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio:			
$V_{CE} = 5$ V, $I_C = 1$ mA, f = 1 kc/s	h_{fe}	30 to 100	
$V_{CE} = 10$ V, $I_C = 5$ mA, f = 1 kc/s	h_{fe}	45 min	
$V_{CE} = 10$ V, $I_C = 50$ mA, f = 20 Mc/s	h_{fe}	2.5 min	
Input Capacitance ($V_{EB} = 0.5$ V, $I_C = 0$)	C_{ibo}	85 max	pF
Output Capacitance ($V_{CBO} = 10$ V, $I_E = 0$)	C_{obo}	15 max	pF
Input Resistance:			
$V_{CE} = 5$ V, $I_C = 1$ mA, f = 1 kc/s	h_{ib}	20 to 30	Ω
$V_{CE} = 10$ V, $I_C = 5$ mA, f = 1 kc/s	h_{ib}	4 to 8	Ω
Voltage-Feedback Ratio:			
$V_{CE} = 5$ V, $I_C = 1$ mA, f = 1 kc/s	h_{rb}	1.25×10^{-4} max	
$V_{CE} = 10$ V, $I_C = 5$ mA, f = 1 kc/s	h_{rb}	1.5×10^{-4} max	
Output Conductance:			
$V_{CE} = 5$ V, $I_C = 1$ mA, f = 1 kc/s	h_{ob}	0.5 max	µmhos
$V_{CE} = 10$ V, $I_C = 5$ mA, f = 1 kc/s	h_{ob}	0.5 max	µmhos
Thermal Resistance, Junction-to-Case	θ_{J-C}	97 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	350 max	°C/W

2N834 COMPUTER TRANSISTOR

Si n-p-n epitaxial planar type used in high-speed switching applications in equipment requiring high reliability and high packing densities. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage (R_{BE} = 0)	V_{CES}	30	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	200	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	0.3	W
T_C up to 25°C	P_T	1	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	175	°C
Storage	T_{STG}	−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	240	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	40 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = 10 mA, I_B = 1 mA	V_{CE}(sat)	0.25 max	V
I_C = 50 mA, I_B = 5 mA	V_{CE}(sat)	0.4 max	V
Base-to-Emitter Saturation Voltage (I_C = 10 mA, I_B = 1 mA)	V_{BE}(sat)	0.9 max	
Collector-Cutoff Current:			
V_{CB} = 20 V, I_E = 0, T_A = 25°C	I_{CBO}	0.5 max	μA
V_{CB} = 20 V, I_E = 0, T_A = 150°C	I_{CBO}	30 max	μA
V_{CE} = 30 V, R_{BE} = 0, T_A = 25°C	I_{CES}	10 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 1 V, I_C = 10 mA)	h_{FE}	25 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 15 V, I_C = 10 mA, f = 100 Mc/s)	h_{fe}	3.5 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 100 kc/s)	C_{obo}	4 max	pF
Gain-Bandwidth Product (V_{CE} = 15 V, I_C = 10 mA, f = 100 Mc/s)	f_T	350 min	Mc/s
Storage Time (V_{CC} = 10 V, I_{B1} = 10 mA, I_{B2} = −10 mA, I_C = 10 mA)	t_s	25 max	ns
Turn-On Time (V_{CC} = 0 to 3.5 V, I_C = 10 mA)	$t_d + t_r$	35 max	ns
Turn-off Time (V_{CC} = 0 to 3.5 V, I_C = 10 mA)	$t_s + t_f$	75 max	ns

2N914 COMPUTER TRANSISTOR

Si n-p-n epitaxial planar type intended for use in high-speed saturated logic-switching and vhf amplifier applications. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage:			
R_{BE} = 10 Ω	V_{CER}	20	V
Base open	V_{CEO}	15	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	Limited by power dissipation	
Transistor Dissipation:			
T_A up to 25°C	P_T	0.36	W
T_C up to 25°C	P_T	1.2	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	40 min	V

CHARACTERISTICS (cont'd)

Emitter-to-Base Breakdown Voltage (I_E = 0.01 mA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 30 mA, I_B = 0, t_p = 300 µs, df = 1%	V_{CEO}(sus)	15 min	V
I_C = 30 mA, R_{BE} = 10 Ω, t_p = 300 µs, df = 1%	V_{CER}(sus)	20 min	V
Collector-to-Emitter Saturation Voltage (I_C = 200 mA, I_B = 20 mA)	V_{CE}(sat)	0.7 max	V
Base-to-Emitter Saturation Voltage (I_C = 10 mA, I_B = 1 mA)	V_{BE}(sat)	0.8 max	V
Collector-Cutoff Current:			
V_{CB} = 20 V, I_E = 0, T_A = 25°C	I_{CBO}	0.025 max	µA
V_{CB} = 20 V, I_E = 0, T_A = 150°C	I_{CBO}	15 max	µA
Collector Current, base forward-biased (V_{CE} = 20 V, V_{BE} = 0.25 V, T_A = 125°C)	I_{CEV}	10 max	µA
Static Pulse Forward-Current Transfer Ratio:			
V_{CE} = 1 V, I_C = 10 mA	h_{FE}	30 to 120	
V_{CE} = 5 V, I_C = 500 mA	h_{FE}	10 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 20 mA, f = 100 Mc/s)	h_{fe}	3 min	
Input Capacitance (V_{EB} = −0.5 V, I_C = 0, f = 0.14 Mc/s)	C_{ibo}	9 max	pF
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 Mc/s)	C_{obo}	6 max	pF
Saturation Stored-Charge Time Constant (V_{CC} = 5 V, I_C = 20 mA, R_C = 240 Ω, I_{B1} = 20 mA, I_{B2} = −20 mA)	τ_s	20 max	ns
Turn-On Time (V_{CC} = 5 V, I_C = 200 mA, R_C = 23 Ω, I_{B1} = 40 mA, I_{B2} = −20 mA)	$t_d + t_r$	40 max	ns
Turn-Off Time (V_{CC} = 5 V, I_C = 200 mA, R_C = 23 Ω, I_{B1} = 40 mA, I_{B2} = −20 mA)	$t_s + t_f$	40 max	ns
Thermal Resistance, Junction-to-case	θ_{J-C}	145	°C/W
Thermal Resistance, Junction-to-ambient	θ_{J-A}	480	°C/W

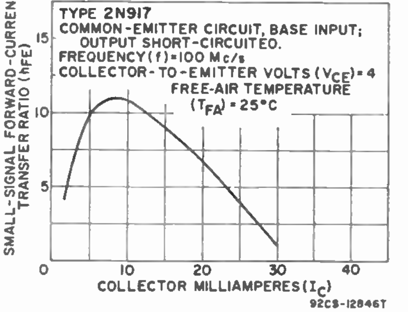
TRANSISTOR 2N917

Si **n-p-n** epitaxial planar type used in low-noise amplifier, oscillator, and converter applications at vhf frequencies. JEDEC TO-72, Outline No.23. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	30	V
Collector-to-Emitter Voltage	V_{CEO}	15	C
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	Limited by power dissipation	
Transistor Dissipation:			
T_A up to 25°C	P_T	200	mW
T_C up to 25°C	P_T	300	mW
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (60 s max)	T_L	230	°C

TYPICAL SMALL-SIGNAL FORWARO-CURRENT TRANSFER-RATIO CHARACTERISTICS



CHARACTERISTICS

Collector-to-Base Breakdown Voltage ($I_C = 0.001$ mA, $I_E = 0$)	$V_{(BR)CBO}$	30 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.01$ mA, $I_C = 0$)	$V_{(BR)EBO}$	3 min	V
Collector-to-Emitter Sustaining Voltage ($I_C = 3$ mA, $I_B = 0$, $t_p = 300$ μs, df = 1%)	V_{CEO}(sus)	15 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 3$ mA, $I_B = 0.15$ mA)	V_{CE}(sat)	0.5 max	V
Base-to-Emitter Saturation Voltage ($I_C = 3$ mA, $I_B = 0.15$ mA)	V_{BE}(sat)	0.87 max	V
Collector-Cutoff Current:			
$V_{CB} = 15$ V, $I_E = 0$, $T_A = 25°C$	I_{CBO}	0.001 max	μA
$V_{CB} = 15$ V, $I_E = 0$, $T_A = 150°C$	I_{CBO}	0.1 max	μA
Static Forward-Current Transfer Ratio ($V_{CE} = 1$ V, $I_C = 3$ mA)	h_{FE}	20 to 200	
Small-Signal Forward-Current Transfer Ratio* ($V_{CE} = 10$ V, $I_C = 4$ mA, f = 100 Mc/s)	h_{fe}	5 min	
Input Capacitance† ($V_{EB} = 0.5$ V, $I_C = 0$, f = 0.1 to 1 Mc/s)	C_{ibo}	1.6 max	pF
Output Capacitance† ($V_{CB} = 10$ V, $I_E = 0$, f = 0.1 to 1 Mc/s)	C_{obo}	1.7 max	pF
Collector-to-Base Time Constant:*			
$V_{CB} = 10$ V, $I_C = 4$ mA, f = 40 Mc/s	$r_b'C_c$	30 typ	ps
$V_{CB} = 10$ V, $I_C = 4$ mA, f = 40 Mc/s	$r_b'C_c$	75 max	ps
Small-Signal Power Gain, Unneutralized Amplifier Circuit:*			
$V_{CE} = 10$ V, $I_C = 5$ mA, f = 200 Mc/s	G_{pe}	11.5 typ	dB
$V_{CE} = 10$ V, $I_C = 5$ mA, f = 200 Mc/s	G_{pe}	9 min	dB
Power Output in Oscillator Circuit† ($V_{CB} = 15$ V, $I_C = 8$ mA, f = 500 Mc/s	P_{oh}	10 min	mW
Noise Figure† ($V_{CE} = 6$ V, $I_C = 1$ mA, $R_G = 400$ Ω, f = 60 Mc/s)	NF	6 max	dB

* Fourth lead (case) grounded.
† Fourth lead (case) floating.

2N918 TRANSISTOR

Si n-p-n epitaxial planar type used in low-noise amplifier, oscillator, and converter applications at vhf frequencies. JEDEC TO-72, **Outline** No.23. **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case. This type is identical with type 2N3600 except for the following items:

MAXIMUM RATINGS

Collector Current	I_C	50	mA

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio* (f = 100 Mc/s, $V_{CE} = 10$ V, $I_C = 4$ mA)	h_{fe}	6 min	
Input Capacitance† (f = 0.1 to 1 Mc/s, $V_{EB} = 0.5$ V, $I_C = 0$)	C_{ibo}	2 max	pF
Output Capacitance† (f = 0.1 to 1 Mc/s, $V_{CB} = 0$, $I_E = 0$)	C_{obo}	3 max	pF
Collector-to-Base Time Constant* (f = 40 Mc/s, $V_{CB} = 6$ V, $I_C = 2$ mA)	$r_b'C_c$	15	ps
Small-Signal Power Gain:*			
Unneutralized Amplifier Circuit ($V_{CE} = 10$ V, $I_C = 5$ mA, f = 200 Mc/s)	G_{pe}	13	dB
Neutralized Amplifier Circuit ($V_{CE} = 12$ V, $I_C = 6$ mA, f = 200 Mc/s)	G_{pe}	15 min 18 typ	dB dB
Power Output, Oscillator Circuit ($V_{CE} = 10$ V, $I_E = 12$ mA, f = 500 Mc/s)	P_{oe}	30 min	mW

* Fourth lead (case) grounded.
† Fourth lead (case) floating.

TRANSISTOR 2N1010

Ge n-p-n alloy-junction type used in small-signal low-noise af amplifier applications such as high-fidelity amplifiers, tape-recorder amplifiers, microphone preamplifiers, and hearing aids. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	10	V
Collector-to-Emitter Voltage	V_{CEO}	10	V
Emitter-to-Base Voltage	V_{EBO}	10	V
Collector Current	I_C	2	mA
Emitter Current	I_E	−2	mA
Transistor Dissipation:			
T_A up to 55°C	P_T	20	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	55	°C
Storage	T_{STG}	−65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-Cutoff Current (V_{CB} = 10 V, I_E = 0)	I_{CBO}	10 max	μA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	6 max	μA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 3.5 V, I_E = −0.3 mA, f = 1 kc/s)	h_{fe}	35	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 3.5 V, I_C = 0.3 mA)	f_{hfb}	2	Mc/s
Noise Figure (V_{CE} = 3.5 V, I_E = −0.3, R_G = 1000 Ω, integrated noise bandwidth = 15 kc/s)	NF	5	dB

TRANSISTOR 2N1023

Ge p-n-p alloy-junction drift-field type used in rf and if amplifier, oscillator, mixer, and converter circuits, and low-level video-amplifier circuits in industrial and military equipment. JEDEC TO-44, Outline No.14. Terminals: 1 - emitter, 2 - base, 3 - collector, Center Lead - interlead shield and case. For collector-characteristics curves and video-amplifier circuit, refer to type 2N274.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−40	V
Collector-to-Emitter Voltage (V_{BE} = 0.5 V)	V_{CEV}	−40	V
Emitter-to-Base Voltage	V_{EBO}	−0.5	V
Collector Current	I_C	−10	mA
Emitter Current	I_E	10	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	120	mW
T_A above 25°C	P_T	See curve page 112	
T_C up to 25°C (with heat sink)	P_T	240	mW
T_C above 25°C (with heat sink)	P_T	See curve page 112	
Ambient-Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 100	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −50 μA, I_E = 0)	$V_{(BR)CBO}$	−40 min	V
Collector-to-Base Reach-Through Voltage (V_{EB} = −0.5)	V_{RT}	−40 min	V
Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−12 max	μA
Emitter-Cutoff Current (V_{EB} = −0.5 V, I_C = 0)	I_{EBO}	−12 max	μA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12 V, I_E = 1.5 mA, f = 1 kc/s)	h_{fe}	20 to 175	
Small-Signal Forward-Current Transfer Ratio Cutoff Frequency (V_{CB} = −12 V, I_E = 1.5 mA)	f_{hfb}	120	Mc/s
Output Capacitance (V_{CB} = −12 V, I_E = 0)	C_{obo}	3 max	pF
Input Resistance (ac output circuit shorted):			
V_{CB} = −12 V, I_E = 1.5 mA, f = 50 Mc/s	R_{ie}	25	Ω
V_{CE} = −12 V, I_E = 1.5 mA, f = 30 Mc/s	R_{ie}	100	Ω
Output Resistance (ac input circuit shorted):			
V_{CB} = −12 V, I_E = 1.5 mA, f = 50 Mc/s	R_{oe}	8000	Ω
V_{CE} = −12 V, I_E = 1.5 mA, f = 30 Mc/s	R_{oe}	8000	Ω

CHARACTERISTICS (cont'd)

Power Gain, Single-Tuned Unilateral Circuit):			
V_{CB} = −12 V, I_E = 1.5 mA, f = 50 Mc/s	G_{pe}	18 to 24	dB
V_{CE} = −12 V, I_E = 1.5 mA, f = 30 Mc/s	G_{pe}	20 to 26	dB
Thermal Resistance, Junction-to-Case	θ_{J-C}	0.31 max	°C/mW
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	0.62 max	°C/mW

TYPICAL OPERATION IN POWER-SWITCHING CIRCUIT

DC Collector-to-Emitter Voltage	V_{CE}	−12	V
DC Emitter Current	I_E	5.8	mA
Source Impedance	R_S	150	Ω
Capacitive Load		16	pF
Frequency Response		20 c/s to 11 Mc/s	
Pulse Rise Time	t_r	0.032	µs
Voltage Gain		26	dB
Maximum Peak-to-Peak Output Voltage		20	V

2N1066 TRANSISTOR

Ge p-n-p alloy-junction drift-field type used in rf and if amplifier, oscillator, mixer, and converter circuits, and low-level video-amplifier circuits in industrial and military equipment. JEDEC TO-33, Outline No.10. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - case and interlead shield. This type is electrically identical with type 2N1023.

2N1090 COMPUTER TRANSISTOR

Ge n-p-n alloy-junction type used in high-current medium-speed switching circuits in electronic computers. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	25	V
Collector-to-Emitter Voltage:			
V_{BE} = −1 V	V_{CEV}	18	V
Base open	V_{CEO}	15	V
Emitter-to-Base Voltage	V_{EBO}	20	V
Collector Current	I_C	400	mA
Emitter Current	I_E	−400	mA
Transistor Dissipation:			
T_A = 25°C	P_T	120	mW
T_A = 55°C	P_T	35	mW
T_A = 71°C	P_T	10	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	85	°C
Storage	T_{STG}	−65 to 85	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 25 µA, I_E = 0)	$V_{(BR)CBO}$	25 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 600 µA, I_B = 0)	$V_{(BR)CEO}$	15 min	V
Emitter-to-Base Breakdown Voltage (I_E = 25 µA, I_C = 0)	$V_{(BR)EBO}$	20 min	V
Base-to-Emitter Voltage:			
I_C = 20 mA, I_B = 0.67 mA	V_{BE}	0.4 max	V
I_C = 200 mA, I_B = 10 mA	V_{BE}	1.5 max	V
Collector-to-Emitter Saturation Voltage:			
I_C = 20 mA, I_B = 0.67 mA	V_{CE}(sat)	0.2 max	V
I_C = 200 mA, I_B = 10 mA	V_{CE}(sat)	0.3 max	V
Emitter-to-Base Reach-Through Voltage (V_{BE} = −1 V)	V_{RT}	18 min	V
Collector-Cutoff Current (V_{CB} = 12 V, I_E = 0)	I_{CBO}	8 max	µA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	5 max	µA
Static Forward-Current Transfer Ratio:			
V_{CE} = 0.2 V, I_C = 20 mA	h_{FE}	30 min	
V_{CE} = 0.3 V, I_C = 200 mA	h_{FE}	20 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 6 V, I_E = −1 mA)	f_{hfb}	5 min	Mc/s
Output Capacitance (V_{CB} = 6 V, I_E = 0)	C_{obo}	25 max	pF
Stored Base Charge (I_C = 20 mA, I_B = 1.33 mA)	Q_S	1600 max	pC

COMPUTER TRANSISTOR 2N1091

Ge **n-p-n alloy-junction** type used in high-current medium-speed switching circuits in electronic computers. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector. This type is identical with type 2N1090 except for the following items:

MAXIMUM RATINGS

Collector-to-Emitter Voltage:			
$V_{BE} = -1$ V	V_{CEV}	15	V
Base open	V_{CEO}	12	V

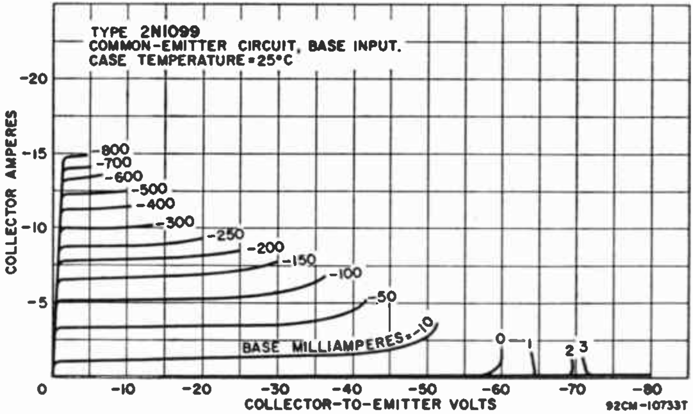
CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage ($I_C = 600\ \mu A$, $I_B = 0$)	$V_{(BR)CEO}$	12 min	V
Base-to-Emitter Voltage:			
$I_C = 20$ mA, $I_B = 0.5$ mA	V_{BE}	0.35 max	V
$I_C = 200$ mA, $I_B = 6.7$ mA	V_{BE}	1.1 max	V
Collector-to-Emitter Saturation Voltage:			
$I_C = 20$ mA, $I_B = 0.5$ mA	V_{CE}(sat)	0.2 max	V
$I_C = 200$ mA, $I_B = 6.7$ mA	V_{CE}(sat)	0.3 max	V
Emitter-to-Base Reach-Through Voltage ($V_{BE} = -1$ V)	V_{RT}	15 min	V
Static Forward-Current Transfer Ratio:			
$V_{CE} = 0.2$ V, $I_C = 20$ mA	h_{FE}	40 min	
$V_{CE} = 0.3$ V, $I_C = 200$ mA	h_{FE}	30 min	
Small-Signal Forward-Current Transfer Ratio Cutoff Frequency ($V_{CB} = 6$ V, $I_E = -1$ mA)	f_{hfb}	10 min	Mc/s
Output Capacitance ($V_{CB} = 6$ V, $I_E = 0$)	C_{obo}	25 max	pF
Stored Base Charge ($I_C = 20$ mA, $I_B = 1$ mA)	Q_S	1000 max	pC

POWER TRANSISTOR 2N1099

Ge **p-n-p alloy-junction** type used in a wide variety of switching and amplifier applications in industrial and military equipment requiring transistors having high voltage, current, and dissipation values. It is used in power-switching, voltage- and current-regulating, dc-to-dc converter, inverter, power-supply, and relay- and solenoid-actuating circuits, and in low-frequency oscillator and audio-amplifier service. It is stud-mounted to provide positive heat-sink contact. JEDEC TO-36, **Outline** No.11. **Terminals:** Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case. This type is identical with type 2N173 except for the following items:

TYPICAL COLLECTOR CHARACTERISTICS



MAXIMUM RATINGS

Collector-to-Base Voltage (V_{BE} = 1.5 V)	V_{CBV}	−80	V
Emitter-to-Base Voltage	V_{EBO}	−40	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
I_C = −0.3 A, R_{BE} = 0	$V_{(BR)CES}$	−70 min	V
I_C = −1 A, I_B = 0	$V_{(BR)CEO}$	−55 min	V
Base-to-Emitter Voltage (I_C = −5 A, V_{CE} = −2 V)	V_{BE}	−0.9 max	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−80 min	V
Collector-Cutoff Current:			
V_{CB} = −80 V, I_E = 0, T_C = 25°C	I_{CBO}	−4 max	mA
V_{CB} = −80 V, I_E = 0, T_C = 71°C	I_{CBO}	−15 max	mA

2N1100

POWER TRANSISTOR

Ge **p-n-p alloy-junction** type used in a wide variety of switching and amplifier applications in industrial and military equipment requiring transistors having high voltage, current, and dissipation values. It is used in power-switching, voltage- and current-regulating, dc-to-dc converter, inverter, power-supply, and relay- and solenoid-actuating circuits, and in low-frequency oscillator and audio-amplifier service. It is stud-mounted to provide positive heat-sink contact. JEDEC TO-36, **Outline** No.11. **Terminals:** Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case. This type is identical with type 2N174 except for the following items:

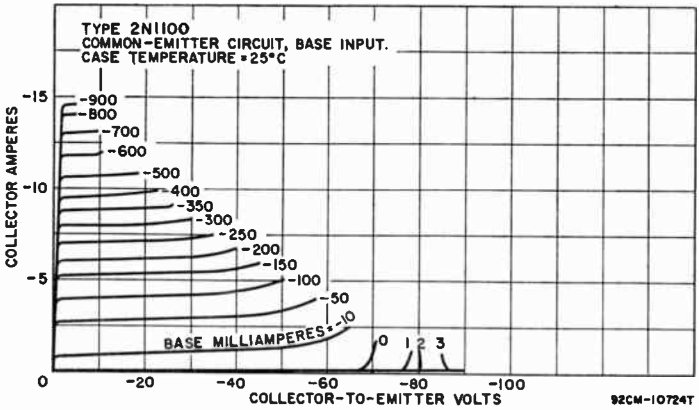
MAXIMUM RATINGS

Collector-to-Base Voltage (V_{BE} = 1.5 V)	V_{CBV}	−100	V
Emitter-to-Base Voltage	V_{EBO}	−80	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
I_C = −0.3 A, R_{BE} = 0	$V_{(BR)CES}$	−80 min	V
I_C = −1 A, I_B = 0	$V_{(BR)CEO}$	−65 min	V
Emitter-to-Base Voltage (V_{CB} = −100 V, I_E = 0)	V_{EB}	−1 max	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−100 min	V
Collector-Cutoff Current:			
V_{CB} = −100 V, I_E = 0, T_C = 25°C	I_{CBO}	−4 max	mA
V_{CB} = −100 V, I_E = 0, T_C = 71°C	I_{CBO}	−15 max	mA
Emitter-Cutoff Current:			
V_{EB} = −80 V, I_C = 0	I_{EBO}	−1 typ	mA
V_{EB} = −80 V, I_C = 0	I_{EBO}	−4 max	mA

TYPICAL COLLECTOR CHARACTERISTICS



TRANSISTOR 2N1177

Ge p-n-p alloy-junction drift-field type used in radio-frequency amplifier applications in FM and AM/FM radio receivers. JEDEC TO-45, Outline No.15. Terminals: 1 - emitter, 2- base, 3 - interpin shield and case, 4 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	—30	V
Emitter-to-Base Voltage	V_{EBO}	—0.5	V
Collector Current	I_C	—10	mA
Emitter Current	I_E	10	mA
Transistor Dissipation:			
T_A = 25°C	P_T	80	mW
T_A = 55°C	P_T	50	mW
T_A = 71°C	P_T	23	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	71	°C
Storage	T_{STG}	—65 to 85	°C

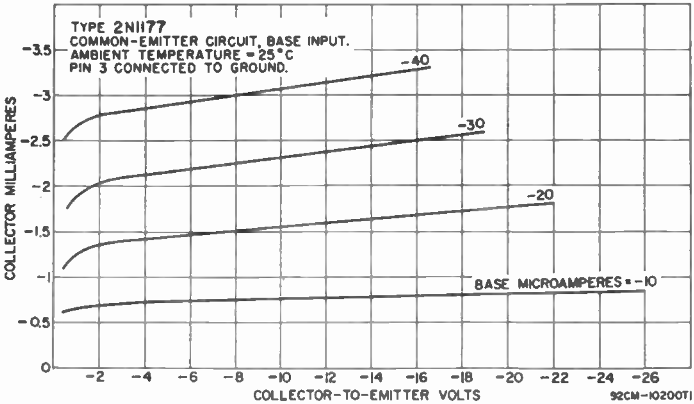
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (V_{BE} = 0.5 V, I_C = —50 µA)	$V_{(BR)CBO}$	—30 min	V
Collector-Cutoff Current (V_{CB} = —12 V, I_E = 0)	I_{CBO}	—12 max	µA
Emitter-Cutoff Current (V_{EB} = —0.5 V, I_C = 0)	I_{EBO}	—12 max	µA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = —6 V, I_C = —1 mA, f = 1 kc/s)	h_{fe}	40 to 170	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = —12 V, I_C = —1 mA)	f_{hfb}	140	Mc/s

TYPICAL OPERATION

Frequency	f	100	Mc/s
DC Collector-to-Base Voltage	V_{CBO}	—12	V
DC Emitter Current	I_E	1.5	mA
Input Resistance (ac output circuit shorted)	R_{ie}	45	Ω
Output Resistance (ac input circuit shorted)	R_{oe}	3800	Ω
Maximum Available Power Gain	MAG	14	dB
Extrinsic Transconductance	g_m	24250	µmhos
Collector Output Capacitance	C_{obo}	2	pF

TYPICAL COLLECTOR CHARACTERISTICS



TRANSISTOR 2N1178

Ge p-n-p alloy-junction drift-field type used in radio-frequency oscillator applications in FM and AM/FM radio receivers. JEDEC TO-45, Outline No.15. Terminals: 1 - emitter, 2 - base, 3 - interpin shield and case, 4 - collector. This type is identical with type 2N1177 except for the following items:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_C = −1 mA, f = 1 kc/s)	h_{fe}	40 to 275	

TYPICAL OPERATION

Frequency	f	10.7	Mc/s
DC Collector-to-Base Voltage	V_{CBO}	−11	V
DC Emitter Current	I_E	2.5	mA
Extrinsic Transconductance	g_m	21800	µmhos
Collector Output Capacitance	C_{obo}	2	pF

2N1179 TRANSISTOR

Ge p-n-p alloy-junction drift-field type used in radio-frequency mixer applications in FM and AM/FM radio receivers. JEDEC TO-45, **Outline** No.15. **Terminals:** 1 - emitter, 2 - base, 3 - interpin shield and case, 4 - collector. This type is identical with type 2N1177 except for the following items:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_C = −1 mA, f = 1 kc/s)	h_{fe}	40 to 275	

TYPICAL OPERATION

Frequency	f	100	Mc/s
DC Emitter Current	I_E	0.8	mA
Input Resistance (ac output circuit shorted)	R_{ie}	40	Ω
Output Resistance* (ac input circuit shorted)	R_{oe}	90000	Ω
Maximum Available Conversion Power Gain		17	dB
RMS Base-to-Emitter Oscillator-Injection Voltage		125	mV
Extrinsic Conversion Transconductance	g_m	7500	µmhos

* At intermediate frequency of 10.7 Mc/s.

2N1180 TRANSISTOR

Ge p-n-p alloy-junction drift-field type used in intermediate-frequency amplifier applications in FM and AM/FM radio receivers. JEDEC TO-45, **Outline** No.15. **Terminals:** 1 - emitter, 2 - base, 3 - interpin shield and case, 4 - collector. This type is identical with type 2N1177 except for the following items:

MAXIMUM RATINGS

Emitter-to-Base Voltage	V_{EBO}	−0.5	V

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio Cutoff Frequency (V_{CB} = −12 V, I_C = −1 mA)	f_{hfb}	100	Mc/s

TYPICAL OPERATION

Frequency	f	10.7	Mc/s
DC Collector-to-Emitter Voltage	V_{CEO}	−12	V
Input Resistance (ac output circuit shorted)	R_{ie}	325	Ω
Output Resistance (ac input circuit shorted)	R_{oe}	24000	Ω
Extrinsic Transconductance	g_m	40250	µmhos
Power Gain:			
Maximum available	MAG	35	dB
Maximum useful:			
Circuit neutralized	MUG	23	dB
Circuit unneutralized	MUG	20	dB

2N1183
2N1183A
2N1183B

POWER TRANSISTORS

Ge p-n-p alloy-junction types intended for use in intermediate-power switching and low-frequency amplifier applications in industrial and military equipment. JEDEC TO-8, Outline No.5. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

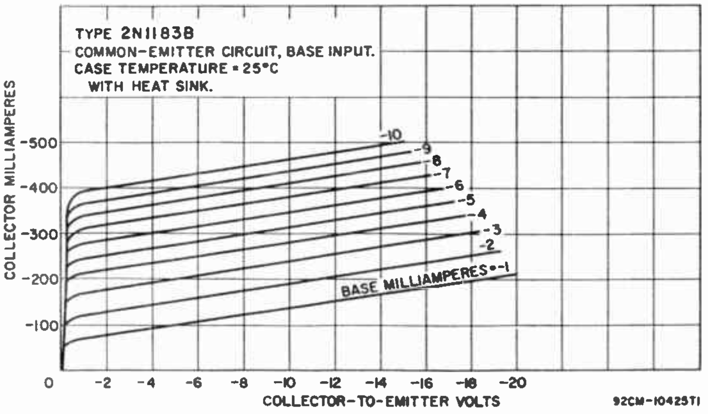
MAXIMUM RATINGS

		2N1183	*2N1183A*	*2N1183B*	
Collector-to-Base Voltage	V_{CBO}	—45	—60	—80	V
Collector-to-Emitter Voltage:					
V_{BE} = 1.2 V	V_{CEV}	—45	—60	—80	V
R_{BE} = 0	V_{CES}	—35	—50	—60	V
Base open	V_{CEO}	—20	—30	—40	V
Emitter-to-Base Voltage	V_{EBO}	—20	—20	—20	V
Collector Current	I_C	—3	—3	—3	A
Emitter Current	I_E	3.5	3.5	3.5	A
Base Current	I_B	—0.5	—0.5	—0.5	A
Transistor Dissipation:					
T_A up to 25°C	P_T	1	1	1	W
T_A above 25°C	P_T	See curve page 112			
T_C up to 25°C (with heat sink)	P_T	7.5	7.5	7.5	W
T_C above 25°C (with heat sink)	P_T	See curve page 112			
Temperature Range:					
Operating (Ambient)	T_A(opr)	—65 to 100			°C
Storage	T_{STG}	—65 to 100			°C

CHARACTERISTICS

		2N1183	*2N1183A*	*2N1183B*	
Collector-to-Emitter Voltage:					
I_C = —50 mA, R_{BE} = 0	V_{CES}	—35 min	—50 min	—60 min	V
V_{BE} = 1.2 V, I_C = —250 mA	V_{CEV}	—45 min	—60 min	—80 min	V
I_C = —50 mA, I_B = 0	V_{CEO}	—20 min	—30 min	—40 min	V
Emitter-to-Base Voltage: (V_{CE} = —2 V, I_C = —400 mA)	V_{EB}	1.5 max	1.5 max	1.5 max	V
Collector-Cutoff Current:					
V_{CB} = —1.5 V, I_E = 0	I_{CBO}	—30 max	—30 max	—30 max	µA
V_{CB} = —45 V, I_E = 0	I_{CBO}	—250 max	—	—	µA
V_{CB} = —60 V, I_E = 0	I_{CBO}	—	—250 max	—	µA
V_{CB} = —80 V, I_E = 0	I_{CBO}	—	—	—250 max	µA
Emitter-Cutoff Current (V_{EB} = —20 V, I_C = 0)	I_{EBO}	—100 max	—100 max	—100 max	µA

TYPICAL COLLECTOR CHARACTERISTICS



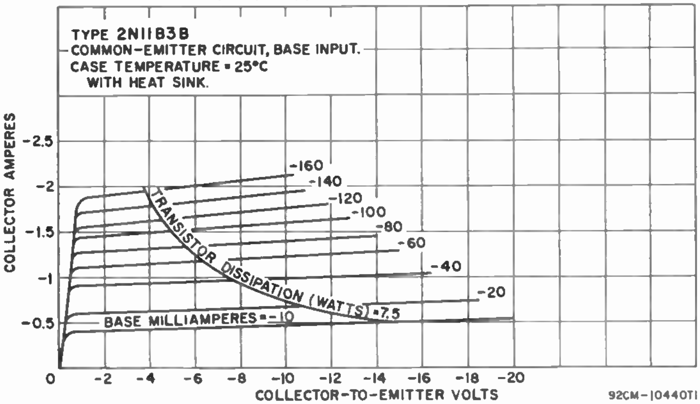
CHARACTERISTICS (cont'd)

		2N1183	*2N1183A*	*2N1183B*	
Static Forward-Current Transfer Ratio (V_{CE} = —2 V, I_C = —400 mA)	h_{FE}	20 to 60	20 to 60	20 to 60	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = —6 V, I_E = 1 mA)	f_{hfb}	0.5 min	0.5 min	0.5 min	Mc/s
Collector Saturation Resistance (I_C = —400 mA, I_B = —40 mA)		1.25 max	1.25 max	1.25 max	Ω
Thermal Resistance, Junction-to-case	θ_{J-C}	10 max	10 max	10 max	°C/W
Thermal Resistance, Junction-to-ambient	θ_{J-A}	75 max	75 max	75 max	°C/W

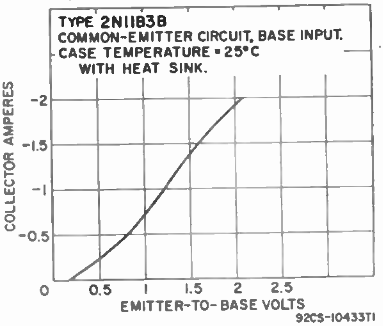
TYPICAL OPERATION IN POWER-SWITCHING CIRCUIT

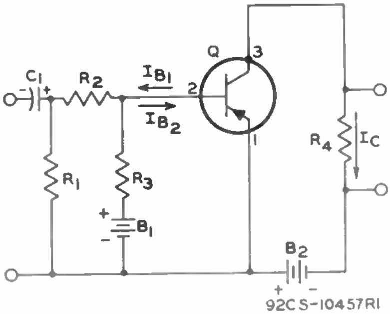
DC Supply Voltage	V_{CC}	—12	V
DC Base-Bias Voltage	V_{BE}	12	V
"On" DC Collector Current	I_C	—400	mA
"Turn-On" Base Current	I_{B1}	—40	mA
"Turn-Off" Base Current	I_{B2}	40	mA
Generator Resistance	R_G	50	Ω
Delay Time	t_d	0.2	μs
Rise Time	t_r	2	μs
Storage Time	t_s	1.8	μs
Fall Time	t_f	1.4	μs

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC





B_1, B_2 = 12 volts
C_1 = 10 μF, electrolytics, 25 volts
R_1 = 51 ohms, 2 watts
R_2 = 120 ohms, 2 watts
R_3 = 230 ohms, 1 watt
R_4 = 29.5 ohms, 5 watts

2N1184
2N1184A
2N1184B

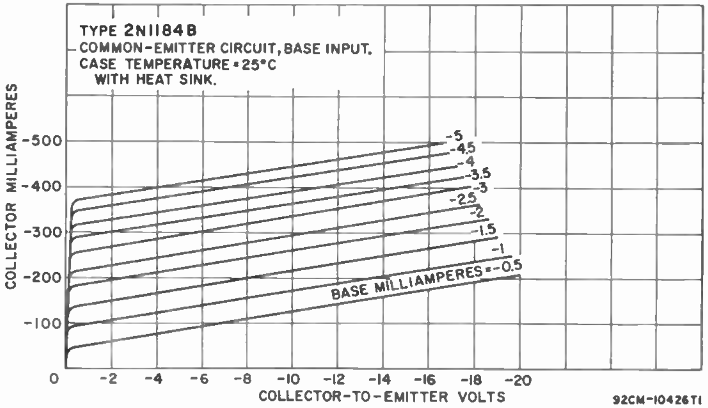
TRANSISTORS

Ge p-n-p alloy-junction type intended for use in intermediate-power switching and low-frequency amplifier applications in industrial and military equipment. JEDEC TO-8, Outline No.5. Terminals: 1 - emitter, 2 - base, 3 - collector and case. These types are identical with types 2N1183, 2N1183A, and 2N1183B, respectively, except for the following items:

CHARACTERISTICS

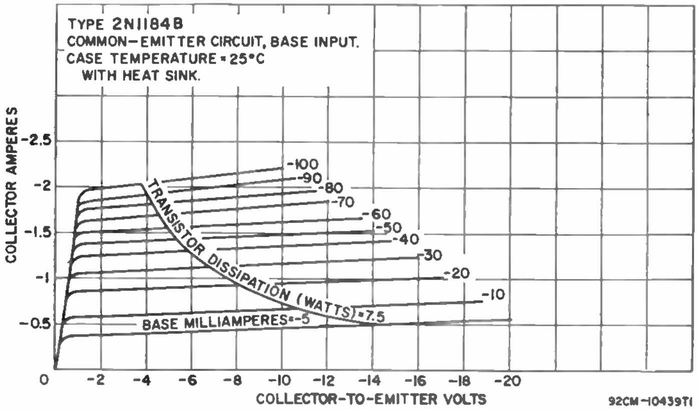
		2N1184	*2N1184A*	*2N1184B*
Static Forward-Current Transfer Ratio (V_{CE} = −2 V, I_C = −400 mA)	h_{FE}	40 to 120	40 to 120	40 to 120

TYPICAL COLLECTOR CHARACTERISTICS



92CM-10426T1

TYPICAL COLLECTOR CHARACTERISTICS



92CM-10439T1

2N1224 TRANSISTOR

Ge **p-n-p alloy-junction drift-field** type used in rf and if amplifier, oscillator, mixer, and converter circuits, and low-level video-amplifier circuits in industrial and military equipment. JEDEC TO-33, Outline No.10. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - interlead shield and case. This type is electrically identical with type 2N274.

2N1225 TRANSISTOR

Ge **p-n-p alloy-junction drift-field** type used in rf and if amplifier, oscillator, mixer, and converter circuits, and low-level video-amplifier circuits in industrial and military equipment. JEDEC TO-33, Outline No.10. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - interlead shield and case. This type is electrically identical with type 2N384. For collector-characteristics curves and video-amplifier circuit, refer to type 2N274.

2N1226 TRANSISTOR

Ge **p-n-p alloy-junction drift-field** type used in rf and if amplifier, oscillator, mixer, and converter circuits, and low-level video-amplifier circuits in industrial and military equipment. JEDEC TO-33, Outline No.10. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - interlead shield and case. This type is identical with type 2N274 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−60	V
Collector-to-Emitter Voltage (V_{BE} = 0.5 V)	V_{CEV}	−60	V

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −50 μA, I_E = 0)	$V_{(BR)CBO}$	−60 min	V
Collector-to-Emitter Reach-Through Voltage (V_{EB} = −0.5 V)	V_{RT}	−60 min	V

2N1300 COMPUTER TRANSISTOR

Ge **p-n-p diffused-junction** type used in computer applications in commercial and military data-processing equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−13	V
Collector-to-Emitter Voltage	V_{CEO}	−12	V
Emitter-to-Base Voltage*	V_{EBO}	−1	V
Collector Current	I_C	−100	mA
Emitter Current	I_E	100	mA
Transistor Dissipation:			
T_A = 25°C	P_T	150	mW
T_A = 55°C	P_T	75	mW
T_A = 71°C	P_T	35	mW
Ambient-Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

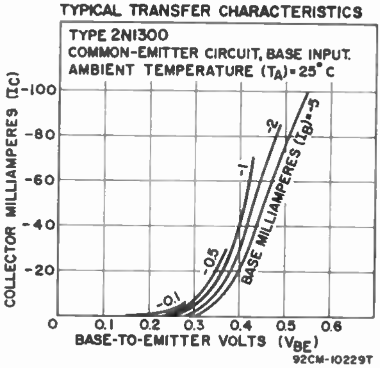
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −0.02 mA, I_E = 0)	$V_{(BR)CBO}$	−13 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	−1 min	V

CHARACTERISTICS (cont'd)

Base-to-Emitter Voltage (I_C = −10 mA, I_B = −0.33 mA)	V_{BE}	−0.4 max	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−12 min	V
Collector-Cutoff Current (V_{CB} = −6 V, I_E = 0)	I_{CBO}	−3 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = −0.3 V, I_C = −10 mA)	h_{FE}	30 min	
Gain-Bandwidth Product (V_{CE} = −3 V, I_C = −10 mA)	f_T	25 min	Mc/s
Output Capacitance (V_{CB} = −6 V, I_E = 0)	C_{obo}	12 max	pF
Thermal Time Constant	τ(thermal)	10	ms
Total Stored Charge (I_C = −10 mA, I_B = −1 mA)	Q_S	400 max	pC
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	400 max	°C/W

* This rating may be exceeded and the emitter-to-base junction operated in the breakdown condition provided the emitter dissipation is limited to 30 milliwatts at 25°C. For ambient temperatures above 25°C, the dissipation must be reduced by 0.5 milliwatts per °C.



COMPUTER TRANSISTOR 2N1301

Ge p-n-p diffused-junction type used in computer applications in data-processing equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector. This type is identical with type 2N1300 except for the following items:

MAXIMUM RATINGS

Emitter-to-Base Voltage	V_{EBO}	−4	V

CHARACTERISTICS

Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	−4 min	V
Base-to-Emitter Voltage (I_C = −40 mA, I_B = −1 mA)	V_{BE}	−0.6 max	V
Static Forward-Current Transfer Ratio: V_{CE} = −0.3 V, I_C = −10 mA	h_{FE}	30 min	
V_{CE} = −0.5 V, I_C = −40 mA	h_{FE}	40 min	
Gain-Bandwidth Product (V_{CE} = −3 V, I_C = −10 mA)	f_T	35 min	Mc/s
Total Stored Charge: I_C = −10 mA, I_B = −1 mA	Q_S	325 max	pC
I_C = −40 mA, I_B = −2 mA	Q_S	800 max	pC

COMPUTER TRANSISTOR 2N1302

Ge n-p-n alloy-junction type used in medium-speed switching applications in commercial and military data-processing equipment. The n-p-n construction permits complementary operation with a matching p-n-p type, such as the 2N1303. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base and case, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	25	V
Emitter-to-Base Voltage	V_{EBO}	25	V
Collector Current	I_C	0.3	A
Transistor Dissipation:			
T_A up to 25°C	P_T	150	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 85	°C
Storage	T_{STG}	−65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage (I_B = 0.5 mA, I_C = 10 mA)	V_{CE}(sat)	0.2 max	V
Base-to-Emitter Voltage (I_B = 0.5 mA, I_C = 0)	V_{BE}	0.15 to 0.4	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	25 min	V
Collector-Cutoff Current (V_{CB} = 25 V, I_E = 0)	I_{CBO}	6 max	µA
Emitter-Cutoff Current (V_{EB} = 25 V, I_C = 0)	I_{EBO}	6 max	µA
Static Forward-Current Transfer Ratio:			
V_{CE} = 1 V, I_C = 10 mA	h_{FE}	20 min	
V_{CE} = 0.35 V, I_C = 200 mA	h_{FE}	10 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 5 V, I_E = −1 mA)	f_{hfb}	3 min	Mc/s
Output Capacitance (V_{CB} = 5 V, I_E = 0)	C_{obo}	20 max	pF

2N1303 COMPUTER TRANSISTOR

Ge **p-n-p alloy-junction** type used in medium-speed switching applications in data-processing equipment. The 2N1303 is the p-n-p complement of the n-p-n type 2N1302. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base and case, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−30	V
Emitter-to-Base Voltage	V_{EBO}	−25	V
Collector Current	I_C	−0.3	A
Transistor Dissipation:			
T_A up to 25°C	P_T	150	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 85	°C
Storage	T_{STG}	−65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage (I_B = −0.5 mA, I_C = −10 mA)	V_{CE}(sat)	−0.2 max	V
Base-to-Emitter Voltage (I_B = −0.5 mA, I_C = −10 mA)	V_{BE}	−0.15 to −0.4	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−25 min	V
Collector-Cutoff Current (V_{CB} = −25 V, I_E = 0)	I_{CBO}	−6 max	µA
Emitter-Cutoff Current (V_{EB} = −25 V, I_C = 0)	I_{EBO}	−6 max	µA
Static Forward-Current Transfer Ratio:			
V_{CE} = −1 V, I_C = −10 mA	h_{FE}	20 min	
V_{CE} = −0.35 V, I_C = −200 mA	h_{FE}	10 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −5 V, I_E = 1 mA)	f_{hfb}	3 min	Mc/s
Output Capacitance (V_{CB} = −5 V, I_E = 0)	C_{obo}	20 max	pF

2N1304 COMPUTER TRANSISTOR

Ge **n-p-n alloy-junction** type used in medium-speed switching applications in data-processing equipment. The n-p-n construction permits complementary operation with a matching p-n-p type, such as the 2N1305. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base and case, 3 - collector. This type is identical with type 2N1302 except for the following items:

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage ($I_B = 0.25$ mA, $I_C = 10$ mA)	V_{CE}(sat)	0.2 max	V
Base-to-Emitter Voltage ($I_B = 0.5$ mA, $I_C = 10$ mA)	V_{BE}	0.15 to 0.35	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	20 min	V
Static Forward-Current Transfer Ratio:			
$V_{CE} = 1$ V, $I_C = 10$ mA	h_{FE}	40 to 200	
$V_{CE} = 0.35$ V, $I_C = 200$ mA	h_{FE}	15 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = 5$ V, $I_E = -1$ mA)	f_{hfb}	5 min	Mc/s

COMPUTER TRANSISTOR 2N1305

Ge **p-n-p alloy-junction** type used in medium-speed switching applications in data-processing equipment. The 2N1305 is the p-n-p complement of the n-p-n type 2N1304. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base and case, 3 - collector. This type is identical with type 2N1303 except for the following items:

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage ($I_B = -25$ mA, $I_C = -10$ mA)	V_{CE}(sat)	—0.2 max	V
Base-to-Emitter Voltage ($I_B = -0.5$ mA, $I_C = -10$ mA)	V_{BE}	—0.15 to —0.35	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	—20 min	V
Static Forward-Current Transfer Ratio:			
$V_{CE} = -1$ V, $I_C = -10$ mA	h_{FE}	40 to 200	
$V_{CE} = -0.35$ V, $I_C = -200$ mA	h_{FE}	15 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = -5$ V, $I_E = 1$ mA)	f_{hfb}	5 min	Mc/s

COMPUTER TRANSISTOR 2N1306

Ge **n-p-n alloy-junction** type used in medium-speed switching applications in data-processing equipment. The 2N1306 is the n-p-n complement of the p-n-p type 2N1307. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base and case, 3 - collector. This type is identical with type 2N1302 except for the following items:

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage ($I_B = 0.17$ mA, $I_C = 10$ mA)	V_{CE}(sat)	0.2 max	V
Base-to-Emitter Voltage ($I_B = 0.5$ mA, $I_C = 10$ mA)	V_{BE}	0.15 to 0.35	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	15 min	V
Static Forward-Current Transfer Ratio:			
$V_{CE} = 1$ V, $I_C = 10$ mA	h_{FE}	60 to 300	
$V_{CE} = 0.35$ V, $I_C = 200$ mA	h_{FE}	20 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = 5$ V, $I_E = -1$ mA)	f_{hfb}	10 min	Mc/s

COMPUTER TRANSISTOR 2N1307

Ge **p-n-p alloy-junction** type used in medium-speed switching applications in data-processing equipment. The 2N1307 is the p-n-p complement of the n-p-n type 2N1306. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base and case, 3 - collector. This type is identical with type 2N1303 except for the following items:

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage ($I_B = -0.17$ mA, $I_C = -10$ mA)	V_{CE}(sat)	—0.2 max	V
Base-to-Emitter Voltage ($I_B = -0.5$ mA, $I_C = -10$ mA)	V_{BE}	—0.15 to —0.35	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	—15 min	V

CHARACTERISTICS (cont'd)

Static Forward-Current Transfer Ratio:			
$V_{CE} = -1$ V, $I_C = -10$ mA	h_{FE}	60 to 300	
$V_{CE} = -0.35$ V, $I_C = -200$ mA	h_{FE}	20 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = -5$ V, $I_E = 1$ mA)	f_{hfb}	10 min	Mc/s

2N1308 COMPUTER TRANSISTOR

Ge **n-p-n alloy-junction** type used in medium-speed switching applications in data-processing equipment. The 2N1308 is the n-p-n complement of the p-n-p type 2N1309. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base and case, 3 - collector. This type is identical with type 2N1302 except for the following items:

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage ($I_B = 0.13$ mA, $I_C = 10$ mA)	$V_{CE}(sat)$	0.2 max	V
Base-to-Emitter Voltage ($I_B = 0.5$ mA, $I_C = 10$ mA)	V_{BE}	0.15 to 0.35	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	15 min	V
Static Forward-Current Transfer Ratio:			
$V_{CE} = 1$ V, $I_C = 10$ mA	h_{FE}	80 min	
$V_{CE} = 0.35$ V, $I_C = 200$ mA	h_{FE}	20 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = 5$ V, $I_E = -1$ mA)	f_{hfb}	15	Mc/s

2N1309 COMPUTER TRANSISTOR

Ge **p-n-p alloy-junction** type used in medium-speed switching applications in data-processing equipment. The 2N1309 is the p-n-p complement of the n-p-n type 2N1308. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base and case, 3 - collector. This type is identical with type 2N1303 except for the following items:

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage ($I_B = -0.13$ mA, $I_C = -10$ mA)	$V_{CE}(sat)$	−0.2 max	V
Base-to-Emitter Voltage ($I_B = -0.5$ mA, $I_C = -10$ mA)	V_{BE}	−0.15 to −0.35	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−15 min	V
Static Forward-Current Transfer Ratio:			
$V_{CE} = -1$ V, $I_C = -10$ mA	h_{FE}	80 min	
$V_{CE} = -0.35$ V, $I_C = -200$ mA	h_{FE}	20 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = -5$ V, $I_E = 1$ mA)	f_{hfb}	15 min	Mc/s

2N1358 POWER TRANSISTOR

Ge **p-n-p alloy-junction** type used in a wide variety of switching and amplifier applications in industrial and military equipment requiring transistors having high voltage, current, and dissipation values. It is used in power-switching, voltage- and current-regulating, dc-to-dc converter, inverter, power-supply, and relay- and solenoid-actuating circuits; and in low-frequency oscillator and audio-amplifier service. It is stud-mounted to provide positive heat-sink contact. JEDEC TO-36, **Outline** No.11. **Terminals:** Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case. This type is identical with type 2N174 except for the following items:

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
$I_C = -0.3$ A, $I_B = 0$	$V_{(BR)CEO}$	−40 min	V

CHARACTERISTICS (cont'd)

Collector-Cutoff Current:			
V_{CB} = −2 V, I_E = 0, T_C = 25°C	I_{CBO}	−200 max	μA
V_{CB} = −30 V, I_E = 0, T_C = 71°C	I_{CBO}	−6 max	mA
Emitter-Cutoff Current (V_{EB} = −30 V, I_C = 0, T_C = 71°C)	I_{EBO}	−6 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = −2 V, I_C = −5 A	h_{FE}	25 min	
V_{CE} = −2 V, I_C = −5 A	h_{FE}	35 typ	
V_{CE} = −2 V, I_C = −1.2 A	h_{FE}	40 to 80	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −12 V, I_C = −1 mA)	f_{hfe}	100 min	kc/s

COMPUTER TRANSISTOR 2N1384

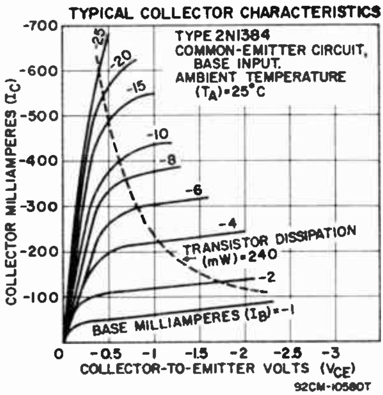
Ge p-n-p drift-field type used in switching applications in military and industrial electronic computers such as memory-core driver, pulse-amplifier, inverter, flip-flop, and logic-gate circuits. JEDEC TO-11, Outline No.7. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−30	V
Collector-to-Emitter Voltage	V_{CEO}	−30	V
Emitter-to-Base Voltage*	V_{EBO}	−1	V
Collector Current	I_C	−0.5	A
Emitter Current	I_E	0.5	A
Transistor Dissipation:			
T_A up to 25°C	P_T	240	mW
T_A above 25°C	P_T	See curve page 112	
Ambient-Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −50 μA, I_E = 0)	$V_{(BR)CBO}$	−30 min	V
Collector-to-Emitter Breakdown Voltage (V_{CC} = 30 V, I_C = 250 mA, I_B = 0, R_{BE} = 1000 Ω)	$V_{(BR)CERL}$	−30 min	V
Emitter-to-Base Breakdown Voltage (I_E = −100 μA, I_C = 0)	$V_{(BR)EBO}$	−1 min	V
Collector-to-Emitter Reach-Through Voltage	R_T	−30 min	V
Base-to-Emitter Voltage (I_C = −200 mA, I_B = −10 mA)	V_{BE}	−0.9 max	V
Collector-Cutoff Current (V_{CB} = −3 V, I_E = 0)	I_{CBO}	−8 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = −0.5 V, I_C = −200 mA)	h_{FE}	20 min	



CHARACTERISTICS (cont'd)

Gain-Bandwidth Product (V_{CB} = —3 V, I_C = —10 mA)	f_T	20 min	Mc/s
Stored Base Charge (I_C = —10 mA, I_B = —1 mA)	Q_S	800 max	pC
Thermal Time Constant	τ(thermal)	14 min	ms
Thermal Resistance, Junction-to-ambient	Θ_{J-A}	250 max	°C/W

* This rating may be exceeded and the emitter-to-base junction operated in the breakdown condition provided the emitter dissipation is limited to 30 milliwatts at 25°C. For ambient temperature above 25°C, dissipation must be reduced by 0.5 milliwatts per °C.

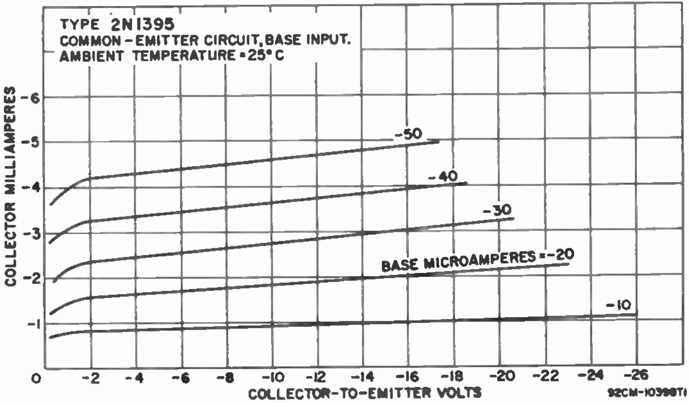
2N1395 TRANSISTOR

Ge p-n-p alloy-junction drift-field type used in rf and if amplifier, oscillator, mixer, and converter circuits, and low-level video-amplifier circuits in industrial and military equipment. JEDEC TO-33, Outline No.10. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - interlead shield and case. This type is identical with type 2N274 except for the following items:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = —12 V, I_E = 1.5 mA, f = 1 kc/s)	h_{fe}	50 to 175

TYPICAL COLLECTOR CHARACTERISTICS



2N1396 TRANSISTOR

Ge p-n-p alloy-junction drift-field type used in rf and if amplifier, oscillator, mixer, and converter circuits, and low-level video-amplifier circuits in industrial and military equipment. JEDEC TO-33, Outline No.10. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - interlead shield and case. This type is identical with type 2N384 except for the collector-characteristics curves, which are the same as for type 2N1395, and the following items:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = —12 V, I_E = 1.5 mA, f = 1 kc/s)	h_{fe}	50 to 175

2N1397 TRANSISTOR

Ge p-n-p alloy-junction drift-field type used in rf and if amplifier, oscillator, mixer, and converter circuits, and low-level video-amplifier circuits in industrial and military equipment. JEDEC TO-33, Outline No.10. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - interlead shield and case. This type is identical with type 2N1023 except for the collector-characteristics curves, which are the same as for type 2N1395, and the following items:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12 V, I_E = 1.5 mA, f = 1 kc/s)	h_{fe}	50 to 175	

POWER TRANSISTOR 2N1412

Ge **p-n-p alloy-junction** type used in a wide variety of switching and amplifier applications in industrial and military equipment requiring transistors having high voltage, current, and dissipation values. It is used in power-switching, voltage- and current-regulating, dc-to-dc converter, inverter, power-supply, and relay- and solenoid-actuating circuits; and in low-frequency oscillator and audio-amplifier service. It is stud-mounted to provide positive heat-sink contact. JEDEC TO-36, Outline No.11. Terminals: Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case. This type is identical with type 2N174 except for the collector-characteristics curves, which are the same as for type 2N1100, and the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage (V_{BE} = 1.5 V)	V_{CBO}	−100	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
I_C = −0.3 A, R_{BE} = 0	$V_{(BR)CES}$	−80 min	V
I_C = −1 A, I_B = 0	$V_{(BR)CEO}$	−65 min	V
Base-to-Emitter Voltage (V_{CE} = −2 V, I_C = −5 A)	V_{BE}	−0.8 max	V
Emitter-to-Base Voltage (V_{CB} = −100 V, I_E = 0)	V_{EB}	−1 max	V
Collector-to-Emitter Reach-Through Voltage	V_{RT}	−100 min	V
Collector-Cutoff Current:			
V_{CB} = −100 V, I_E = 0, T_C = 25°C	I_{CBO}	−4 max	mA

POWER TRANSISTOR 2N1479

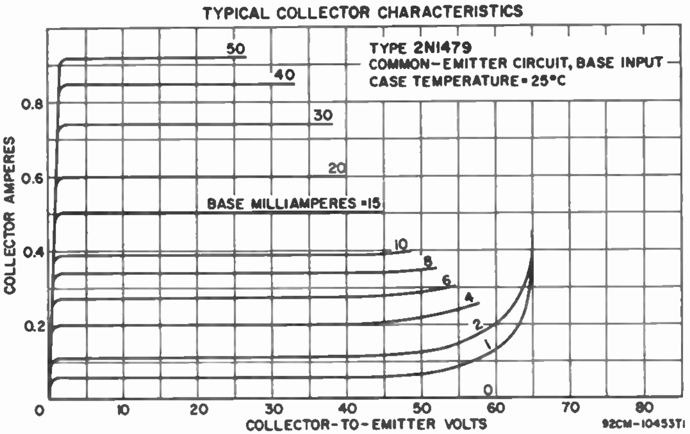
Si **n-p-n diffused-junction** type used in power switching circuits such as dc-to-dc converters, inverters, choppers, solenoid and relay controls; in oscillators, regulators, and pulse amplifier circuits; and as class A and class B push-pull audio and servo amplifiers in industrial and military equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	60	V
Base open (sustaining voltage)	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	12	V
Collector Current	I_C	1.5	A
Emitter Current	I_E	−1.75	A
Base Current	I_B	1	A
Transistor Dissipation:			
T_C up to 25°C	P_T	5	W
T_C above 25°C	P_T	See curve page 112	
Case-Temperature Range:			
Operating (T_C) and Storage (T_{STG})		−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 50 mA, I_B = 0)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5, I_C = 0.25 mA)	V_{CEV}	60 min	V



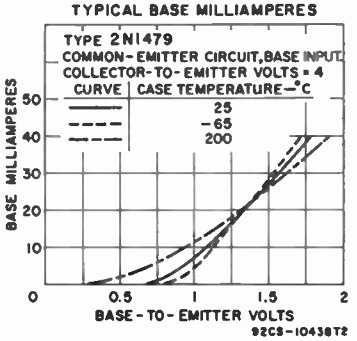
CHARACTERISTICS (cont'd)

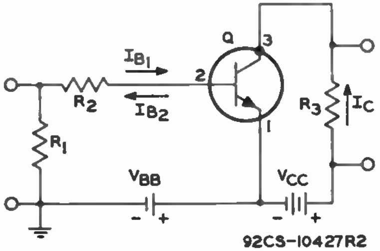
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 200 mA)	V_{BE}	3 max	V
Collector-Cutoff Current:			
V_{CB} = 30 V, I_E = 0, T_C = 25°C	I_{CBO}	10 max	µA
V_{CB} = 30 V, I_E = 0, T_C = 150°C	I_{CBO}	500 max	µA
Emitter-Cutoff Current (V_{EB} = 12 V, I_C = 0)	I_{EBO}	10 max	µA
Collector-to-Emitter Saturation Resistance (I_C = 200 mA, I_B = 20 mA)	r_{CE}(sat)	7 max	Ω
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 200 mA)	h_{FE}	20 to 60	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 5 mA, f = 1 kc/s)	h_{fe}	50	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 28 V, I_C = 5 mA)	f_{hfb}	1.5	Mc/s
Gain-Bandwidth Product	f_T	50 max	kc/s
Output Capacitance (V_{CB} = 40 V, I_C = 0, f = 1 kc/s)	C_{obo}	150	pF
Thermal Time Constant	τ(thermal)	10	ms
Thermal Resistance, Junction-to-Case	Θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	200 max	°C/W

TYPICAL OPERATION IN POWER-SWITCHING CIRCUIT

(At case temperature = 25°C)

DC Supply Voltage	V_{CC}	12	V
DC Base-Bias Voltage		−8.5	V
Generator Resistance	R_G	50	Ω
"On" DC Collector Current	I_C	200	mA
"Turn-On" Base Current	I_{B1}	20	mA
"Turn-Off" Base Current	I_{B2}	−8.5	mA





V_{BB} = 8.5 volts
V_{CC} = 12 volts
R_1 = 50 ohms, 1 watt
R_2 = 30 ohms, 1 watt
R_3 = 7.8 ohms, 2 watts

TYPICAL OPERATION (cont'd)

Delay Time	t_d	0.2	µs
Rise Time	t_r	1	µs
Storage Time	t_s	0.6	µs
Fall Time	t_f	1	µs

POWER TRANSISTOR 2N1480

Si **n-p-n diffused-junction** type used in power switching circuits such as dc-to-dc converters, inverters, choppers, solenoid and relay controls; in oscillators, regulators, and pulse amplifier circuits; and as class A and class B push-pull audio and servo amplifiers in industrial and military equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N1479 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	100	V
Base open (sustaining voltage)	V_{CEO}(sus)	55	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage ($I_C = 50$ mA, $I_B = 0$)	V_{CEO}(sus)	55 min	V
Collector-to-Emitter Voltage ($V_{BE} = -1.5$ V, $I_C = 0.25$ mA)	V_{CEV}	100 min	V

POWER TRANSISTOR 2N1481

Si **n-p-n diffused-junction** type used in power switching circuits such as dc-to-dc converters, inverters, choppers, solenoid and relay controls; in oscillators, regulators, and pulse amplifier circuits; and as class A and class B push-pull audio and servo amplifiers in industrial and military equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N1479 except for the following items:

CHARACTERISTICS (At case temperature = 25°C)

Static Forward-Current Transfer Ratio ($V_{CE} = 4$ V, $I_C = 200$ mA)	h_{FE}	35 to 100	
Collector-to-Emitter Saturation Resistance ($I_C = 200$ mA, $I_B = 10$ mA)	r_{CE}(sat)	7 max	Ω

POWER TRANSISTOR 2N1482

Si **n-p-n diffused-junction** type used in power switching circuits such as dc-to-dc converters, inverters, choppers, solenoid and relay controls; in oscillators, regulators, and pulse amplifier circuits; and as class A and class B push-pull audio and servo amplifiers in industrial and military equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N1479 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	100	V
Base open (sustaining voltage)	V_{CEO}(sus)	55	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 50 mA, I_B = 0)	V_{CEO}(sus)	55 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 0.25 mA)	V_{CEV}	100 min	V
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 200 mA)	h_{FE}	35 to 100	
Collector-to-Emitter Saturation Resistance (I_C = 200 mA, I_B = 10 mA)	r_{CE}(sat)	7 max	Ω

2N1483 POWER TRANSISTOR

Si **n-p-n diffused-junction** type used in dc-to-dc converters, inverters, choppers, dc and servo amplifiers, relay- and solenoid-actuating circuits in industrial and military equipment. JEDEC TO-8, Outline No.5. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

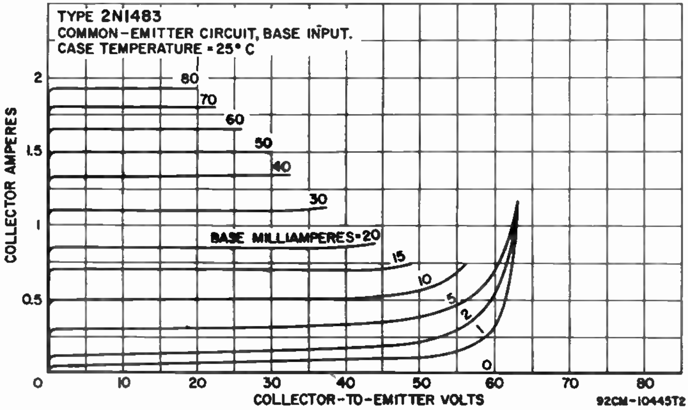
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	60	V
Base open (sustaining voltage)	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	12	V
Collector Current	I_C	3	A
Emitter Current	I_E	−3.5	A
Base Current	I_B	1.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	25	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_C) and Storage (T_{STG})		−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	235	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 0.25 mA)	V_{CEV}	60 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 750 mA)	V_{BE}	3.5 max	V
Collector-Cutoff Current:			
V_{CB} = 30 V, I_E = 0, T_A = 25°C	I_{CBO}	15 max	µA
V_{CB} = 30 V, I_E = 0, T_A = 100°C	I_{CBO}	750 max	µA
Emitter-Cutoff Current (V_{EB} = 12 V, I_C = 0)	I_{EBO}	15 max	µA
Collector-to-Emitter Saturation Resistance (I_C = 750 mA, I_B = 75 mA)	r_{CE}(sat)	2.67 max	Ω
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 750 mA)	h_{FE}	20 to 60	

TYPICAL COLLECTOR CHARACTERISTICS

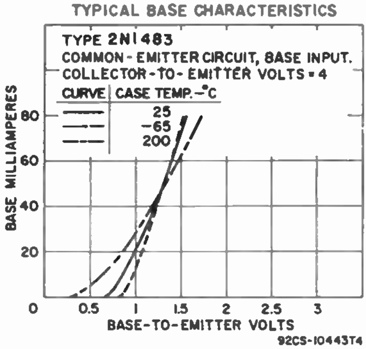


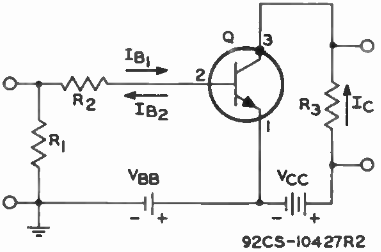
CHARACTERISTICS (cont'd)

Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 28 V, I_C = 5 mA)	f_{hfb}	1.25	Mc/s
Output Capacitance (V_{CB} = 40 V, I_E = 0)	C_{obo}	175	pF
Thermal Time Constant	τ (thermal)	10	ms
Thermal Resistance, Junction-to-Case	Θ_{J-C}	7 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	100 max	°C/W

TYPICAL OPERATION IN POWER-SWITCHING CIRCUIT (At case temperature = 25°C)

DC Supply Voltage	V_{CC}	12	V
DC Base-Bias Voltage		−8.5	V
Generator Resistance	R_G	50	Ω
"On" DC Collector Current	I_C	750	mA
"Turn-On" Base Current	I_{B1}	65	mA
"Turn-Off" Base Current	I_{B2}	−35	mA
Delay Time	t_d	0.2	μs
Rise Time	t_r	1	μs
Storage Time	t_s	0.8	μs
Fall Time	t_f	1.1	μs





V_{BB} = 8.5 volts
V_{CC} = 12 volts
R_1 = 50 ohms, 1 watt
R_2 = 700 ohms, 1 watt
R_3 = 59 ohms, 2 watts

POWER TRANSISTOR 2N1484

Si **n-p-n** diffused-junction type used in dc-to-dc converters, inverters, choppers, dc and servo amplifiers, relay- and solenoid-actuating circuits in industrial and military equipment. JEDEC TO-8, **Outline** No.5. Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N1483 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	100	V
Base open (sustaining voltage)	V_{CEO} (sus)	55	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO} (sus)	55 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 0.25 mA)	V_{CEV}	100 min	V

POWER TRANSISTOR 2N1485

Si **n-p-n** diffused-junction type used in dc-to-dc converters, inverters, choppers, dc and servo amplifiers, relay- and solenoid-actuating circuits in industrial and military equipment. JEDEC TO-8, **Outline** No.5. Terminals:

1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N1483 except for the following items:

CHARACTERISTICS (At case temperature = 25°C)

Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 750 mA)	V_{BE}	2.5 max	V
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 750 mA)	h_{FE}	35 to 100	

2N1486 POWER TRANSISTOR

Si **n-p-n diffused-junction** type used in dc-to-dc converters, inverters, choppers, dc and servo amplifiers, relay- and solenoid-actuating circuits in industrial and military equipment. JEDEC TO-8, **Outline** No.5. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N1483 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	100	V
Base open (sustaining voltage)	V_{CEO}(sus)	55	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	55 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 0.25 mA)	V_{CEV}	100 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 750 mA)	V_{BE}	2.5 max	V
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 750 mA)	h_{FE}	35 to 100	
Collector-to-Emitter Saturation Resistance (I_C = 750 mA, I_B = 40 mA)	r_{CE}(sat)	1 max	Ω

2N1487 POWER TRANSISTOR

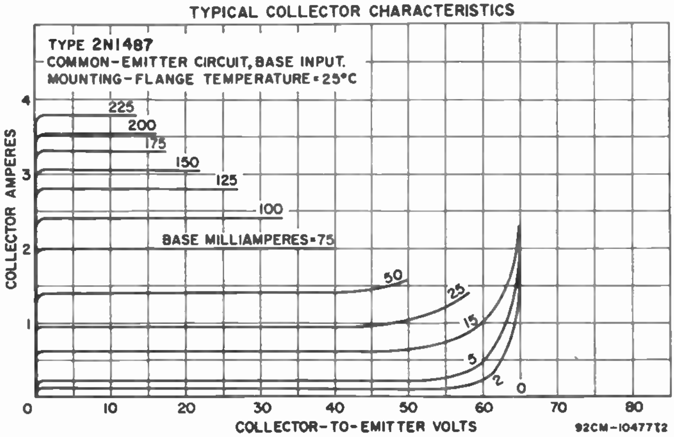
Si **n-p-n diffused-junction** type used in dc-to-dc converters, inverters, choppers, voltage and current regulators, dc and servo amplifiers, relay- and solenoid-actuating circuits. Similar to JEDEC TO-3, **Outline** No.2 (Variant 1). **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	60	V
Base open (sustaining voltage)	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	10	V
Collector Current	I_C	6	A
Emitter Current	I_E	−8	A
Base Current	I_B	3	A
Transistor Dissipation:			
T_{MF} at 25°C	P_T	75	W
T_{MF} above 25°C	P_T	See curve page 112	
Mounting-Flange Temperature Range: Operating (T_{MF}) and Storage (T_{STG})		−65 to 200	°C

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 0.5 mA)	V_{CEV}	60 min	V
Base-to-Emitter Saturation Voltage (V_{CE} = 4 V, I_C = 1.5 A)	V_{BE}	3.5 max	V
Collector-Cutoff Current:			
V_{CB} = 30 V, I_E = 0, T_A = 25°C	I_{CBO}	25 max	μA
V_{CB} = 30 V, I_E = 0, T_A = 150°C	I_{CBO}	1000 max	μA
Emitter-Cutoff Current (V_{EB} = 10 V, I_C = 0)	I_{EBO}	25 max	μA

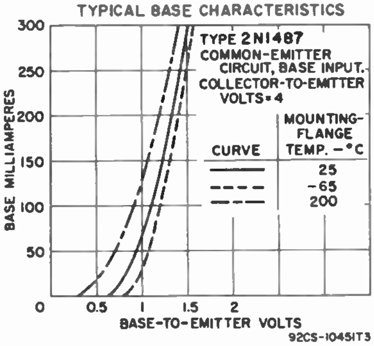


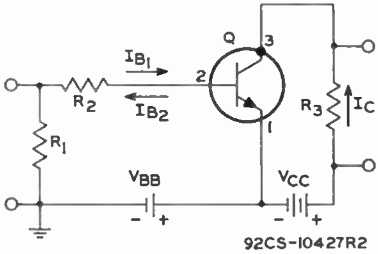
CHARACTERISTICS (cont'd)

Collector-to-Emitter Saturation Resistance (I_C = 1.5 A, I_B = 300 mA)	r_{CE}(sat)	2 max	Ω
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 1.5 A)	h_{FE}	15 to 45	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 12 V, I_C = 100 mA)	f_{hfb}	1	Mc/s
Output Capacitance (V_{CB} = 40 V, I_E = 0)	C_{obo}	200	pF
Thermal Time Constant	τ(thermal)	12	ms
Thermal Resistance, Junction-to-Mounting Flange	θ_{J-MF}	2.33 max	°C/W

TYPICAL OPERATION IN POWER-SWITCHING CIRCUIT

DC Collector Supply Voltage	V_{CC}	12	V
DC Base-Bias Voltage		−8.5	V
Generator Resistance	R_G	50	Ω
On DC Collector Current	I_C	1.5	mA
Turn-On DC Base Current	I_{B1}	300	mA
Turn-Off DC Base Current	I_{B2}	−150	mA
Delay time	t_d	0.2	µs
Rise time	t_r	1	µs
Storage time	t_s	1	µs
Fall time	t_f	1.2	µs





V_{BB} = 8.5 volts
V_{CC} = 12 volts
R_1 = 50 ohms, 1 watt
R_2 = 30 ohms, 1 watt
R_3 = 7.8 ohms, 2 watts

POWER TRANSISTOR 2N1488

Si **n-p-n** diffused-junction type used in dc-to-dc converters, inverters, choppers, voltage and current regulators, dc and servo amplifiers, relay-and solenoid-actuating circuits. Similar to JEDEC TO-3, Outline No.2 (Variant 1). Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N1487 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	100	V
Base open (sustaining voltage)	V_{CEO}(sus)	55	V

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	55 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 0.5 mA)	V_{CEV}	100 min	V

2N1489 POWER TRANSISTOR

Si **n-p-n diffused-junction** type used in dc-to-dc converters, inverters, choppers, voltage and current regulators, dc and servo amplifiers, relay- and solenoid-actuating circuits. Similar to JEDEC TO-3, Outline No.2 (Variant 1). Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N1487 except for the following items:

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 1.5 A)	V_{BE}	2.5 max	V
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 1.5 A)	h_{FE}	25 to 75	
Collector-to-Emitter Saturation Resistance (I_C = 1.5 A, I_B = 100 mA)	r_{CE}(sat)	0.67 max	Ω

2N1490 POWER TRANSISTOR

Si **n-p-n diffused-junction** type used in dc-to-dc converters, inverters, choppers, voltage and current regulators, dc and servo amplifiers, relay- and solenoid-actuating circuits. Similar to JEDEC TO-3. Outline No.2 (Variant 1). Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N1487 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	100	V
Base open (sustaining voltage)	V_{CEO}(sus)	55	V

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (V_C = 100 mA, I_B = 0)	V_{CEO}(sus)	55 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 0.5 mA)	V_{CEV}	100 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 1.5 A)	V_{BE}	2.5 max	V
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 1.5 A)	h_{FE}	25 to 75	
Collector-to-Emitter Saturation Resistance (I_C = 1.5 A, I_B = 100 mA)	r_{CE}(sat)	0.67 max	Ω

2N1491 TRANSISTOR

Si **n-p-n triple-diffused** type used in vhf applications for rf-amplifier, video-amplifier, oscillator, and mixer circuits in industrial and military equipment.

JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

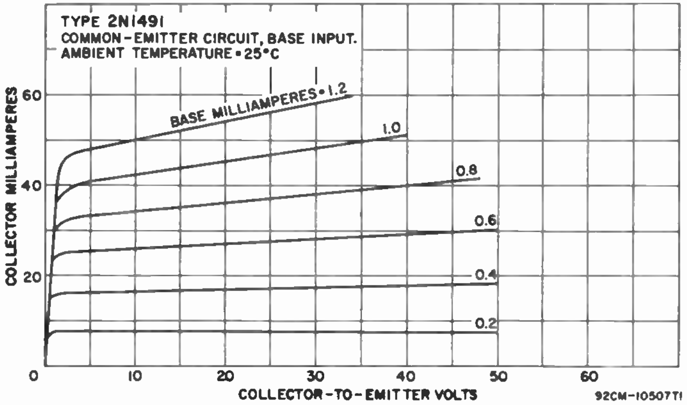
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	30	V
Collector-to-Emitter Voltage (V_{BE} = –0.5 V)	V_{CEV}	30	V
Emitter-to-Base Voltage	V_{EBO}	1	V
Collector Current	I_C	0.25	A
Emitter Current	I_E	–0.25	A
Transistor Dissipation:			
T_C up to 25°C	P_T	3	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_C) and Storage (T_{STG})		–65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

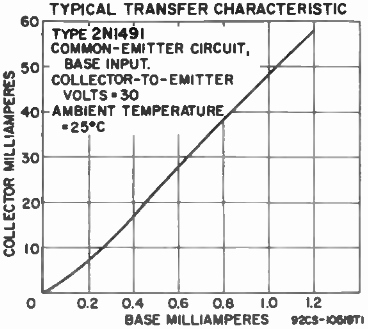
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	30 min	V
Emitter-to-Base Floating Potential (V_{CB} = 30 V, I_E = 0)	$V_{EB(fl)}$	0.5 max	V
Collector-Cutoff Current (V_{CB} = 12 V, I_E = 0)	I_{CBO}	10 max	µA
Emitter-Cutoff Current (V_{EB} = 1 V, I_C = 0)	I_{EBO}	100 max	µA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 20 V, I_C = 15 mA, f = 1 kc/s)	h_{fe}	15 to 200	
Gain-Bandwidth Product (V_{CB} = 30 V, I_C = 15 mA)	f_T	200	Mc/s
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 0.15 Mc/s)	C_{obo}	5 max	pF
Small-Signal Power Gain (V_{CC} = 15 V, I_E = –15 mA, P_{oe} = 10 mW, f = 70 Mc/s)	G_{pe}	13 min	dB
Thermal Resistance, Junction-to-Case	θ_{J-C}	50	°C/W

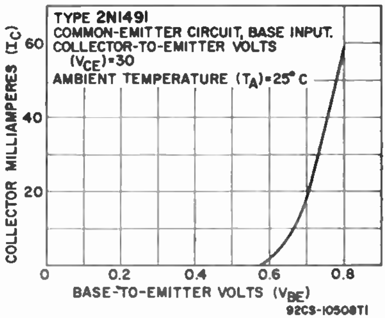
TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC



TYPICAL TRANSFER CHARACTERISTIC



2N1492 TRANSISTOR

Si n-p-n triple-diffused type used in vhf applications for rf-amplifier, video-amplifier, oscillator, and mixer circuits in industrial and military equipment. **JEDEC TO-5, Outline No.3. Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N1491 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage (V_{BE} = —0.5 V)	V_{CEV}	60	V
Emitter-to-Base Voltage	V_{EBO}	2	V

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	60 min	V
Emitter-to-Base Floating Potential (V_{CB} = 60 V, I_E = 0)	V_{EB} (fl)	0.5 max	V
Emitter-Cutoff Current (V_{EB} = 2 V, I_C = 0)	I_{EBO}	100 max	μA
Small-Signal Power Gain (V_{CC} = 30 V, I_E = —15 mA, P_{oe} = 100 mW, f = 70 Mc/s)	G_{pe}	13 min	dB

2N1493 TRANSISTOR

Si n-p-n triple-diffused type used in vhf applications for rf-amplifier, video-amplifier, oscillator, and mixer circuits in industrial and military equipment. **JEDEC TO-5, Outline No.3. Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N1491 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage (V_{BE} = —0.5 V)	V_{CEV}	100	V
Emitter-to-Base Voltage	V_{EBO}	4.5	V

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	100 min	V
Emitter-to-Base Floating Potential (V_{CB} = 100 V, I_E = 0)	V_{EB} (fl)	0.5 max	V
Emitter-Cutoff Current (V_{EB} = 4.5 V, I_C = 0)	I_{EBO}	100 max	μA
Small-Signal Power Gain (V_{CC} = 50 V, I_E = —25 mA, P_{oe} = 500 mW, f = 70 Mc/s)	G_{pe}	10 min	dB

2N1524 TRANSISTOR

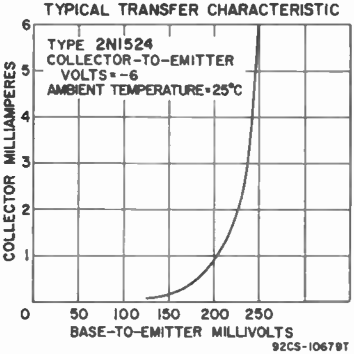
Ge p-n-p drift-field type used in 455-kilocycle if-amplifier service in battery-operated portable radio receivers and automobile radio receivers operating from either a 6-volt or a 12-volt supply. **JEDEC TO-1, Outline No.1. Terminals:** 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	—24	V
Emitter-to-Base Voltage	V_{EBO}	—0.5	V
Collector Current	I_C	—10	mA
Emitter Current	I_E	10	mA
Transistor Dissipation:			
T_A = 25°C	P_T	80	mW
T_A = 55°C	P_T	50	mW
T_A = 71°C	P_T	35	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	71	°C
Storage	T_{STG}	—65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (V_{BE} = 0.5 V, I_C = −50 µA)	$V_{(BR)CBV}$	−24 min	V
Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−16 max	µA
Emitter-Cutoff Current (V_{EB} = −0.5 V, I_C = 0)	I_{EBO}	−16 max	µA
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −12 V, I_C = −1 mA)	f_{hfb}	33 max	Mc/s
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_E = −1 mA, f = 1 kc/s)	h_{fe}	27 to 100	
Output Capacitance (V_{CB} = −12 V, I_E = 0, f = 455 kc/s)	C_{obo}	3.6 max	pF
Thermal Resistance, Junction-to-Ambient	$\theta_{J\text{-}A}$	0.4	°C/mW



TYPICAL OPERATION IN SINGLE-STAGE 455-kc/s AMPLIFIER CIRCUIT

DC Collector Supply Voltage	V_{CC}	−6	−12	V
DC Collector-to-Emitter Voltage	V_{CE}	−5.7	−11	V
Collector Current	I_C	−1	−1	mA
Input Resistance	R_{ie}	1300	1550	Ω
Output Resistance	R_{oe}	0.31	0.525	MΩ
Collector-to-Base Capacitance	C_{obo}	2.2	2	pF
Maximum Power Gain	MAG	51	54.4	dB
Useful Power Gain (Single-tuned unilateralized circuit):				
In neutralized circuit	MUG	33	33	dB
In unneutralized circuit	MUG	29.7	30.2	dB

TRANSISTOR 2N1525

Ge **p-n-p drift-field** type used in 455-kilocycle if-amplifier service in battery-operated portable radio receivers and automobile radio receivers operating from either a 6-volt or a 12-volt supply. JEDEC TO-40, **Outline** No.13. **Terminals:** 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N1524.

TRANSISTOR 2N1526

Ge **p-n-p drift-field** type used in mixer and oscillator applications in battery-operated portable radio receivers and automobile radio receivers operating from either a 6-volt or a 12-volt supply. JEDEC TO-1, **Outline** No.1. **Terminals:** 1 - emitter, 2 - base, 3 - collector. This type is identical with type 2N1524 except for the following items:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CB} = −6 V, I_E = −1 mA, f = 1 kc/s)	h_{fe}	27 to 170

TYPICAL OPERATION IN SELF-EXCITED 1.5 Mc/s CONVERTER CIRCUIT

DC Collector Supply Voltage	V_{CC}	—6	—12	V
DC Collector-to-Emitter Voltage	V_{CE}	—5	—11	V
DC Collector Current	I_C	—0.65	—0.65	mA
Input Resistance	R_{ie}	1850	2150	Ω
Output Resistance	R_{oe}	0.19	0.48	MΩ
RMS Base-to-Emitter Oscillator-Injection Voltage		100	100	mV
Conversion Power Gain:				
Maximum Available	MAG_C	44.2	48.9	dB
Useful	MUG_C	34.2	35.8	dB

2N1527

TRANSISTOR

Ge p-n-p drift-field type used in mixer and oscillator applications in battery-operated portable radio receivers and automobile radio receivers operating from either a 6-volt or a 12-volt supply. JEDEC TO-40, **Outline** No.13. **Terminals:** 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N1526.

2N1605
2N1605A

COMPUTER TRANSISTORS

Ge n-p-n alloy-junction types used in medium-speed switching applications in data-processing equipment. The n-p-n construction permits complementary operation with a matching p-n-p type such as the 2N404. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base and case, 3 - collector.

MAXIMUM RATINGS

		2N1605	*2N1605A*	
Collector-to-Base Voltage	V_{CBO}	25	40	V
Collector-to-Emitter Voltage (V_{BE} = —1 V)	V_{CEV}	24	40	V
Emitter-to-Base Voltage	V_{EBO}	12	12	V
Collector Current	I_C	100	100	mA
Emitter Current	I_E	—100	—100	mA
Transistor Dissipation:				
T_A up to 25°C	P_T	150	200	mW
T_A above 25°C	P_T	See curve page 112		
Temperature Range:				
Operating (Junction)	T_J(opr)	100	100	°C
Storage	T_{STG}	—65 to 100		°C
Lead-Soldering Temperature (10 s max)	T_L	235	235	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage:				
I_C = 0.02 mA, I_E = 0	$V_{(BR)CBO}$	25	— min	V
I_C = 0.01 mA, I_E = 0	$V_{(BR)CBO}$	—	40 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.02 mA, I_C = 0)	$V_{(BR)EBO}$	12	12 min	V
Collector-to-Emitter Saturation Voltage:				
I_C = 12 mA, I_B = 0.4 mA	V_{CE}(sat)	0.15	0.15 max	V
I_C = 24 mA, I_B = 1 mA	V_{CE}(sat)	0.2	0.2 max	V
Base-to-Emitter Voltage:				
I_C = 12 mA, I_B = 0.4 mA	V_{BE}	0.35	0.35 max	V
I_C = 24 mA, I_B = 1 mA	V_{BE}	0.4	0.4 max	V
Emitter Floating Potential (11-MΩ voltmeter between emitter and base):				
V_{CB} = 24 V	V_{EB}(fl)	1	— max	V
V_{CB} = 40 V	V_{EB}(fl)	—	1 max	V
Collector-Cutoff Current:				
V_{CB} = 12 V, I_E = 0, T_A = 25°C	I_{CBO}	5	— max	µA
V_{CB} = 12 V, I_E = 0, T_A = 80°C	I_{CBO}	125	125 max	µA
V_{CB} = 40 V, I_E = 0, T_A = 25°C	I_{CBO}	—	10 max	µA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	2.5	2.5 max	µA
Static Forward-Current Transfer Ratio:				
V_{CE} = 0.15 V, I_C = 12 mA	h_{FE}	30	30 min	
V_{CE} = 0.2 V, I_C = 24 mA	h_{FE}	24	24 min	
V_{CE} = 0.25 V, I_C = 20 mA	h_{FE}	40	40 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 6 V, I_E = 1 mA)	f_{hfb}	4	4 min	Mc/s

CHARACTERISTICS (cont'd)

		2N1605	*2N1605A*	
Total Stored Charge (V_{CC} = 5.25 V, I_C = 10 mA, I_B = 1 mA)	Q_S	1400	1400 max	pC
Output Capacitance (V_{CB} = 6 V, I_E = 1 mA, f = 2 Mc/s)	C_{obo}	20	20 max	pF

TRANSISTOR 2N1613

Si **n-p-n planar** type used in small-signal and medium-power applications in industrial and military equipment. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N2102 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	75	V
Collector-to-Emitter Voltage (R_{BE} ≦ 10 Ω)	V_{CER}	50	V
Transistor Dissipation:			
T_A up to 25°C	P_T	0.8	W
T_C up to 25°C	P_T	3	W
Lead-Soldering Temperature (10 s max)	T_L	265	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	75 min	V
Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, R_{BE} = 10 Ω, t_p = 300 μs, df = 1.8%)	V_{CER}(sus)	50 min	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p = 300 μs, df = 1.8%)	V_{CE}(sat)	1.5 max	V
Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p = 300 μs, df = 1.8%)	V_{BE}(sat)	1.3 max	V
Collector-Cutoff Current:			
V_{CB} = 60 V, I_E = 0, T_A = 25°C	I_{CBO}	0.01 max	μA
V_{CB} = 60 V, I_E = 0, T_A = 150°C	I_{CBO}	10 max	μA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	0.01 max	μA
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 0.1 mA, T_A = 25°C	h_{FE}	20 min	
V_{CE} = 10 V, I_C = 150 mA, T_A = 25°C, t_p = 300 μs, df = 1.8%	h_{FE}	40 to 120	
V_{CE} = 10 V, I_C = 10 mA, T_A = −55°C, t_p = 300 μs, df = 1.8%	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{fe}	30 to 100	
V_{CE} = 10 V, I_C = 50 mA, f = 20 Mc/s	h_{fe}	3 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0)	C_{obo}	25 max	pF
Noise Figure (V_{CE} = 10 V, I_C = 0.3 mA, f = 1 kc/s, R_G = 510 Ω, circuit bandwidth = 1 c/s)	NF	12 max	dB
Thermal Resistance, Junction-to-Case	θ_{J-C}	58.3 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	219 max	°C/W

TRANSISTOR 2N1631

Ge **p-n-p drift-field** type used in rf-amplifier applications in battery-operated AM radio receivers. JEDEC TO-40, **Outline** No.13. **Terminals:** 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−34	V
Emitter-to-Base Voltage	V_{EBO}	−0.5	V
Collector Current	I_C	−10	mA
Emitter Current	I_E	10	mA
Transistor Dissipation:			
T_A = 25°C	P_T	80	mW
T_A = 55°C	P_T	50	mW
T_A = 71°C	P_T	35	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	71	°C
Storage	T_{STG}	−65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

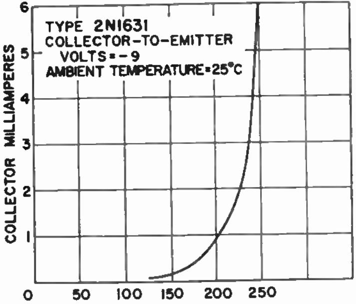
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = —50 µA, I_E = 0)	$V_{(BR)CBO}$	—34 min	V
Collector-Cutoff Current (V_{CB} = —12 V, I_E = 0)	I_{CBO}	—16 max	µA
Emitter-Cutoff Current (V_{EB} = —0.5 V, I_C = 0)	I_{EBO}	—16 max	µA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = —6 V, I_C = —1 mA, f = 1 kc/s)	h_{fe}	40 to 170	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = —12 V, I_E = 1 mA)	f_{hfb}	45	Mc/s
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	0.4 max	°C/W

TYPICAL OPERATION IN RF-AMPLIFIER CIRCUIT

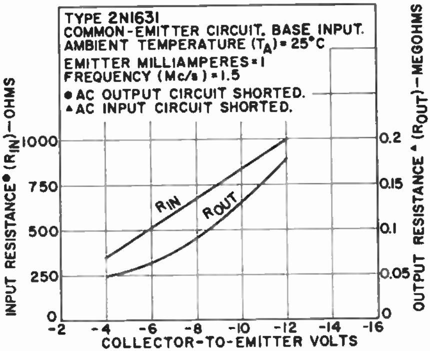
DC Collector Supply Voltage	V_{CC}	—6	—12	V
DC Collector-to-Emitter Voltage	V_{CE}	—5.7	—11	V
Emitter Current	I_E	1	1	mA
Signal-Frequency	f	1.5	1.5	Mc/s
Input Resistance	R_{ie}	520	1000	Ω
Output Resistance	R_{oe}	0.065	0.18	MΩ
Output Capacitance	C_{obo}	2.2	2	pF
Extrinsic Transconductance	g_m	36000	36000	µmhos
Maximum Power Gain	MAG	40.4	47.7	dB
Useful Power Gain (Unneutralized circuit)	MUG	25.3	25.6	dB

TYPICAL TRANSFER CHARACTERISTIC



92CS-10678T

TYPICAL INPUT AND OUTPUT CHARACTERISTICS



92CS-10561T1

2N1632 TRANSISTOR

Ge p-n-p drift-field type used in rf-amplifier applications in battery-operated AM radio receivers. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector. This type is electrically identical with type 2N1631.

2N1637 TRANSISTOR

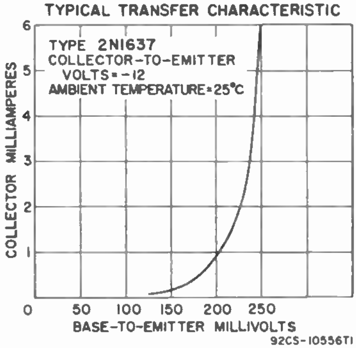
Ge p-n-p drift-field type used in rf-amplifier applications in AM automobile radio receivers. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	—34	V
Emitter-to-Base Voltage	V_{EBO}	—1.5	V
Collector Current	I_C	—10	mA
Emitter Current	I_E	10	mA
Transistor Dissipation:			
T_A = 25°C	P_T	80	mW
T_A = 55°C	P_T	50	mW
T_A = 71°C	P_T	35	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	71	°C
Storage	T_{STG}	—65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage ($I_C = -50\ \mu A$, $I_E = 0$)	$V_{(BR)CBO}$	−34 min	V
Collector-Cutoff Current ($V_{CB} = -12$ V, $I_E = 0$)	I_{CBO}	−12 max	μA
Emitter-Cutoff Current ($V_{EB} = -1.5$ V, $I_C = 0$)	I_{EBO}	−15 max	μA
Small-Signal Forward-Current Transfer Ratio ($V_{CE} = -6$ V, $I_C = -1$ mA, f = 1 kc/s)	h_{fe}	40 to 170	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = -12$ V, $I_E = 1$ mA)	f_{hfb}	45	Mc/s
Output Capacitance ($V_{CE} = -12$ V, $I_C = -1$ mA, f = 1 kc/s)	C_{obo}	2	pF
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	0.4 max	°C/W



TYPICAL OPERATION IN RF-AMPLIFIER CIRCUIT

DC Collector-to-Emitter Voltage	V_{CE}	−5.5	−11.2	V
Emitter Current	I_E	1	1	mA
Signal Frequency	f	1.5	1.5	Mc/s
Input Resistance	R_{ie}	520	1000	Ω
Output Resistance	R_{oe}	0.065	0.18	MΩ
Maximum Power Gain	MAG	40.4	47.7	dB
Useful Power Gain (Unneutralized circuit)	MUG	25.3	25.6	dB

TRANSISTOR 2N1638

Ge p-n-p drift-field type used in if-amplifier applications in AM automobile radio receivers. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector. This type is identical with type 2N1637 except for the following items:

MAXIMUM RATINGS

Emitter-to-Base Voltage	V_{EBO}	−0.5	V

CHARACTERISTICS

Collector-Cutoff Current ($V_{CB} = -12$ V, $I_C = 0$)	I_{CBO}	−12 max	μA
Emitter-Cutoff Current ($V_{EB} = -0.5$ V, $I_C = 0$)	I_{EBO}	−12 max	μA
Small-Signal Forward-Current Transfer Ratio ($V_{CE} = -6$ V, $I_C = -1$ mA, f = 1 kc/s)	h_{fe}	70 to 275	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = -12$ V, $I_E = 1$ mA)	f_{hfb}	40	Mc/s

TYPICAL OPERATION IN SINGLE-STAGE IF-AMPLIFIER CIRCUIT

DC Collector-to-Emitter Voltage	V_{CE}	−5	−11	
Emitter Current	I_E	1.6	2	mA
Signal Frequency	f	262.6	262.5	kc/s
Input Resistance	R_{ie}	1800	1400	Ω
Output Resistance	R_{oe}	0.47	0.72	MΩ
Maximum Power Gain	MAG	58.6	61.5	dB
Useful Power Gain (Unneutralized circuit)	MUG	35	36.6	dB

2N1639 TRANSISTOR

Ge **p-n-p drift-field** type used in converter, mixer, and oscillator applications in AM automobile radio receivers. JEDEC TO-1, **Outline** No.1. **Terminals:** 1 - emitter, 2 - base, 3 - collector. This type is identical with type 2N1637 except for the following items:

TYPICAL OPERATION IN SELF-EXCITEO 1.5-Mc/s CONVERTER CIRCUIT

DC Collector-to-Emitter Voltage	V_{CE}	−5	−11	V
DC Collector Current	I_C	0.65	0.65	mA
Input Resistance	R_{ie}	1850	2200	Ω
Output Resistance	R_{oe}	0.1	0.2	MΩ
RMS Base-to-Emitter Oscillator-Injection Voltage		100	100	mV
Conversion Power Gain (useful)	MUG_C	35.4	37	dB

2N1683 COMPUTER TRANSISTOR

Ge **p-n-p diffused-junction** type used in computer applications in data-processing equipment. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector. This type is identical with type 2N1300 except for the following items:

MAXIMUM RATINGS

Emitter-to-Base Voltage	V_{EBO}*	−4	V

CHARACTERISTICS

Emitter-to-Base Breakdown Voltage (I_E = −0.1 mA, I_C = 0)	$V_{(BR)EBO}$	−4 min	V
Base-to-Emitter Voltage (I_C = −40 mA, I_B = −1 mA)	V_{BE}	−0.6 max	V
Static Forward-Current Transfer Ratio:			
V_{CE} = −0.3 V, I_C = −10 mA	h_{FE}	50 min	75 typ
V_{CE} = −0.5 V, I_C = −40 mA	h_{FE}	50 min	85 typ
Gain-Bandwidth Product (V_{CE} = −3 V, I_C = −10 mA)	f_T	50 min	Mc/s
Total Stored Charge:			
I_C = −10 mA, I_B = −0.4 mA	Q_S	160 max	pC
I_C = −40 mA, I_B = −1.6 mA	Q_S	410 max	pC

* This rating may be exceeded and the emitter-to-base junction operated in the breakdown condition provided the emitter dissipation is limited to 30 milliwatts at 25°C. For ambient temperatures above 25°C, reduce the dissipation by 0.5 milliwatts per °C.

2N1700 POWER TRANSISTOR

Si **n-p-n diffused-junction** type used in power-switching circuits such as dc-to-dc converters, inverters, choppers, solenoid and relay controls; in oscillators, regulators, and pulse-amplifier circuits; and as class A and class B push-pull audio and servo amplifiers in industrial and military equipment. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. For typical operation in a power-switching circuit, refer to type 2N1479.

MAXIMUM RATINGS

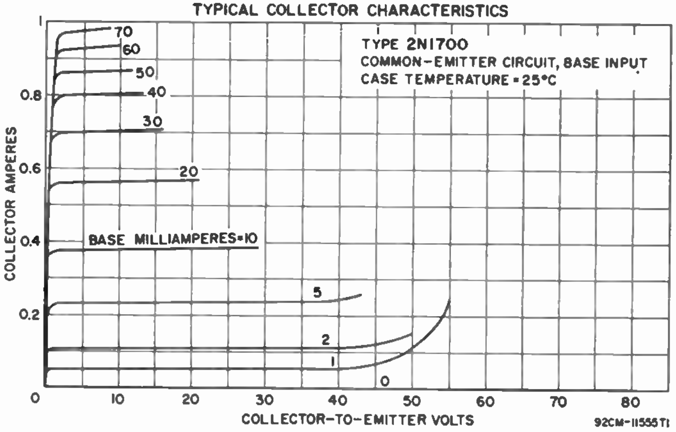
Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	60	V
Base open (sustaining voltage)	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	6	V
Collector Current	I_C	1	A
Base Current	I_B	0.75	A

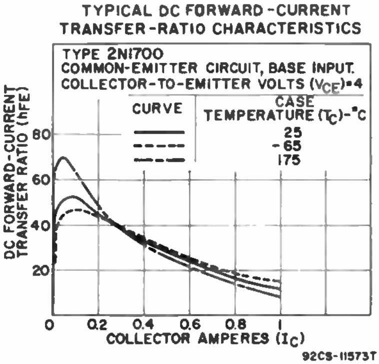
MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_C up to 25°C	P_T	5	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 50 mA, I_B = 0)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 0.5 mA)	V_{CEV}	60 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 100 mA)	V_{BE}	2 max	V
Collector-Cutoff Current:			
V_{CB} = 30 V, I_E = 0, T_C = 25°C	I_{CBO}	75 max	μA
V_{CB} = 30 V, I_E = 0, T_C = 150°C	I_{CBO}	1000 max	μA
Emitter-Cutoff Current (V_{EB} = 6 V, I_C = 0)	I_{EBO}	25 max	μA
Collector-to-Emitter Saturation Resistance (I_C = 100 mA, I_B = 10 mA)	r_{CE}(sat)	10 max	Ω
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 100 mA)	h_{FE}	20 to 80	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 5 mA, f = 1 kc/s)	h_{fe}	40	





CHARACTERISTICS (cont'd)

Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 28 V, I_C = 5 mA)	f_{hfb}	1.2	Mc/s
Output Capacitance (V_{CB} = 40 V, I_C = 0, f = 1 kc/s)	C_{obo}	150	pF
Thermal Time Constant	τ(thermal)	10	ms
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	200 max	°C/W

2N1701

POWER TRANSISTOR

Si n-p-n diffused-junction type used in power-switching applications such as dc-to-dc converter, inverter, chopper, solenoid and relay control circuits; in oscillator, regulator, and pulse-amplifier circuits; and as class A and class B push-pull audio and servo amplifiers in industrial and military equipment. JEDEC TO-8, **Outline** No.5. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

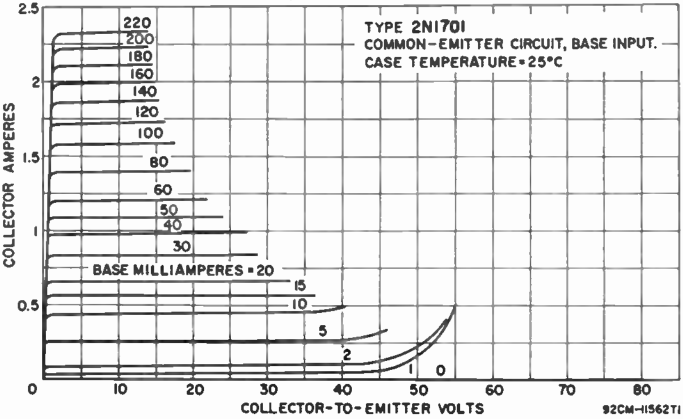
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	60	V
Base open (sustaining voltage)	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	6	V
Collector Current	I_C	2.5	A
Base Current	I_B	1	A
Transistor Dissipation:			
T_C up to 25°C	P_T	25	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	235	°C

CHARACTERISTICS

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5, I_C = 0.75 mA)	V_{CEV}	60 min	V
Collector-to-Emitter Saturation Voltage: (I_C = 2.5 A, I_B = 1 A)	V_{CE}(sat)	12.5 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 300 mA)	V_{BE}	3 max	V
Collector-Cutoff Current:			
V_{CB} = 30 V, I_E = 0, T_C = 25°C	I_{CBO}	100 max	μA
V_{CB} = 30 V, I_E = 0, T_C = 150°C	I_{CBO}	1500 max	μA
Emitter-Cutoff Current (V_{EB} = −6 V, I_C = 0)	I_{EBO}	50 max	μA
Collector-to-Emitter Saturation Resistance (I_C = 300 mA, I_B = 30 mA)	r_{CE}(sat)	5 max	Ω

TYPICAL COLLECTOR CHARACTERISTICS

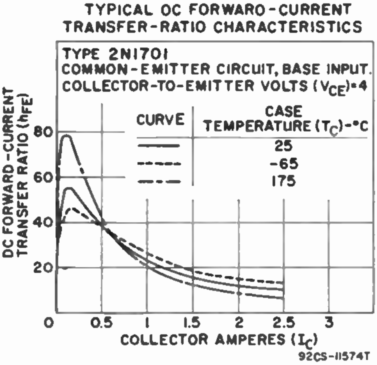


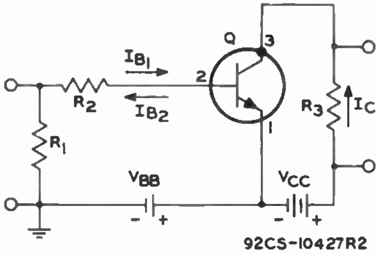
CHARACTERISTICS (cont'd)

Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 28 V, I_C = 5 mA)	f_{hfb}	1 max	Mc/s
Static Forward-Current Transfer Ratio:			
V_{CE} = 4 V, I_C = 300 mA	h_{FE}	20 to 80	
V_{CE} = 20 V, I_C = 2.5 A	h_{FE}	5 min	
Output Capacitance (V_{CB} = 40 V, I_E = 0, f = 1 kc/s)	C_{obo}	175 max	pF
Thermal Resistance, Junction-to-Case	θ_{J-C}	7 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	100 max	°C/W

TYPICAL OPERATION IN POWER-SWITCHING CIRCUIT

DC Supply Voltage	V_{CC}	12	V
DC Base-Bias Voltage		−8.5	V
Generator Resistance	R_G	50	Ω
"On" DC Collector Current	I_C	750	mA
"Turn-On" Base Current	I_{B1}	65	mA
"Turn-Off" Base Current	I_{B2}	−35	mA
Delay Time	t_d	0.2	µs
Rise Time	t_r	1	µs
Storage Time	t_s	0.8	µs
Fall Time	t_f	1.1	µs





V_{BB} = 8.5 volts
V_{CC} = 12 volts
R_1 = 50 ohms, 1 watt
R_2 = 220 ohms, 1 watt
R_3 = 15.9 ohms, 2 watts

TRANSISTOR 2N1702

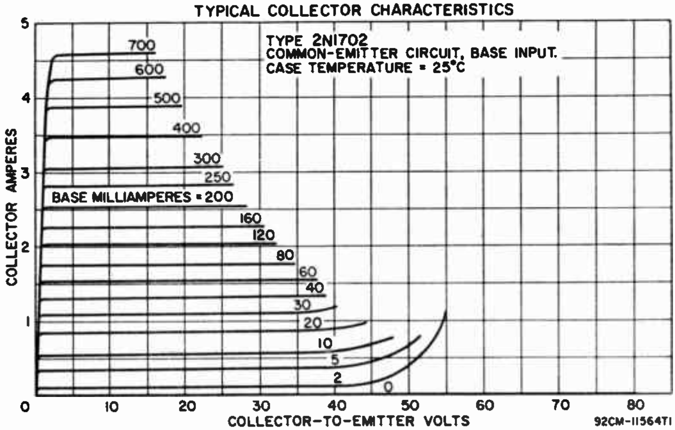
Si n-p-n diffused-junction type used in power-switching applications such as dc-to-dc converter, inverter, chopper, and relay control circuits; in voltage and current regulator circuits; and in dc and servo amplifier circuits. Similar to JEDEC TO-3, Outline No.2 (Variant 1). Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - case and collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	60	V
Base open (sustaining voltage)	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	6	V
Collector Current	I_C	5	A
Base Current	I_B	2.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	75	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C

CHARACTERISTICS

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 1 mA)	V_{CEV}	60 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 800 mA)	V_{BE}	4 max	V

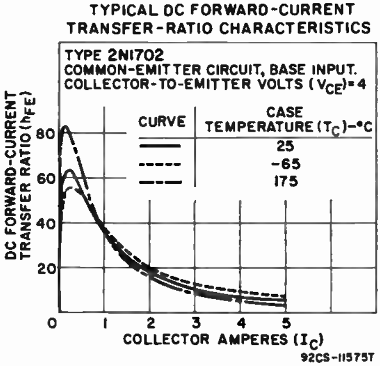


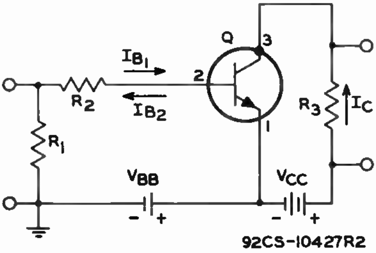
CHARACTERISTICS (cont'd)

Collector-Cutoff Current:			
V_{CB} = 30 V, I_E = 0, T_C = 25°C	I_{CBO}	200	μA
V_{CB} = 30 V, I_E = 0, T_C = 150°C	I_{CBO}	2000	μA
Emitter-Cutoff Current (V_{EB} = 6 V, I_C = 0)	I_{EBO}	100	μA
Collector-to-Emitter Saturation Resistance (I_C = 800 mA, I_B = 80 mA)	r_{CE}(sat)	4 max	Ω
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 800 mA)	h_{FE}	15 to 60	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 28 V, I_C = 5 mA)	f_{hfb}	1	Mc/s
Output Capacitance (V_{CB} = 40 V, I_E = 0)	C_{obo}	200 max	pF
Thermal Resistance, Junction-to-Case	θ_{J-C}	2.33 max	°C/W

TYPICAL OPERATION IN POWER-SWITCHING CIRCUIT

DC Supply Voltage	V_{CC}	12	V
DC Base-Bias Voltage		—8.5	V
Generator Resistance	R_G	50	Ω
"On" DC Collector Current	I_C	1.5	A
"Turn-On" Base Current	I_{B1}	0.3	A
"Turn-Off" Base Current	I_{B2}	—0.15	A
Delay Time	t_d	0.2	μs
Rise Time	t_r	1	μs
Storage Time	t_s	1	μs
Fall Time	t_f	1.2	μs





V_{BB} = 8.5 volts
V_{CC} = 12 volts
R_1 = 50 ohms, 1 watt
R_2 = 30 ohms, 1 watt
R_3 = 7.8 ohms, 2 watts

2N1708 COMPUTER TRANSISTOR

Si n-p-n double-diffused epitaxial planar type used in high-speed switching applications in military and industrial equipment where high reliability and high packaging densities are essential. JEDEC TO-46, **Outline** No.16. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is electrically identical with type 2N2205.

TRANSISTOR 2N1711

Si **n-p-n triple-diffused planar** type used in a wide variety of small-signal and medium-power applications in military and industrial equipment. It features exceptionally low noise characteristics. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

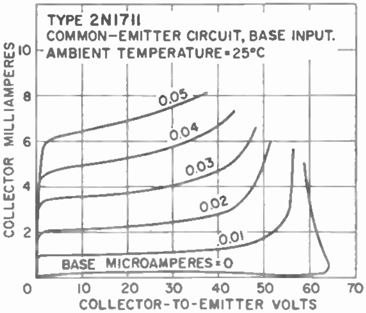
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	75	V
Collector-to-Emitter Voltage ($R_{BE} \leqq 10\ \Omega$)	V_{CER}	50	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.8	W
T_C up to 25°C	P_T	3	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C

CHARACTERISTICS (At case temperature = 25°C)

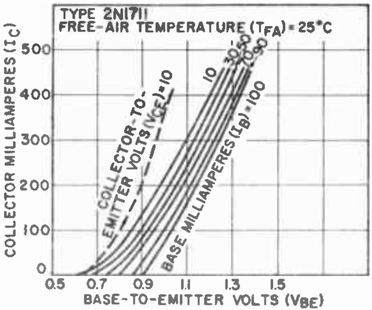
Collector-to-Base Breakdown Voltage ($I_C = 0.1$ mA, $I_E = 0$)	$V_{(BR)CBO}$	75 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.1$ mA, $I_C = 0$)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Reach-Through Voltage (V_{BE} (fl) = −1.5 V, $I_C = 0.1$ mA)	V_{RT}	75 min	V
Collector-to-Emitter Sustaining Voltage ($R_{BE} = 10\ \Omega$, $I_C = 100$ mA, $t_p = 300\ \mu s$, df = 18%)	V_{CER}(sus)	50 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 150$ mA, $I_B = 15$ mA)	V_{CE}(sat)	1.5 max	V
Base-to-Emitter Voltage Saturation Voltage ($I_C = 150$ mA, $I_B = 15$ mA)	V_{BE}(sat)	1.3 max	V
Collector-Cutoff Current:			
$V_{CB} = 60$ V, $I_E = 0$, $T_A = 25°C$	I_{CBO}	0.01 max	µA
$V_{CB} = 60$ V, $I_E = 0$, $T_A = 150°C$	I_{CBO}	10 max	µA
Emitter-Cutoff Current ($V_{EB} = 5$ V, $I_C = 0$)	I_{EBO}	0.005 max	µA
Pulsed Static Forward-Current Transfer Ratio:			
$V_{CE} = 10$ V, $I_C = 10$ mA, $t_p = 300\ \mu s$, df = 1.8%	h_{FE}(pulsed)	75min	
$V_{CE} = 10$ V, $I_C = 500$ mA, $t_p = 300\ \mu s$, df = 1.8%	h_{FE}(pulsed)	40 min	
Static Forward-Current Transfer Ratio:			
$V_{CE} = 10$ V, $I_C = 0.01$ mA, $T_C = 25°C$	h_{FE}	20 min	
$V_{CE} = 10$ V, $I_C = 10$ mA, $T_C = -55°C$	h_{FE}	35 min	
Small-Signal Forward-Current Transfer Ratio:			
$V_{CE} = 10$ V, $I_C = 5$ mA, f = 1 kc/s	h_{fe}	70 to 300	
$V_{CE} = 10$ V, $I_C = 50$ mA, f = 20 Mc/s	h_{fe}	3.5 min	

TYPICAL COLLECTOR CHARACTERISTICS



92CS-11630T

TYPICAL TRANSFER CHARACTERISTICS



92CS-11685T1

CHARACTERISTICS (cont'd)

Input Capacitance (V_{EB} = 0.5 V, I_C = 0)	C_{ibo}	80 max	pF
Output Capacitance (V_{CB} = 10 V, I_E = 0)	C_{obo}	25 max	pF
Noise Figure (V_{CE} = 10 V, I_C = 0.3 mA, R_G = 50Ω, f = 1 kc/s, circuit bandwidth = 1 c/s)	NF	8 max	dB
Input Resistance (V_{CB} = 10 V, I_C = 5 mA, f = 1 kc/s)	h_{ib}	4 to 8	Ω
Voltage-Feedback Ratio (V_{CB} = 10 V, I_C = 5 mA, f = 1 kc/s)	h_{rb}	5×10^{-4} max	
Output Conductance (V_{CB} = 10 V, I_C = 5 mA, f = 1 kc/s)	h_{ob}	0.1 to 1	µmho
Thermal Resistance, Junction-to-Case	Θ_{J-C}	58.3 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	219 max	°C/W

2N1853 COMPUTER TRANSISTOR

Ge **p-n-p diffused-junction** type used in switching applications in military and commercial data-processing equipment. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−18	V
Collector-to-Emitter Voltage	V_{CEO}	−6	V
Emitter-to-Base Voltage*	V_{EBO}	−2	V
Collector Current	I_C	−100	A
Transistor Dissipation:†			
T_A up to 25°C	P_T	150	mW
T_A above 25°C	P_T	See curve page 112	
Emitter-to-Base Dissipation (Under breakdown conditions with reverse bias)	P_T	25	mW
Ambient-Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	235	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −0.025 mA, I_E = 0)	$V_{(BR)CBO}$	−18 min	V
Collector-to-Emitter Breakdown Voltage (V_{BE} = 0.15 V, I_C = −0.025 mA)	$V_{(BR)CEV}$	−18 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.1 mA, I_C = 0)	$V_{(BR)EBO}$	−2 min	V
Collector-to-Emitter Saturation Voltage (I_C = −6 mA, I_B = −0.2 mA)	V_{CE}(sat)	−0.2 max	V
Base-to-Emitter Voltage (I_C = −6 mA, I_B = −0.2 mA)	V_{BE}	−0.4 max	V
Collector-Cutoff Current:			
V_{CB} = −15 V, I_E = 0, T_A = 25°C	I_{CBO}	−4.2 max	µA
V_{CB} = −18 V, I_E = 0, T_A = 60°C	I_{CBO}	−35 max	µA
Emitter-Cutoff Current (V_{EB} = −2 V, I_C = 0)	I_{EBO}	−100 max	µA
Static Forward-Current Transfer Ratio:			
V_{CE} = −1 V, I_B = −0.2 mA	h_{FE}	30 to 400	
V_{CE} = −0.4 V, I_C = −6 mA	h_{FE}	30 min	
Turn-On Time■ (V_{CC} = −15 V, R_G = 100 Ω)	$t_d + t_r$	0.8 max	µs
Storage Time■ (V_{CC} = −15 V, R_G = 100 Ω)	t_s	0.8 max	µs
Turn-Off Time■ (V_{CC} = −15 V, R_G = 100 Ω)	$t_s + t_f$	0.9 max	µs

* This rating may be exceeded and the emitter-to-base junction operated in the breakdown condition provided the emitter-to-base dissipation is limited to 25 milliwatts at 25°C. For ambient temperatures above 25°C, reduce the dissipation.

† For higher dissipation values in switching applications under transient operating conditions, the maximum dissipation can be computed by utilization of the method described in RCA Application Note "Transistor Dissipation Ratings for Pulse and Switching Service" (AN-181).

■ This characteristic applies only to type 2N1853.

2N1854 COMPUTER TRANSISTOR

Ge **p-n-p diffused-junction** type used in switching applications in military and commercial data-processing equipment. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector. This type is identical with type 2N1853 except for the following items:

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage (V_{BE} = 0.2 V, I_C = −0.025 mA)	$V_{(BR)CEV}$	−18 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = −20 mA, I_B = −0.66 mA	$V_{CE}(sat)$	−0.25 max	V
I_C = −80 mA, I_B = −2.7 mA	$V_{CE}(sat)$	−0.7 max	V
Base-to-Emitter Voltage (I_C = −20 mA, I_B = −0.5 mA)	V_{BE}	−0.8 max	V
Collector-to-Emitter Latching Voltage (V_{CC} = −18 V, R_{BE} = 1 kΩ, R_L = 178 Ω)	V_{CERL}	−17 min	V
Collector-Cutoff Current: V_{CB} = −15 V, I_E = 0, T_A = 65°C	I_{CBO}	−40 max	µA
Static Forward-Current Transfer Ratio:			
V_{CE} = −1 V, I_C = −50 mA	h_{FE}	400 max	
V_{CE} = −0.5 V, I_C = −20 mA	h_{FE}	40 min	
Gain-Bandwidth Product (V_{CE} = −1 V, I_C = −10 mA, h_{fe} = 5)	f_T	40 min	Mc/s
Output Capacitance (V_{CB} = −10 V, I_E = 0, f = 140 kc/s)	C_{obo}	12 max	pF
Charge Storage Time (I_C = −80 mA, I_{B1} = −4.5 mA, V_{CC} = −15 V, R_L = 189 Ω)	t_{Qs}	80 max	ns

TRANSISTOR 2N1893

Si n-p-n triple-diffused planar type used in small-signal and medium-power applications in industrial and military equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N2405 except for the following items:

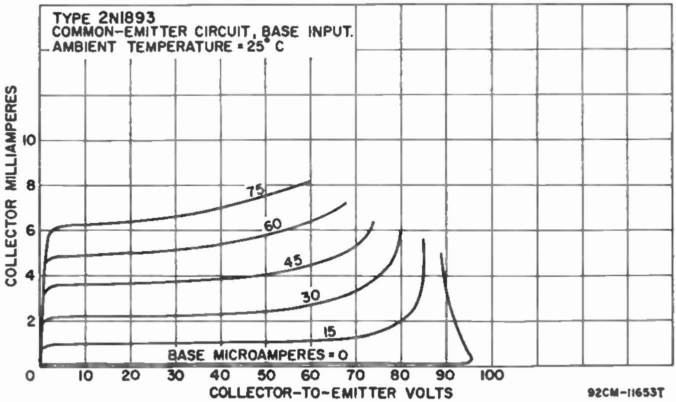
MAXIMUM RATINGS

Collector-to-Emitter Voltage:			
R_{BE} ≦ 10 Ω	V_{CER}	100	V
Base open	V_{CEO}	80	V
Collector Current	I_C	0.5	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.8	W
T_C up to 25°C	P_T	3	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	$T_J(opr)$	−65 to 200	°C
Storage	T_{STG}	−65 to 300	°C

CHARACTERISTICS

Collector-to-Emitter Sustaining Voltage:			
I_C = 30 mA, I_B = 0, t_p = 300 µs, df = 1.8%	$V_{CEO}(sus)$	80 min	V
I_C = 100 mA, R_{BE} = 10 Ω, t_p = 300 µs, df = 1.8%	$V_{CER}(sus)$	100 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = 150 mA, I_B = 15 mA	$V_{CE}(sat)$	5 max	V
I_C = 50 mA, I_B = 5 mA	$V_{CE}(sat)$	1.2 max	V

TYPICAL COLLECTOR CHARACTERISTICS



CHARACTERISTICS (cont'd)

Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA)	V_{BE}(sat)	1.3 max	V
Collector-Cutoff Current (V_{CB} = 90 V, I_E = 0, T_C = 150°C)	I_{CBO}	15 max	µA
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{fe}	30 to 100	
V_{CE} = 10 V, I_C = 50 mA, f = 20 Mc/s	h_{fe}	2.5 min	
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 0.1 mA)	h_{FE}	20 min	
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 150 mA, t_p = 300 µs, df = 1.8%)	h_{FE} (pulsed)	40 to 120	
Gain-Bandwidth Product	f_T	50 min	Mc/s
Input Capacitance (V_{EB} = 0.5 V, I_C = 0)	C_{ibo}	85 max	pF
Input Resistance (V_{CB} = 5 V, I_C = 1 mA, f = 1 kc/s)	h_{ib}	20 to 30	Ω
Voltage-Feedback Ratio:			
V_{CB} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{rb}	1.25 x 10^{-4} max	
V_{CB} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{rb}	1.5 x 10^{-4} max	
Thermal Resistance, Junction-to-Case	Θ_{J-C}	58.3 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	219 max	°C/W

2N1905

POWER TRANSISTOR

Ge p-n-p drift-field type intended for use in power-switching circuits, dc-to-dc converters, inverters, ultrasonic oscillators, and large-signal wide-band linear amplifiers. Similar to JEDEC TO-3, Outline No.2 (Variant 2). Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

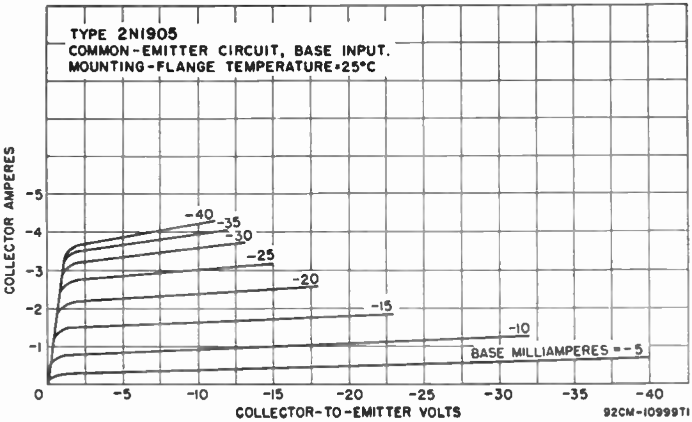
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−100	V
Collector-to-Emitter Voltage	V_{CEO}	−50	V
Emitter-to-Base Voltage	V_{EBO}	−1.5	V
Collector Current	I_C	−6	A
Emitter Current	I_E	6	A
Base Current	I_B	−1	A
Transistor Dissipation:			
T_{MF} up to 55°C	P_T	30	W
T_{MF} above 55°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 100	°C
Storage	T_{STG}	−65 to 100	°C
Pin-Soldering Temperature (10 s max)	T_P	255	°C

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = −100 mA, I_B = 0)	V_{CEO}(sus)	−50 min	V

TYPICAL COLLECTOR CHARACTERISTICS



CHARACTERISTICS (cont'd)

Collector-to-Emitter Saturation Voltage (I_C = –5 A, I_B = 0.25 A)	V_{CE}(sat)	–1 max	V
Base-to-Emitter Voltage (V_{CE} = –2 V, I_C = –1 A)	V_{BE}	–0.5 max	V
Collector-Cutoff Current:			
V_{CB} = –100 V, V_{BE}(fl) = 1 V	I_{CBO}	–10 max	mA
V_{CE} = –40 V, V_{BE} = –1 V, T_{MF} = 55°C	I_{CEV}	–3 max	mA
V_{CE} = –40 V, I_B = 0	I_{CEO}	–75 max	mA
Emitter-Cutoff Current (V_{EB} = –1.5 V, I_C = 0)	I_{EBO}	–2.5 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = –2 V, I_C = –5 A	h_{FE}	30 min	
V_{CE} = –2 V, I_C = –1 A	h_{FE}	50 to 150	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = –5 V, I_C = –0.5 A, f = 1 kc/s	h_{fe}	30 to 200	
V_{CE} = –5 V, I_C = –0.5 A, f = 1 Mc/s	h_{fe}	2 min	

POWER TRANSISTOR 2N1906

Ge p-n-p drift-field type used in power-switching circuits, dc-to-dc converters, inverters, ultrasonic oscillators, and large-signal wide-band linear amplifiers. Similar to JEDEC TO-3, Outline No.2 (variant 2). Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N1905 except for the following items:

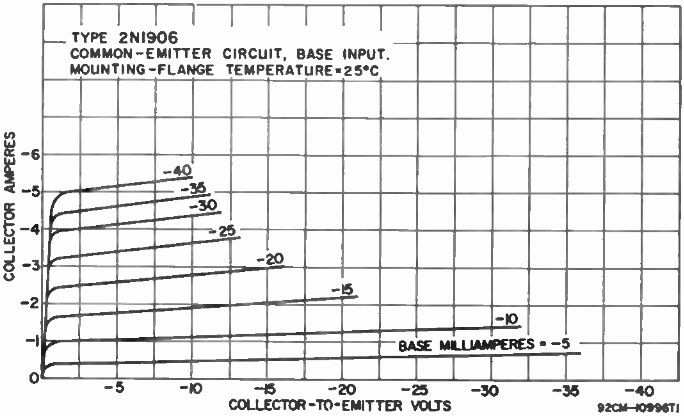
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	–130	V
Collector-to-Emitter Voltage	V_{CEO}	–60	V

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = –100 mA, I_B = 0)	V_{CEO}(sus)	–60 min	V
Collector-to-Emitter Saturation Voltage (I_C = –5 A, I_B = –0.25 A)	V_{CE}(sat)	–0.5 max	V
Collector-Cutoff Current (V_{CB} = –130 V, V_{BE}(fl) = 1 V)	I_{CBO}	–10 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = –2 V, I_C = –5 A	h_{FE}	75 max	
V_{CE} = –2 V, I_C = –1 A	h_{FE}	75 to 250	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = –5 V, I_C = –0.5 A, f = 1 kc/s	h_{fe}	50 to 300	
V_{CE} = –5 V, I_C = –0.5 A, f = 1 Mc/s	h_{fe}	3 min	

TYPICAL COLLECTOR CHARACTERISTICS

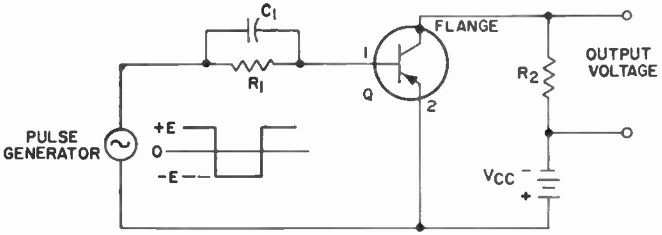


TYPICAL OPERATION IN POWER-SWITCHING CIRCUIT
(At mounting-flange temperature = 25°C)

DC Collector-Supply Voltage	V_{CC}	5	12.5	12.5	V
On DC Collector Current	I_C	–1	–2.5	–5	A
Turn-On DC Base Current	I_{B1}	—	–0.25	–0.25	A

TYPICAL OPERATION (cont'd)

Turn-Off DC Base Current	I_{B2}	—	0.25	0.25	A
Pulse-Generator Open-Circuit Voltage	E	2	—	—	V
Base-Bias Resistor	R_1	75	5	5	Ω
Speed-Up Capacitor	C_1	0.1	—	—	μF
Load Resistor	R_2	5	5	2.5	Ω
Generator Impedance	R_G	5	5	5	Ω
Delay Time	t_d	0.1	0.1	0.1	μs
Rise Time	t_r	0.1	0.4	0.9	μs
Storage Time	t_s	1	7	7	μs
Fall Time	t_f	0.6	1	2	μs



92CS-11009R2

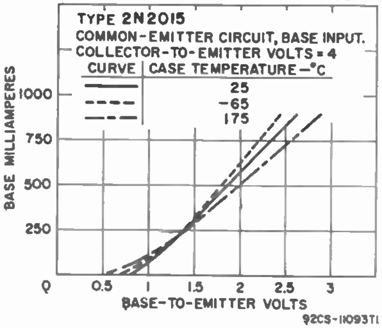
POWER TRANSISTOR 2N2015

Si n-p-n diffused-junction type used in dc-to-dc converter, inverter, chopper, relay-control, oscillator, regulator, pulse-amplifier circuits; and class A and class B push-pull amplifiers for af and servo amplifier applications. JEDEC TO-36, Outline No.11. **Terminals:** Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case.

MAXIMUM RATINGS

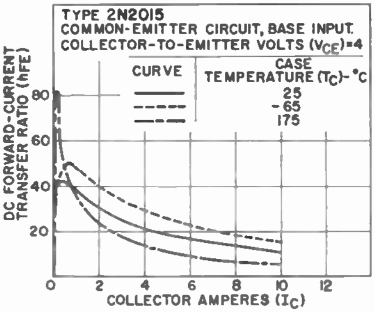
Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage	V_{CEO}	50	V
Emitter-to-Base Voltage	V_{EBO}	10	V
Collector Current	I_C	10	A
Emitter Current	I_E	−13	A
Base Current	I_B	6	A
Transistor Dissipation:			
T_C up to 25°C	P_T	150	W
T_C above 25°C	P_T	See curve page 112	
Case-Temperature Range:			
Operating (T_C) and Storage (T_{STG})		−65 to 200	°C
Lug-Soldering Temperature (10 s max)	T(lug)	235	°C

TYPICAL BASE CHARACTERISTICS



92CS-11093T1

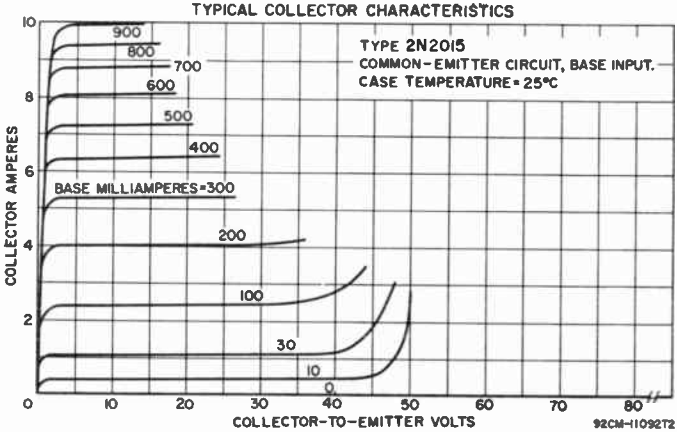
TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



92CS-11090T1

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 2 mA)	V_{CEV}	100 min	V
Collector-to-Emitter Sustaining Voltage (I_C = 200 mA, I_B = 0)	V_{CEO}(sus)	50 min	V
Collector-to-Emitter Voltage (I_C = 5 A, I_B = 0.5 A)	V_{CE}(sat)	1.25 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 5 A)	V_{BE}	2.2 max	V
Collector-Cutoff Current:			
V_{CE} = 40 V, I_B = 0	I_{CEO}	0.2 max	mA
V_{CE} = 100 V, V_{BE} = −1.5 V	I_{CEV}	2 max	mA
V_{CE} = 30 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	2 max	mA
Emitter-Cutoff Current (V_{EB} = 10 V, I_C = 0)	I_{EBO}	0.05 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = 4 V, I_C = 5 A	h_{FE}	15 to 50	
V_{CE} = 4 V, I_C = 9 A	h_{FE}	8 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 1 A, f = 1 kc/s)	h_{fe}	12 to 60	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = 4 V, I_C = 5 A)	f_{hfe}	12 min	kc/s
Collector-to-Emitter Saturation Resistance (I_C = 5 A, I_B = 0.5 A)	r_{CE}(sat)	0.25 max	Ω
Output Capacitance (V_{CB} = 40 V, I_C = 50 μA, f = 1 Mc/s)	C_{obo}	400 max	pF
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.17 max	°C/W



POWER TRANSISTOR 2N2016

Si n-p-n diffused-junction type used in dc-to-dc converter, inverter, chopper, relay-control, oscillator, regulator, and pulse-amplifier circuits; and class A and class B push-pull amplifiers for af and servo amplifier applications. JEDEC TO-36, Outline No.11. Terminals: Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case. This type is identical with type 2N2015 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	130	V
Collector-to-Emitter Voltage	V_{CEO}	65	V

CHARACTERISTICS

Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 2 mA)	V_{CEV}	130 min	V
Collector-to-Emitter Sustaining Voltage (I_C = 200 mA, I_B = 0)	V_{CEO}(sus)	65 min	V
Collector-Cutoff Current (V_{CB} = 130 V, V_{BE} = −1.5 V)	I_{CEV}	2 max	mA

2N2102 TRANSISTOR

Si n-p-n triple-diffused planar type used in small-signal and medium-power applications in industrial and military equipment. This type features exceptionally low-noise low-leakage characteristics, high switching speed, and high pulse h_{FE}. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

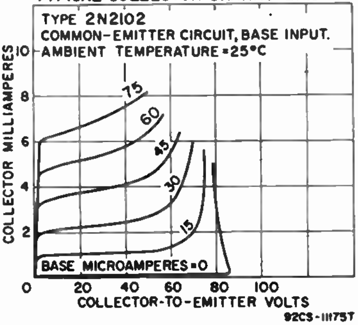
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	120	V
Collector-to-Emitter Voltage:			
$R_{BE} \leqq 10\ \Omega$	V_{CER}	80	V
Base open	V_{CEO}	65	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J (opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 300	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C

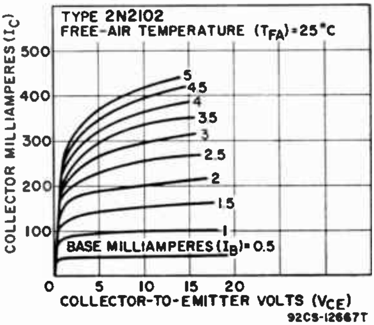
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	120 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 100 mA, R_{BE} = 10 Ω, t_p = 300 μs, df = 1.8%	V_{CER}(sus)	80 min	V
I_C = 100 mA, I_B = 0, t_p = 300 μs, df = 1.8%	V_{CEO}(sus)	65 min	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p = 300 μs, df = 1.8%)	V_{CE}(sat)	0.5 max	V
Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p = 300 μs, df = 1.8%)	V_{BE}(sat)	1.1 max	V
Collector-Cutoff Current:			
V_{CB} = 60 V, I_E = 0, T_A = 25°C	I_{CBO}	0.002 max	μA
V_{CB} = 60 V, I_E = 0, T_A = 150°C	I_{CBO}	2 max	μA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	0.005 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 0.01 mA, T_C = 25°C)	h_{FE}	10* min	
Pulsed Static Forward-Current Transfer Ratio			
V_{CE} = 10 V, I_C = 150 mA, T_C = 25°C, t_p = 300 μs, df = 1.8%	h_{FE}(pulsed)	40 to 120	
V_{CE} = 10 V, I_C = 1 A, T_C = 25°C, t_p = 300 μs, df = 1.8%	h_{FE}(pulsed)	10* min	
V_{CE} = 10 V, I_C = 10 mA, T_C = −55°C, t_p = 300 μs, df = 1.8%	h_{FE}(pulsed)	20 min	
Small-Signal Forward-Current Transfer Ratio:			
V_{CB} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{fe}	40 to 125	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{fe}	45 to 190	
V_{CE} = 10 V, I_C = 50 mA, f = 20 Mc/s	h_{fe}	6 min	

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL COLLECTOR CHARACTERISTICS

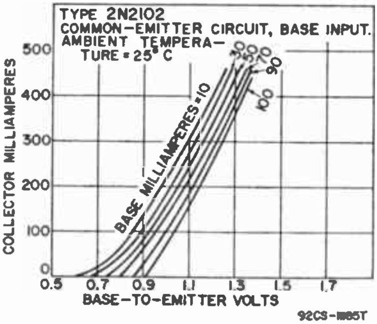


CHARACTERISTICS (cont'd)

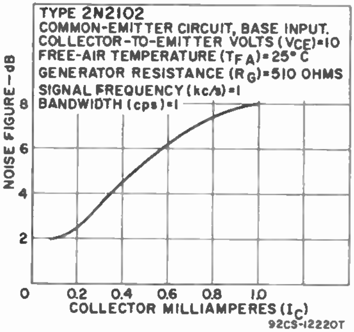
Input Capacitance (V_{EB} = 0.5 V, I_C = 0)	C_{ibo}	80 max	pF
Output Capacitance (V_{CB} = 10 V, I_C = 0)	C_{obo}	15 max	pF
Input Resistance:			
V_{CB} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{ib}	24 to 34	Ω
V_{CB} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{ib}	4 to 8	Ω
Small-Signal Reverse-Voltage (Feedback) Transfer Ratio:			
V_{CB} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{rb}	3 x 10^{-4} max	
V_{CB} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{rb}	3 x 10^{-4} max	
Output Conductance:			
V_{CB} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{ob}	0.1 to 0.5	μmho
V_{CB} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{ob}	0.1 to 1	μmho
Noise Figure (V_{CE} = 10 V, I_C = 0.3 mA, f = 1 kc/s, R_G = 510 Ω, circuit bandwidth = 1 c/s)	NF	6 max	dB
Thermal Resistance, Junction-to-Case	Θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	175 max	°C/W

* This value applies only to type 2N2102.

TYPICAL TRANSFER CHARACTERISTICS



TYPICAL NOISE-FIGURE CHARACTERISTIC



POWER TRANSISTOR 2N2147

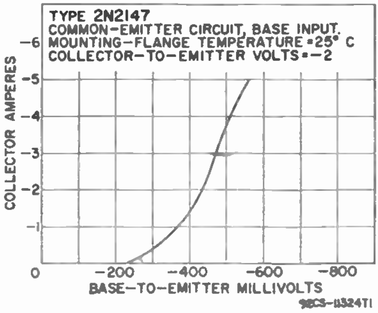
Ge p-n-p drift-field type used in high-fidelity amplifiers where wide frequency range and low distortion are required. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

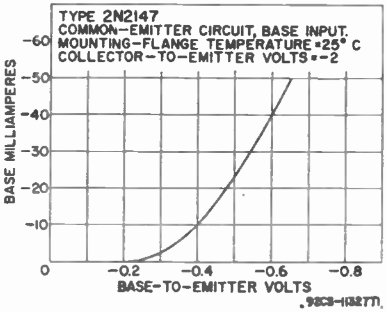
Collector-to-Base Voltage	V_{CBO}	−75	V
Collector-to-Emitter Voltage	V_{CEO}	−50	V
Emitter-to-Base Voltage*	V_{EBO}	−1.5	V

* This rating may be exceeded provided the combined dissipation in the emitter and collector does not exceed the maximum dissipation rating for the device.

TYPICAL TRANSFER CHARACTERISTIC



TYPICAL BASE CHARACTERISTIC

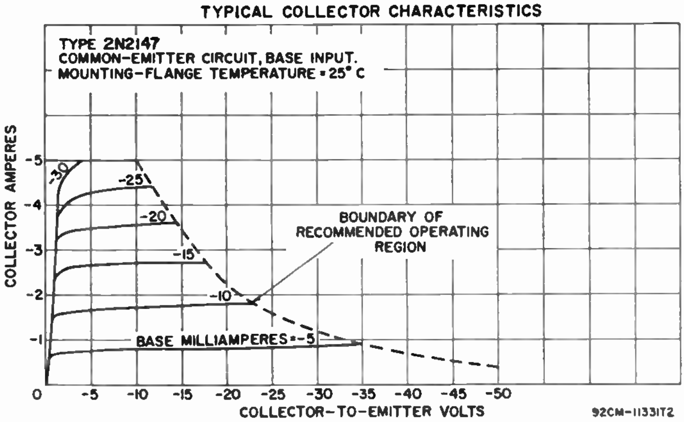


MAXIMUM RATINGS (cont'd)

Collector Current	I_C	−5	A
Emitter Current	I_E	5	A
Base Current	I_B	−1	A
Transistor Dissipation:			
T_{MF} up to 81°C	P_T	12.5	W
T_{MF} above 81°C	P_T	Derate linearly 0.66	W/°C
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 100	°C
Storage	T_{STG}	−65 to 100	°C
Pin-Soldering Temperature (10 s max)	T_P	255	°C

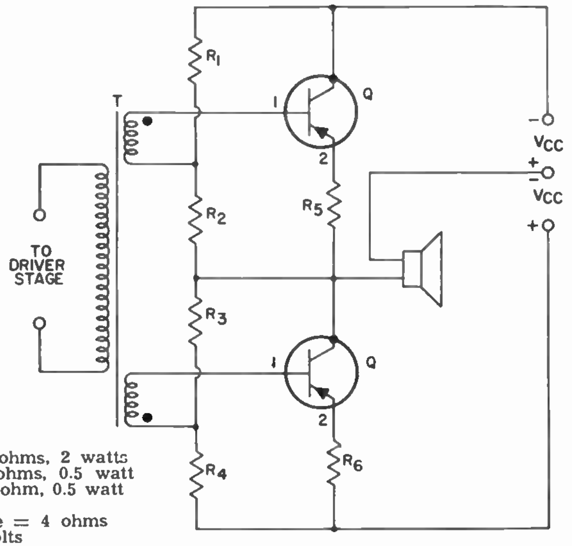
CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = −10 mA, I_E = 0)	$V_{(BR)CBO}$	−75 min	V
Collector-to-Emitter Breakdown Voltage (I_C = −100 mA, I_B = 0)	$V_{(BR)CEO}$	−50 min	V
Base-to-Emitter Voltage (V_{CE} = −10 V, I_C = −50 mA)	V_{BE}	−0.24	V
Collector-Cutoff Current (V_{CB} = −40 V, I_E = 0)	I_{CBO}	−1 max	mA
Collector-Cutoff Saturation Current (V_{CB} = −0.5 V, I_E = 0)	I_{CBO}(sat)	−70 max	µA
Emitter-Cutoff Current (V_{EB} = −1.5 V, I_C = 0)	I_{EBO}	−2.5 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = −1 V, I_C = −1 A)	h_{FE}	100 min	
Gain-Bandwidth Product (V_{CE} = −5 V, I_C = −500 mA)	f_T	4	Mc/s
Thermal Resistance, Junction-to-Mounting Flange	Θ_{J-MF}	1.5 max	°C/W



TYPICAL OPERATION IN "SINGLE-ENDED PUSH-PULL" CLASS B AF-AMPLIFIER CIRCUIT (At mounting-flange temperature = 25°C)

DC Collector Supply Voltage	V_{CC}	−22	V
Zero-Signal DC Collector Current	I_C	−0.05	A
Zero-Signal Base-Bias Voltage		−0.24	V
Peak Collector Current	i_C(peak)	−3.5	A
Maximum-Signal DC Collector Current	I_C(max)	−1.1	A
Input Impedance of Stage (per base)		75	Ω
Load Impedance (speaker voice-coil)	R_L	4	Ω
Maximum Collector Dissipation (per transistor) under worst-case conditions		12.5	W
EIA Music Power Output Rating		45	W
Power Gain		33	dB
Maximum-Signal Power Output	P_{OE}	25	W
Total Harmonic Distortion at Maximum-Signal Power Output		5	%



R₁, R₃ = 330 ohms, 2 watts
R₂, R₄ = 3.9 ohms, 0.5 watt
R₅, R₆ = 0.27 ohm, 0.5 watt
Voice coil
impedance = 4 ohms
V_{CC} = 22 volts

92CS-11332R2

POWER TRANSISTOR 2N2148

Ge p-n-p drift-field type used in high-fidelity amplifiers where wide frequency range and low distortion are required. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N2147 except for the following items:

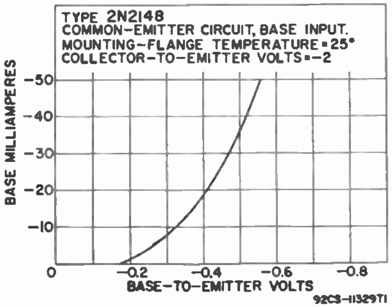
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	—60	V
Collector-to-Emitter Voltage	V_{CEO}	—40	V

CHARACTERISTICS (At mounting-flange temperature = 25°C)

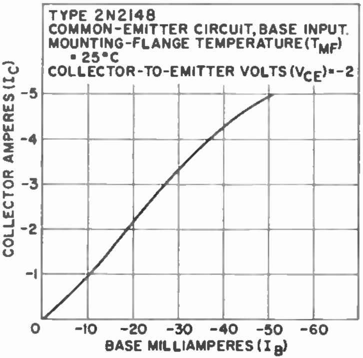
Collector-to-Base Breakdown Voltage (I_C = —10 mA, I_E = 0)	$V_{(BR)CBO}$	—60 min	V
Collector-to-Emitter Breakdown Voltage (I_C = —100 mA, I_B = 0)	$V_{(BR)CEO}$	—40 min	V
Emitter-to-Base Breakdown Voltage (I_E = —5 mA, I_C = 0)	$V_{(BR)EBO}$	—1 min	V

TYPICAL BASE CHARACTERISTIC

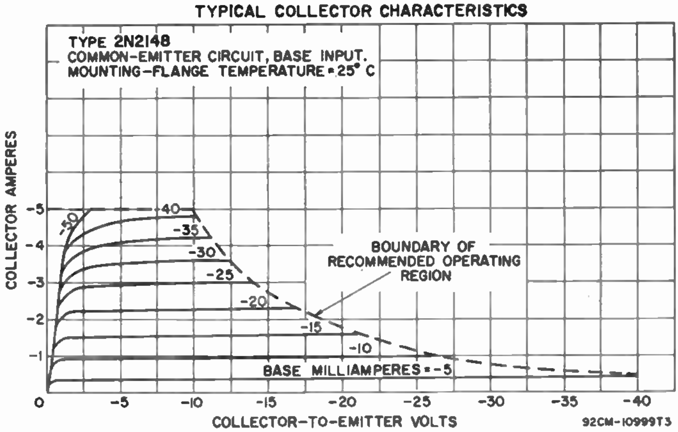


92CS-11329T1

TYPICAL TRANSFER CHARACTERISTIC



92CS-10993T1

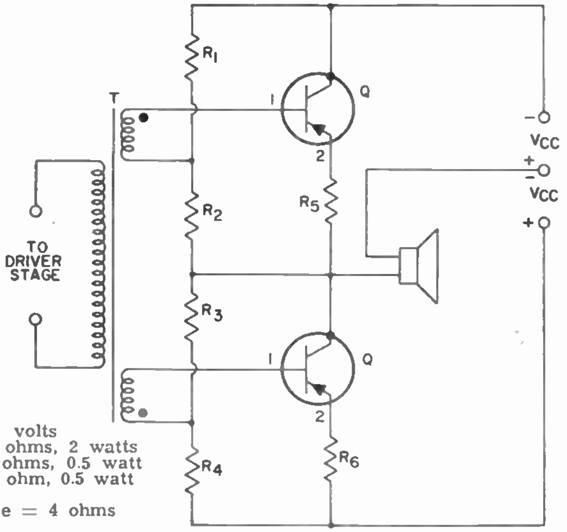


CHARACTERISTICS (cont'd)

Base-to-Emitter Voltage (V_{CE} = —10 V, I_C = —50 mA)	V_{BE}	—0.26	V
Collector-Cutoff Saturation Current (V_{CB} = —0.5 V, I_E = 0)	I_{CBO}(sat)	—100 max	µA
Emitter-Cutoff Current (V_{EB} = —1.5 V, I_C = 0)	I_{EBO}	—10 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = —1 V, I_C = —1 A)	h_{FE}	60 min	
Gain-Bandwidth Product (V_{CE} = —5 V, I_C = —500 mA)	f_T	3 typ	Mc/s

TYPICAL OPERATION IN "SINGLE-ENDED PUSH-PULL" CLASS B AF-AMPLIFIER CIRCUIT (At mounting-flange temperature = 25°C)

DC Collector Supply Voltage	V_{CC}	—16.5	V
Zero-Signal DC Collector Current	I_C	—0.05	A
Zero-Signal Base-Bias Voltage		—0.26	V
Peak Collector Current	i_C(peak)	—2.7	A



V_{CC} = 16.5 volts
R_1, R_3 = 270 ohms, 2 watts
R_2, R_4 = 3.9 ohms, 0.5 watt
R_5, R_6 = 0.39 ohm, 0.5 watt
Voice coil impedance = 4 ohms

TYPICAL OPERATION (cont'd)

Maximum-Signal DC Collector Current	I_C(max)	—0.85	A
Input Impedance of Stage (per base)		65	Ω
Load Impedance (speaker voice-coil)	R_L	4	Ω
Maximum Collector Dissipation (per transistor) under worst-case conditions		7.5	W
EIA Music Power Output Rating		25	W
Power Gain		31	dB
Maximum-Signal Power Output	P_{OE}	15	W
Total Harmonic Distortion at Maximum-Signal Power Output		5	%

COMPUTER TRANSISTOR 2N2205

Si n-p-n double-diffused epitaxial planar type used in high-speed switching applications in military and industrial equipment where high reliability and high packaging densities are essential. JEDEC TO-18, Outline No.9. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

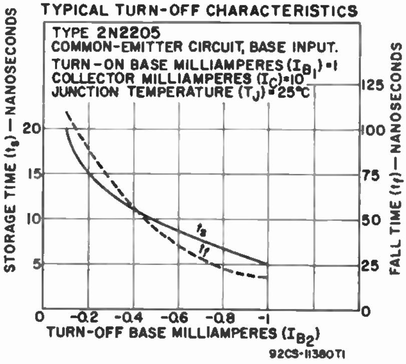
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	25	V
Collector-to-Emitter Latching Voltage (R_{BE} = 1000 Ω, R_L = 100 Ω)	V_{CERL}	20	V
Collector-to-Emitter Voltage	V_{CEO}	12	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.3	W
T_C up to 25°C	P_T	1	W
T_A or T_C above 25°C	P_T	See curve page	112
Temperature Range:			
Operating (T_A or T_C)		—65 to 175	°C
Storage	T_{STG}	—65 to 300	°C
Lead-Soldering Temperature (10 s max)	T_L	235	°C

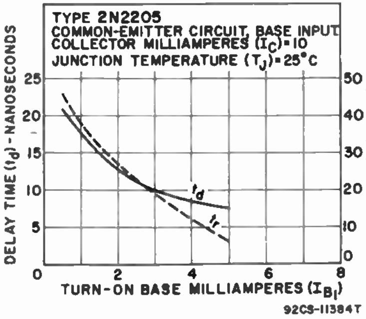
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	25 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = 10 mA, I_B = 1 mA	V_{CE}(sat)	0.22 max	V
I_C = 50 mA, I_B = 5 mA	V_{CE}(sat)	0.35 max	V
Base-to-Emitter Saturation Voltage (I_C = 10 mA, I_B = 1 mA)	V_{BE}(sat)	0.7 to 0.9	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_A = 25°C	I_{CBO}	0.025 max	μA
V_{CB} = 15 V, I_E = 0, T_A = 150°C	I_{CBO}	15 max	μA
V_{CE} = 10 V, V_{BE} = 0.35 V, T_A = 100°C	I_{CEV}	15 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 1 V, I_C = 10 mA)	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 10 mA, f = 100 Mc/s)	h_{fe}	2 min	

TYPICAL TURN-OFF CHARACTERISTICS



TYPICAL TURN-ON CHARACTERISTICS



CHARACTERISTICS (cont'd)

Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 Mc/s)	C_{obo}	6 max	pF
Storage Time (V_{CC} = 10 V, I_C = 10 mA, I_{B1} = 10 mA, I_{B2} = −10 mA, R_C = 1000 Ω)	t_s	25 max	ns
Turn-On Time (V_{CC} = 10 V, I_C = 10 mA, I_{B1} = 3 mA, I_{B2} = −1 mA)	$t_d + t_r$	40 max	ns
Turn-Off Time (V_{CC} = 10 V, I_C = 10 mA, I_{B1} = 3 mA, I_{B2} = −1 mA)	$t_s + t_f$	75 max	ns

2N2270

TRANSISTOR

Si n-p-n triple-diffused planar type used in rf-amplifiers, mixers, oscillators, and converters, and in af small-signal and power amplifiers. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

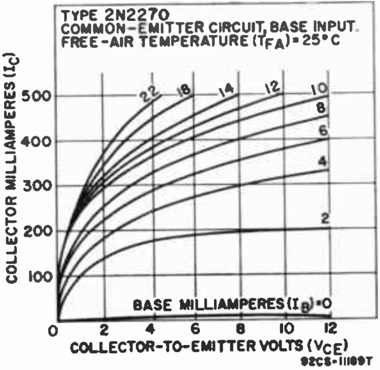
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
R_{BE} ≦ 10 Ω	V_{CER}	60	V
Base open	V_{CEO}	45	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

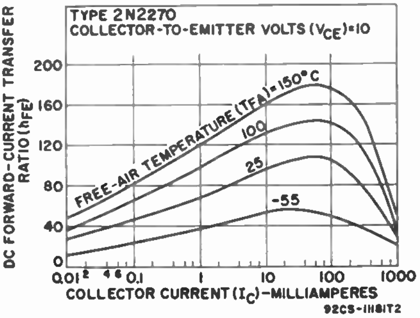
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	60 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 100 mA, t_p = 300 μs, df = 1.8%	V_{CEO}(sus)	45 min	V
I_C = 100 mA, R_{BE} = 10 Ω, t_p = 300 μs, df = 1.8%	V_{CER}(sus)	60 min	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA)	V_{CE}(sat)	0.9 max	V
Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA)	V_{BE}(sat)	1.2 max	V
Collector-Cutoff Current:			
V_{CB} = 60 V, I_E = 0, T_C = 25°C	I_{CBO}	0.1 max	μA
V_{CB} = 60 V, I_E = 0, T_C = 150°C	I_{CBO}	50 max	μA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	0.1 max	μA
Pulsed Static Forward-Current Transfer Ratio: (V_{CE} = 10 V, I_C = 150 mA, t_p = 300 μs, df = 1.8%)	h_{FE}(pulsed)	50 to 200	

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL OC FORWARO-CURRENT TRANSFER-RATIO CHARACTERISTICS



CHARACTERISTICS (cont'd)

Static Forward-Current Transfer Ratio ($V_{CE} = 10$ V, $I_C = 1$ mA)	h_{FE}	35 min	
Small-Signal Forward-Current Transfer Ratio:			
$V_{CE} = 10$ V, $I_C = 5$ mA, f = 1 kc/s	h_{fe}	30 to 180	
$V_{CE} = 10$ V, $I_C = 50$ mA, f = 20 Mc/s	h_{fe}	3 min	
Input Capacitance ($V_{EB} = 0.5$ V, $I_C = 0$)	C_{ibo}	80 max	pF
Output Capacitance ($V_{CB} = 10$ V, $I_E = 0$)	C_{obo}	15 max	pF
Noise Figure ($V_{CC} = 10$ V, $I_C = 0.3$ mA, $R_G = 1000\ \Omega$, f = 1 kc/s, circuit bandwidth = 1 c/s)	NF	6 max	dB
Thermal Resistance, Junction-to-Case	$\theta_{J\text{-}C}$	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	$\theta_{J\text{-}A}$	175 max	°C/W

POWER TRANSISTOR 2N2338

Si n-p-n diffused-junction type used in dc-to-dc converters, inverters, choppers, and relay-control circuits; in oscillators and voltage- and current-regulator circuits; and in dc and servo-amplifier circuits. JEDEC TO-36, Outline No.11. Terminals: Lug 1 - base, Lug 2 - emitter, Mounting Stud - collector and case.

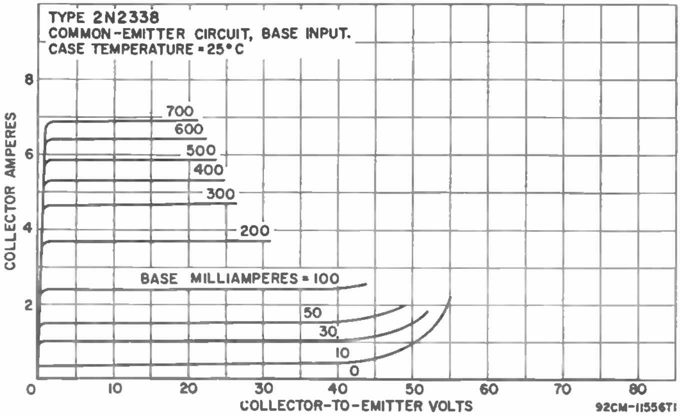
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	60	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	6	V
Collector Current	I_C	7.5	A
Base Current	I_B	5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	150	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J (opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lug-Soldering Temperature (10 s max)	T (lug)	235	°C

CHARACTERISTICS

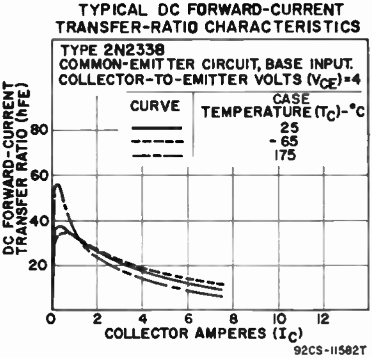
Collector-to-Emitter Voltage ($V_{BE} = -1.5$ V, $I_C = 2$ mA)	V_{CEV}	60 min	V
Collector-to-Emitter Sustaining Voltage ($I_C = 200$ mA, $I_B = 0$)	V_{CEO} (sus)	40 min	V
Collector-to-Emitter Saturation Voltage:			
$I_C = 6$ A, $I_B = 1$ A	V_{CE} (sat)	3.5 max	V
$I_C = 3$ A, $I_B = 0.3$ A	V_{CE} (sat)	1.5 max	V
Base-to-Emitter Saturation Voltage ($V_{CE} = 4$ V, $I_C = 3$ A)	V_{BE}	3 max	V

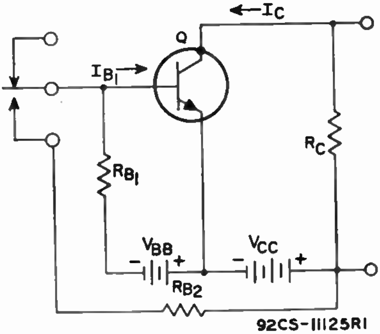
TYPICAL COLLECTOR CHARACTERISTICS



CHARACTERISTICS (cont'd)

Collector-Cutoff Current:			
$V_{CB} = 30$ V, $I_E = 0$, $T_C = 25°C$	I_{CBO}	0.2 max	mA
$V_{CB} = 30$ V, $I_E = 0$, $T_C = 150°C$	I_{CBO}	3 max	mA
$V_{CE} = 30$ V, $I_B = 0$	I_{CEO}	5 max	mA
$V_{CE} = 60$ V, $V_{BE} = -1.5$ V, $T_C = 25°C$	I_{CEV}	2 max	mA
$V_{CE} = 30$ V, $V_{BE} = -1.5$ V, $T_C = 200°C$	I_{CEV}	50 max	mA
Emitter-Cutoff Current ($V_{EB} = 6$ V, $I_C = 0$)	I_{EBO}	0.1 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = 4$ V, $I_C = 3$ A)	h_{FE}	15 to 60	
Small-Signal Forward-Current Transfer Ratio ($V_{CE} = 4$ V, $I_C = 0.5$ A, f = 1 kc/s)	h_{fe}	12 to 72	
Output Capacitance ($V_{CB} = 40$ V, $I_E = 0$, f = 0.1 Mc/s)	C_{obo}	600 max	pF
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CE} = 4$ V, $I_C = 5$ A)	f_{hfe}	0.015 min	Mc/s
Collector-to-Emitter Saturation Resistance ($I_C = 3$ A, $I_B = 0.3$ A)	r_{CE}(sat)	0.5 max	Ω
Thermal Time Constant	τ(thermal)	30	ms
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.17 max	°C/W





TYPICAL OPERATION IN PULSE-RESPONSE TEST CIRCUIT

DC Collector Supply Voltage	V_{CC}	24	V
DC Base-Bias Voltage		−6	V
On DC Collector Current	I_C	10	A
Turn-On DC Base Current	I_{B1}	2	A
Base-Circuit Resistance	R_{B1}, R_{B2}	10	Ω
Collector-Circuit Resistance	R_C	2	Ω
Turn-On Time	$t_d + t_r$	4	μs
Turn-Off Time	$t_s + t_f$	7	μs

2N2369A COMPUTER TRANSISTOR

Si n-p-n planar epitaxial type used for high-speed saturated switching in logic applications. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage	V_{CEO}	15	V
Emitter-to-Base Voltage	V_{EBO}	4.5	V
Collector Current	I_C	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.36	W
T_C up to 25°C	P_T	1.2	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (60 s max)	T_L	300	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.01 mA, I_E = 0)	$V_{(BR)CBO}$	40 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 0.01 mA, R_{BE} = 0)	$V_{(BR)CES}$	40 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.01 mA, I_C = 0)	$V_{(BR)EBO}$	4.5 min	V
Collector-to-Emitter Sustaining Voltage (I_C = 10 mA, I_B = 0, t_p = 300 µs, df = 2%)	V_{CEO}(sus)	15 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = 10 mA, I_B = 1 mA, T_A = 25°C	V_{CE}(sat)	0.2 max	V
I_C = 10 mA, I_B = 1 mA, T_A = 125°C	V_{CE}(sat)	0.3 max	V
I_C = 100 mA, I_B = 10 mA, T_A = 25°C	V_{CE}(sat)	0.5 max	V
Base-to-Emitter Saturation Voltage:			
I_C = 10 mA, I_B = 1 mA, T_A = 25°C	V_{BE}(sat)	0.7 to 0.85	V
I_C = 10 mA, I_B = 1 mA, T_A = 125°C	V_{BE}(sat)	0.59 min	V
I_C = 10 mA, I_B = 1 mA, T_A = —55°C	V_{BE}(sat)	1.02 max	V
I_C = 100 mA, I_B = 10 mA, T_A = 25°C	V_{BE}(sat)	1.6 max	V
Collector-Cutoff Current (V_{CB} = 20 V, I_E = 0, T_A = 150°C)	I_{CBO}	30 max	µA
Collector-Cutoff Current (V_{CE} = 20 V, R_{BE} = 0)	I_{CES}	0.4 max	µA
Pulsed Static Forward-Current Transfer Ratio:			
V_{CE} = 1 V, I_C = 10 mA, T_A = 25°C, t_p = 300 µs, df = 2%	h_{FE}(pulsed)	120 max	
V_{CE} = 0.35 V, I_C = 10 mA, T_A = —55°C, t_p = 300 µs, df = 2%	h_{FE}(pulsed)	20 min	
V_{CE} = 1 V, I_C = 100 mA, T_A = 25°C, t_p = 300 µs, df = 2%	h_{FE}(pulsed)	20 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 10 mA, f = 100 Mc/s	h_{fe}	5 min	
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 0.14 Mc/s)	C_{obo}	4 max	pF
Storage Time (V_{CC} = 10 V, I_C = 10 mA, I_{B1} = 10 mA, I_{B2} = —10 mA)	t_s	13 max	ns
Turn-On Time (V_{CC} = 3 V, I_C = 10 mA, I_{B1} = 3 mA, V_{BE}(off) = —3 V)	$t_d + t_r$	12 max	ns
Turn-Off Time (V_{CC} = 3 V, I_C = 10 mA, I_{B1} = 3 mA, I_{B2} = —1.5 mA)	$t_s + t_f$	18 max	ns

POWER TRANSISTOR 2N2405

Si n-p-n triple-diffused planar type used in small-signal and medium-power applications in industrial and military equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage:			
V_{BE} = — 1.5 V	V_{CBV}	120	V
Emitter open	V_{CBO}	120	V
Collector-to-Emitter Voltage:			
$R_{BE} \leqq 500$	V_{CER}	120	V
$R_{BE} \leqq 10$	V_{CER}	140	V
Base open	V_{CEO}	90	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_J) and Storage (T_{STG})		—65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

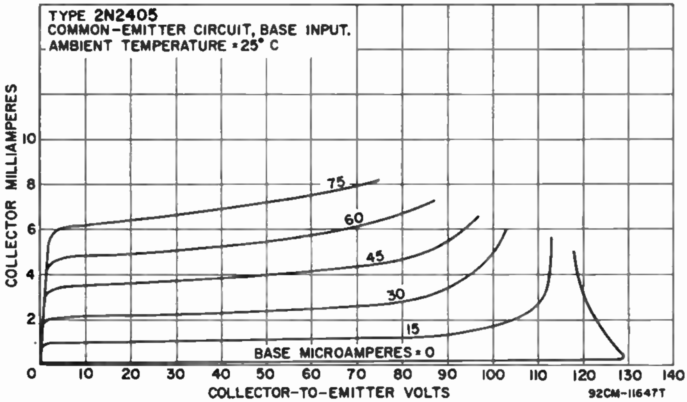
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	120 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.01 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 100 mA, I_B = 0, t_p = 300 µs, df = 1.8%	V_{CEO}(sus)	90 min	V
I_C = 30 mA, I_B = 0, t_p = 300 µs, df = 1.8%	V_{CEO}(sus	90 min	V
I_C = 100 mA, R_{BE} = 10 Ω, t_p = 300 µs, df = 1.8%	V_{CER}(sus)	140 min	V
I_C = 100 mA, R_{BE} = 500 Ω, t_p = 300 µs, df = 1.8%	V_{CER}(sus)	120 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = 150 mA, I_B = 15 mA	V_{CE}(sat)	0.5 max	V
I_C = 50 mA, I_B = 5 mA	V_{CE}(sat)	0.2 max	V

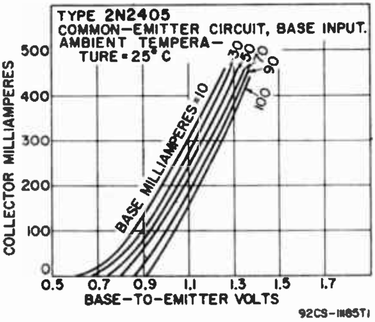
CHARACTERISTICS (cont'd)

Base-to-Emitter Saturation Voltage:			
I_C = 150 mA, I_B = 15 mA	V_{BE}(sat)	1.1 max	V
I_C = 50 mA, I_B = 5 mA	V_{BE}(sat)	0.9 max	V
Collector-Cutoff Current:			
V_{CB} = 90 V, I_E = 0, T_C = 25°C	I_{CBO}	0.01 max	µA
V_{CB} = 90 V, I_E = 0, T_C = 150°C	I_{CBO}	10 max	µA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	0.01 max	µA
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 5 mA, f = 1 kc/s	h_{fe}	50 to 275	
V_{CE} = 10 V, I_C = 50 mA, f = 20 Mc/s	h_{fe}	6 min	
Pulsed Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 500 mA, T_A = 25°C, t_p = 300 µs, df = 1.8%	h_{FE}(pulsed)	25 min	
V_{CE} = 10 V, I_C = 150 mA, T_A = 25°C, t_p = 300 µs, df = 1.8%	h_{FE}(pulsed)	60 to 200	
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 10 mA, T_A = 25°C	h_{FE}	35 min	
V_{CE} = 10 V, I_C = 10 mA, T_A = −55°C	h_{FE}	20 min	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0)	C_{ibo}	80 max	pF
Output Capacitance (V_{CB} = 10 V, I_E = 0)	C_{obo}	15 max	pF
Input Resistance:			
V_{CB} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{ib}	24 to 34	Ω
V_{CB} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{ib}	4 to 8	Ω
Voltage-Feedback Ratio:			
V_{CB} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{rb}	3×10^{-4} max	
V_{CB} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{rb}	3×10^{-4} max	
Output Conductance:			
V_{CB} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{ob}	0.5 max	µmho
V_{CB} = 10 V, I_C = 5 mA, f = 1 kc/s	h_{ob}	0.5 max	µmho

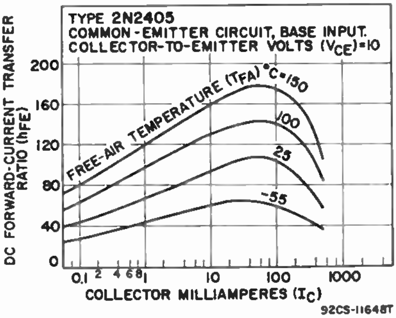
TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



CHARACTERISTICS (cont'd)

Noise Figure (V_{CE} = 10 V, I_C = 0.3 mA, f = 1 kc/s, R_G = 500 Ω, circuit bandwidth = 15 kc/s)	NF	6 max	dB
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

COMPUTER TRANSISTOR 2N2475

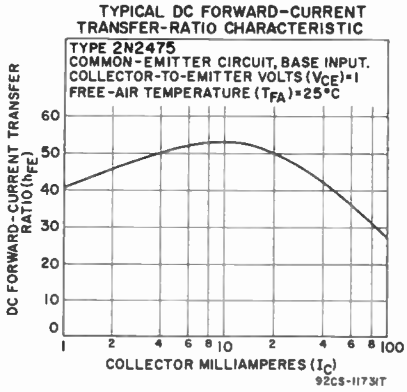
Si **n-p-n** epitaxial planar type used in very-high-speed switching applications in logic circuits in military and commercial data-processing equipment. Similar to JEDEC TO-18, Outline No.9, except has minimum case height of 0.100 inch. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	15	V
Collector-to-Emitter Voltage	V_{CEO}	6	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	Limited by power dissipation		
Transistor Dissipation:			
T_A up to 25°C	P_T	0.3	W
T_C up to 100°C	P_T	0.5	W
T_A above 25°C or T_C above 100°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 10 μA, I_E = 0)	$V_{(BR)CBO}$	15 min	V
Emitter-to-Base Breakdown Voltage (I_E = 10 μA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Sustaining Voltage (I_C = 10 mA, I_B = 0, $t_p \geqq$ 300 ns, df $\leqq$ 2%)	V_{CEO}(sus)	6 min	V
Collector-to-Emitter Saturation Voltage (I_C = 20 mA, I_B = 0.66 mA)	V_{CE}(sat)	0.4 max	V
Base-to-Emitter Saturation Voltage (I_C = 20 mA, I_B = 0.66 mA)	V_{BE}(sat)	0.8 to 1	V
Collector-Cutoff Current:			
V_{CB} = 5 V, I_E = 0, T_A = 25°C	I_{CBO}	0.05 max	μA
V_{CB} = 5 V, I_E = 0, T_A = 150°C	I_{CBO}	5 max	μA
Static Forward-Current Transfer Ratio:			
V_{CE} = 0.5 V, I_C = 50 mA, T_A = 25°C	h_{FE}	20 min	
V_{CE} = 0.4 V, I_C = 20 mA, T_A = −55°C	h_{FE}	15 min	
V_{CE} = 0.4 V, I_C = 20 mA, T_A = 25°C	h_{FE}	30 to 150	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 2 V, I_C = 20 mA, f = 100 Mc/s)	h_{fe}	6 min	



CHARACTERISTICS (cont'd)

Turn-On Time (I_C = 20 mA, I_{B1} = 1 mA, I_{B2} = −1 mA, V_{CC} = 1.8 V)	$t_d + t_r$	20 max	ns
Turn-Off Time (I_C = 20 mA, I_{B1} = 1 mA, I_{B2} = −1 mA, V_{CC} = 1.8 V)	$t_s + t_f$	15 max	ns

2N2476

COMPUTER TRANSISTOR

Si n-p-n double-diffused epitaxial planar type used in core-driving and line-driving applications where high switching speeds at high current are primary design requirements. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

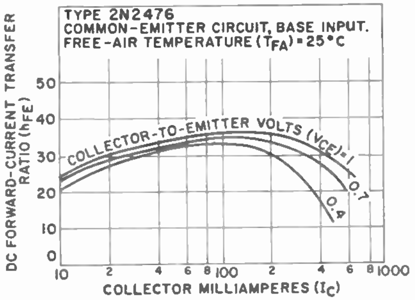
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage	V_{CEO}	20	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	Limited by power dissipation		
Transistor Dissipation:			
T_A up to 25°C	P_T	0.6	W
T_C up to 25°C	P_T	2	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C

CHARACTERISTICS

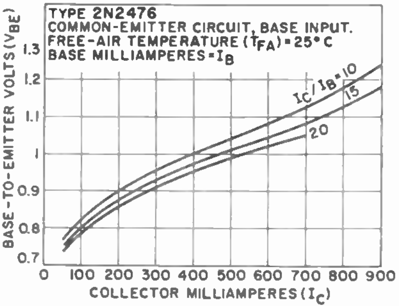
Collector-to-Base Breakdown Voltage (I_C = 10 μA, I_E = 0)	$V_{(BR)CBO}$	60 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 50 mA, I_B = 0, $t_p \leqq$ 400 μs, df = 3%)	$V_{(BR)CEO}$	20 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Saturation Voltage			
I_C = 150 mA, I_B = 7.5 mA	V_{CE}(sat)	0.4 max	V
I_C = 500 mA, I_B = 50 mA	V_{CE}(sat)	0.75 max	V
Base-to-Emitter Voltage (I_C = 150 mA, I_B = 7.5 mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
V_{CB} = 30 V, I_E = 0, T_A = 25°C	I_{CBO}	0.2 max	μA
V_{CB} = 30 V, I_E = 0, T_A = 150°C	I_{CBO}	200 max	μA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	100 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 0.4 V, I_C = 150 mA)	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA, f = 100 Mc/s)	h_{fe}	2.5 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 Mc/s)	C_{obo}	10 max	pF

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



92CS-11761T

TYPICAL TRANSFER CHARACTERISTICS

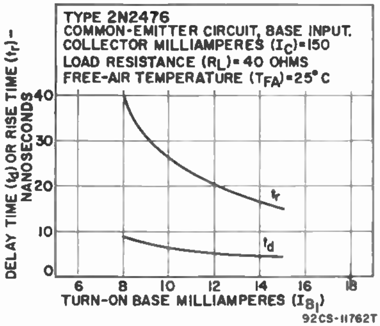


92CS-11767T

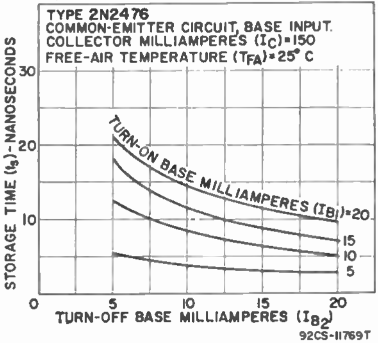
CHARACTERISTICS (cont'd)

Storage Time (V_{CC} = 6.4 V, R_C = 40 Ω, I_{B1} = 15 mA, I_{B2} = −15 mA, I_C = 150 mA)	t_s	25 max	ns
Turn-On Time (V_{CC} = 6.4 V, I_{B1} = 15 mA, I_{B2} = −15 mA, I_C = 150 mA)	$t_d + t_r$	25 max	ns
Turn-Off Time (V_{CC} = 6.4 V, I_{B1} = 15 mA, I_{B2} = −15 mA, I_C = 150 mA)	$t_s + t_f$	45 max	ns

TYPICAL DELAY-TIME AND RISE-TIME CHARACTERISTICS



TYPICAL STORAGE-TIME CHARACTERISTICS



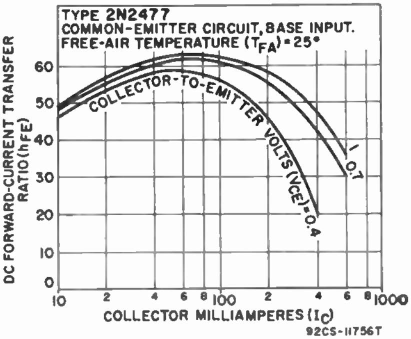
COMPUTER TRANSISTOR 2N2477

Si **n-p-n** double-diffused epitaxial planar type used in core-driving and line-driving applications where high switching speeds at high current are primary design requirements. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N2476 except for its switching characteristics and the following items:

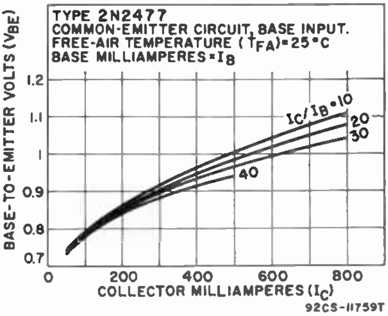
CHARACTERISTICS

Collector-to-Emitter Saturation Voltage:			
I_C = 150 mA, I_B = 3.75 mA	V_{CE}(sat)	0.4 max	V
I_C = 500 mA, I_B = 50 mA	V_{CE}(sat)	0.65 max	V
Base-to-Emitter Voltage (I_C = 150 mA, I_B = 3.75 mA)	V_{BE}	0.95 max	V
Static Forward-Current Transfer Ratio (V_{CE} = 0.4 V, I_C = 150 mA)	h_{FE}	40 min	

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



2N2613 TRANSISTOR

Ge **p-n-p alloy-junction** type used in small-signal and low-power audio frequency applications. It is a low-noise type for use in input and low-level stages. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

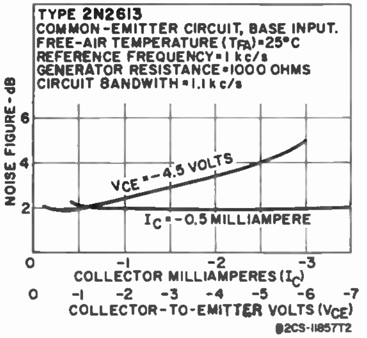
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−30	V
Collector-to-Emitter Voltage (R_{BE} = 10 kΩ)	V_{CER}	−25	V
Emitter-to-Base Voltage	V_{EBO}	−25	V
Collector Current	I_C	−50	mA
Emitter Current	I_E	50	mA
Transistor Dissipation:			
T_A up to 55°C	P_T	120	mW
T_A above 55°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 100	°C
Storage	T_{STG}	−65 to 100	°C
Lead-Soldering Temperature (10 s max)			

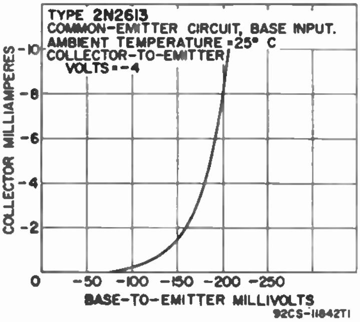
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (V_{BE} = 2 V, I_C = −0.05 mA)	$V_{(BR)CBV}$	−30 min	V
Collector-to-Emitter Breakdown Voltage (R_{BE} = 10000 Ω, I_C = −1 mA)	$V_{(BR)CER}$	−25 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.05 mA, I_C = 0)	$V_{(BR)EBO}$	−25 min	V

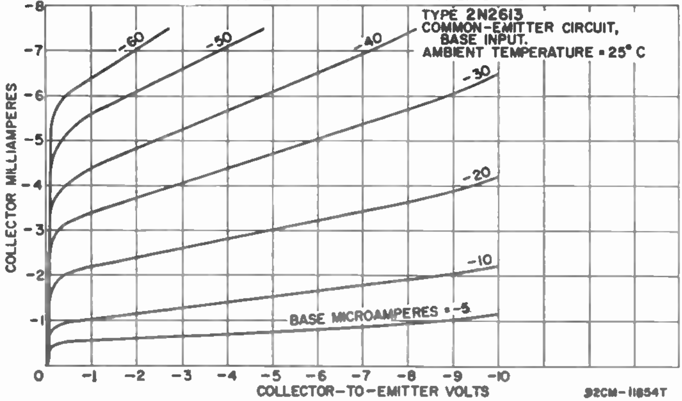
TYPICAL NOISE-FIGURE CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC



TYPICAL COLLECTOR CHARACTERISTICS



CHARACTERISTICS (cont'd)

Collector-Cutoff Current (V_{CB} = –20 V, I_E = 0)	I_{CBO}	–5 max	µA
Emitter-Cutoff Current (V_{EB} = –20 V, I_C = 0)	I_{EBO}	–7.5 max	µA
Intrinsic Base Spreading Resistance (V_{CE} = –4.5 V, I_C = –0.5 mA, f = 20 Mc/s)	$r_{bb'}$	300	Ω
Collector-to-Base Feedback Capacitance (V_{CB} = –4.5 V, I_C = –0.5 mA)	$C_{b'c}$	10	pF
Small-Signal Forward-Current Transfer Ratio (V_{CE} = –4 V, I_C = –0.5 mA, f = 1 kc/s)	h_{fe}	120 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = –4.5 V, I_C = –0.5 mA)	f_{hfb}	10	Mc/s
RMS Noise Input Current (Equivalent) (V_{CE} = –4.5 V, I_C = –0.5 mA, R_{BE} = 5000 Ω, f = 20 to 20000 c/s)		0.001 max	µA
Noise Figure (Circuit bandwidth = 1.1 kc/s, (V_{CE} = –4.5 V, I_C = –0.5 mA, R_G = 1000 Ω, f = 1 kc/s)	NF	4 max	dB

TRANSISTOR 2N2614

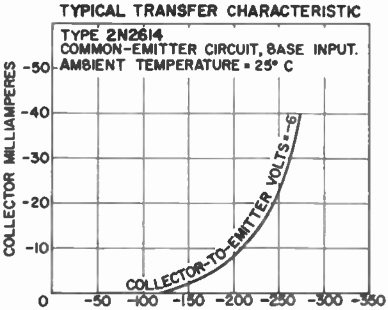
Ge p-n-p alloy-junction type used in small-signal and low-power audio frequency applications. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

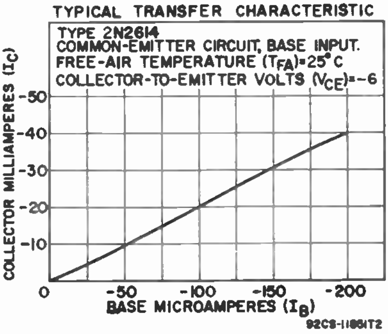
MAXIMUM RATINGS

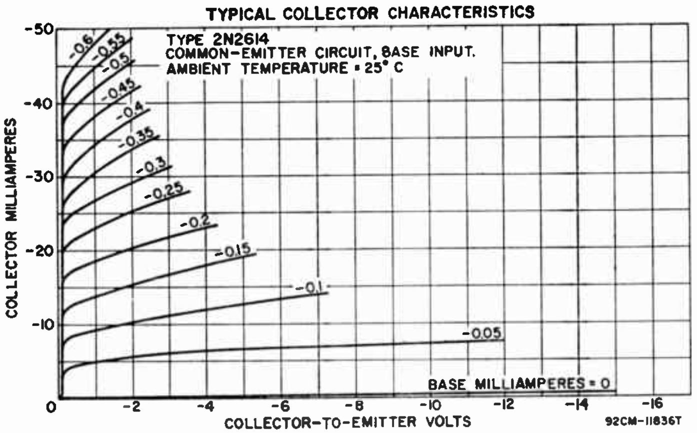
Collector-to-Base Voltage	V_{CBO}	–40	V
Collector-to-Emitter Voltage (R_{BE} = 10 kΩ)	V_{CER}	–35	V
Emitter-to-Base Voltage	V_{EBO}	–25	V
Collector Current	I_C	–50	mA
Emitter Current	I_E	50	mA
Transistor Dissipation:			
T_A up to 55°C	P_T	120	mW
T_C up to 55°C	P_T	300	mW
T_A or T_C above 55°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J (opr)	–65 to 100	°C
Storage	T_{STG}	–65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = –0.05 mA, V_{BE} = 2 V)	$V_{(BR)CBV}$	–40 min	V
Collector-to-Emitter Breakdown Voltage (I_C = –1 mA, R_{BE} = 10 kΩ)	$V_{(BR)CER}$	–35 min	V
Emitter-to-Base Breakdown Voltage (I_E = –0.05 mA, I_C = 0)	$V_{(BR)EBO}$	–25 min	V
Collector-Cutoff Current (V_{CB} = –20 V, I_E = 0)	I_{CBO}	–5 max	µA
Emitter-Cutoff Current (V_{EB} = –20 V, I_C = 0)	I_{EBO}	–7.5 max	µA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = –6 V, I_C = –1 mA, f = 1 kc/s)	h_{fe}	100 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = –6 V, I_C = –1 mA)	f_{hfe}	10	Mc/s
Collector-to-Base Feedback Capacitance (V_{CE} = –6 V, I_C = –1 mA)	$C_{b'c}$	9	pF
Intrinsic Base-Spreading Resistance (V_{CE} = –6 V, I_C = –1 mA, f = 20 Mc/s)	$r_{bb'}$	300	Ω







2N2631 POWER TRANSISTOR

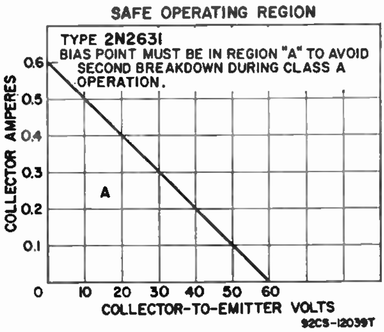
Si **n-p-n triple-diffused planar** type used in large-signal vhf applications such as AM, FM, and cw service at frequencies up to 150 Mc/s in industrial and military equipment. JEDEC TO-39, **Outline** No.12. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N2876 except for the following items:

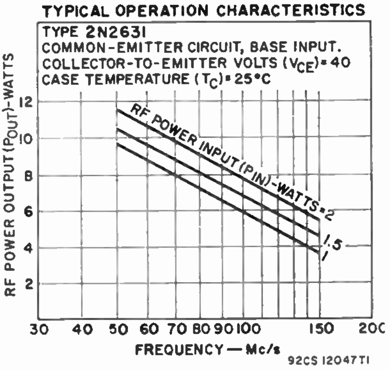
MAXIMUM RATINGS

Collector Current	I_C	1.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	8.75	W
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage (I_C = 1.5 A, I_B = 0.3 A)	V_{CE}(sat)	1 max	V
RF Power Output, Unneutralized (V_{CE} = 28 V, I_C = 0.375 A, P_{IE} = 1 W, f = 50 Mc/s)	P_{OE}	7.5 min	W





2N2708 TRANSISTOR

Si **n-p-n double-diffused epitaxial planar** type used in rf amplifiers, mixers, and oscillator circuits for vhf and uhf applications (200 to 500 Mc/s).

JEDEC TO-72, Outline No.23. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - case.

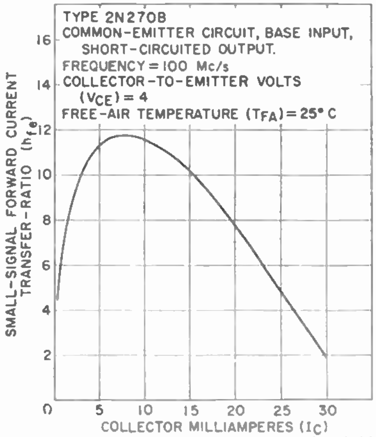
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	35	V
Collector-to-Emitter Voltage	V_{CEO}	20	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	Limited by power dissipation		
Transistor Dissipation:			
T_A up to 25°C	P_T	0.2	W
T_C up to 25°C	P_T	0.3	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

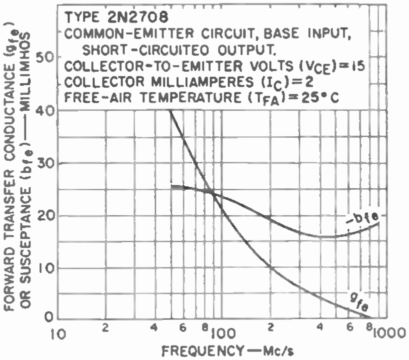
Collector-to-Base Breakdown Voltage (I_C = 1 μA, I_E = 0)	$V_{(BR)CBO}$	35 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 3 mA, I_B = 0, t_p = 300 μs, df = 1%)	$V_{(BR)CEO}$(sus)	20 min	V
Emitter-to-Base Breakdown Voltage (I_E = 10 μA, I_C = 0)	$V_{(BR)EBO}$	3 min	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_A = 25°C	I_{CBO}	0.01 max	μA
V_{CB} = 15 V, I_E = 0, T_A = 150°C	I_{CBO}	1 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 2 V, I_C = 2 mA)	h_{FE}	30 to 200	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 15 V, I_C = 2 mA, f = 1 kc/s	h_{fe}	30 to 180	
V_{CE} = 15 V, I_C = 2 mA, f = 100 Mc/s	h_{fe}	7 to 12	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 0.14 Mc/s)	C_{ibo}	1.4	pF
Output Capacitance (V_{CB} = 15 V, I_E = 0, f = 0.14 Mc/s)	C_{obo}	1.5 max	pF
Collector-to-Base Time Constant (V_{CB} = 1.5 V, I_C = 2 mA, f = 31.9 Mc/s)	$r_b'C_c$	9 to 33	ps
Small-Signal Common-Emitter Power Gain:			
(In neutralized amplifier) V_{CE} = 15 V, I_C = 2 mA, f = 200 Mc/s	G_{pe}	15 to 22	dB
(In unneutralized amplifier) V_{CE} = 15 V, I_C = 2 mA, f = 200 Mc/s	G_{pe}	12	dB
Small-Signal Transconductance (V_{CE} = 15 V, I_C = 2 mA, f = 200 Mc/s)	g_{me}	25	mmhos
Noise Figure:			
V_{CE} = 15 V, I_C = 2 mA, R_S = 50 Ω, f = 200 Mc/s	NF	7.5 max	dB
V_{CE} = 6 V, I_C = 1 mA, R_S = 400 Ω, f = 60 Mc/s	NF	3.5	dB

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC



92CS-11940T

TYPICAL SMALL-SIGNAL FORWARD TRANSFER CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



92CS-11938T

2N2857 UHF TRANSISTOR

Si n-p-n double-diffused epitaxial planar type used in low-noise amplifier, oscillator, and converter applications at frequencies up to 500 Mc/s in a common-emitter circuit, and up to 1200 Mc/s in a common-base circuit. JEDEC TO-72, Outline No.23. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

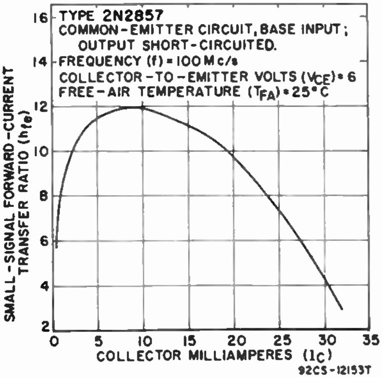
Collector-to-Base Voltage	V_{CBO}	30	V
Collector-to-Emitter Voltage	V_{CEO}	15	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	20	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	200	mW
T_C up to 25°C	P_T	300	mW
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

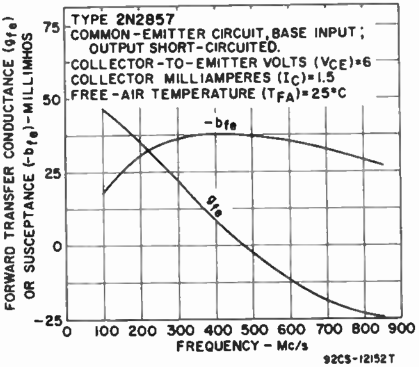
Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	30 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 3 mA, I_B = 0)	$V_{(BR)CEO}$	15 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.01 mA, I_C = 0)	$V_{(BR)EBO}$	2.5 min	V
Collector-Cutoff Current (V_{CB} = 15 V, I_E = 0)	I_{CBO}	0.01 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 1 V, I_C = 3 mA)	h_{FE}	30 to 150	
Small-Signal Forward-Current Transfer Ratio:*			
V_{CB} = 6 V, I_C = 5 mA, f = 100 Mc/s	h_{fe}	10 to 19	
V_{CE} = 6 V, I_C = 2 mA, f = 1 kc/s	h_{fe}	50 to 220	
Input Capacitance* (V_{EB} = 0.5 V, I_C = 0, f = 0.140 Mc/s)	C_{ibo}	1.4	pF
Output Capacitance:			
V_{CB} = 10 V, I_E = 0, f = 0.140 Mc/s	C_{obo}	1.3† max	pF
V_{CB} = 10 V, I_E = 0, f = 0.140 Mc/s	C_{obo}	1.8* max	pF
Collector-to-Base Time Constant†			
V_{CB} = 6 V, I_C = 2, f = 31.9 Mc/s	$r_b'C_c$	4 to 15	ps
Small-Signal Power Gain, Neutralized Amplifier			
V_{CE} = 6 V, I_C = 1.5 mA, f = 450 Mc/s	G_{pe}	12.5 to 19	dB
Power Output, Oscillator Circuit			
V_{CB} = 10 V, I_E = −12 mA, f = 500 Mc/s	P_{oe}	30 min	mW
Noise Figure:†			
V_{CE} = 6 V, I_C = 1.5 mA, R_G = 50 Ω, f = 450 Mc/s	NF	4.5 max	dB
V_{CE} = 6 V, I_C = 1 mA, R_G = 400 Ω, f = 60 Mc/s	NF	2	dB

* Fourth lead floating † Fourth lead grounded

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC



TYPICAL SMALL-SIGNAL FORWARD TRANSFER CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



POWER TRANSISTOR

2N2869/ 2N301

Ge p-n-p alloy-junction type used in class A and class B af output-amplifier stages of automobile radio receivers and mobile communications equipment. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−60	V
Collector-to-Emitter Voltage	V_{CEO}	−50	V
Emitter-to-Base Voltage	V_{EBO}	−10	V
Collector Current	I_C	−10	A
Emitter Current	I_E	10	A
Base Current	I_B	−3	A
Transistor Dissipation:			
T_{MF} up to 55°C	P_T	30	W
T_{MF} above 55°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 100	°C
Storage	T_{STG}	−65 to 100	°C
Pin-Soldering Temperature (10 s max)	T_P	255	°C

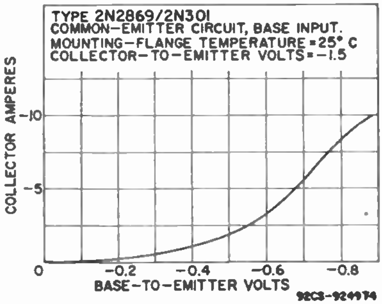
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.005 A, I_E = 0)	$V_{(BR)CBO}$	−60 min	V
Collector-to-Emitter Breakdown Voltage (I_C = −0.6 A, I_B = 0)	$V_{(BR)CEO}$	−50 min	V
Emitter-to-Base Breakdown Voltage (I_E = −2 mA, I_C = 0)	$V_{(BR)EBO}$	−10 min	V
Collector-to-Emitter Saturation Voltage (I_C = 10 A, I_B = −1 A)	V_{CE}(sat)	−0.75 max	V
Base-to-Emitter Voltage (V_{CE} = −2 V, I_C = −1 A)	V_{BE}	−0.5 max	V
Collector-Cutoff Current:			
V_{CB} = −30 V, I_E = 0	I_{CBO}	−0.5 max	mA
V_{CB} = −0.5 V, I_E = 0	I_{CBO}(sat)	−0.1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = −2 V, I_C = −1 A)	h_{FE}	50 to 165	
Gain-Bandwidth Product (V_{CE} = −2 V, I_C = −1 A)	f_T	200 min	kc/s

TYPICAL OPERATION IN CLASS A POWER-AMPLIFIER CIRCUIT

DC Collector-Supply Voltage	V_{CC}	−14.4	V
DC Collector-to-Emitter Voltage	V_{CE}	−12.2	V
DC Base-to-Emitter Voltage	V_{BE}	−0.35	V
Zero-Signal Collector Current	I_C	−0.9	A
Load Impedance	R_L	15	Ω
Signal Frequency	f	400	c/s
Signal-Source Impedance	R_S	10	Ω
Power Gain		38	dB
Total Harmonic Distortion (at a power output of 5 W)		5	%
Zero-Signal Collector Dissipation		11	W
Maximum-Signal Power Output	P_{OE}	5	W
Circuit Efficiency (at a power output of 5 W)	η	45	%

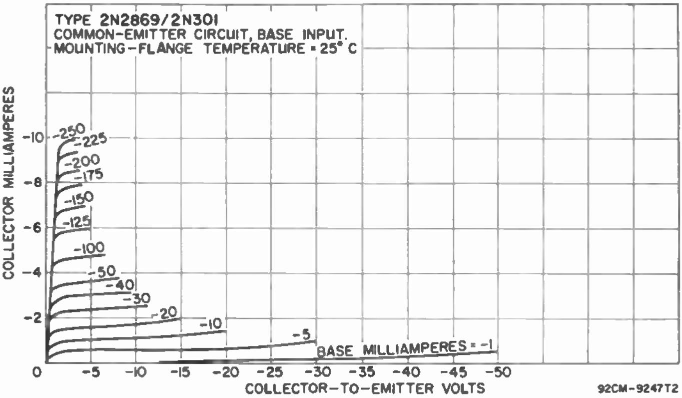
TYPICAL TRANSFER CHARACTERISTIC



TYPICAL OPERATION IN "SINGLE-ENDED PUSH-PULL" CLASS B AF-AMPLIFIER CIRCUIT

DC Collector Supply Voltage	V_{CC}	—14.4	V
Zero-Signal DC Collector Current (per transistor)	I_C	—0.05	A
Zero-Signal Base-Bias Voltage		—0.13	V
Peak Collector Current (per transistor)	i_C(peak)	—2	A
Maximum-Signal DC Collector Current (per transistor)	I_C(max)	—0.64	A
Signal Frequency	f	400	c/s
Input Impedance of Stage (per base)	R_S	10	Ω
Load Impedance (per collector)	R_L	6	Ω
Power Gain		30	dB
Circuit Efficiency (at a power output of 12 W)	η	67	%
Maximum-Signal Power Output	P_{OE}	12	W
Total Harmonic Distortion (at maximum-signal power output of 12 W)		5	%
Maximum Collector Dissipation (per transistor at a power output of 12 W)		3	W

TYPICAL COLLECTOR CHARACTERISTICS



2N2870/ 2N301A

POWER TRANSISTOR

Ge p-n-p alloy-junction type used in class A and class B af output-amplifier stages of automobile radio receivers and mobile communications equipment. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N2869/2N301 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	—80	V

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = —0.005 A, I_E = 0)	$V_{(BR)CBO}$	—80 min	V
Collector-to-Emitter Saturation Voltage (I_C = —10 A, I_B = —1 A)	V_{CE}(sat)	—0.5 max	V

2N2876

POWER TRANSISTOR

Si n-p-n triple-diffused planar type used in large-signal vhf applications such as AM, FM, and cw service at frequencies up to 150 Mc/s in industrial and military equipment. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

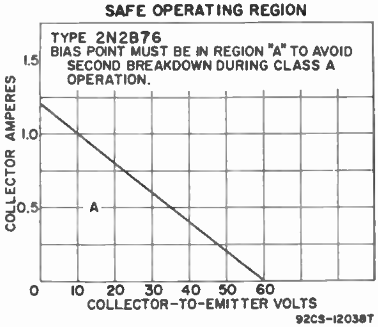
Collector-to-Base Voltage	V_{CBO}	80	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	80	V
Base open	V_{CEO}	60	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	2.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	17.5	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

CHARACTERISTICS

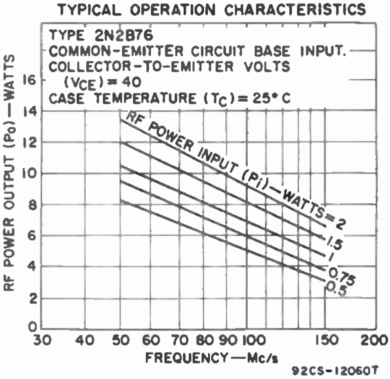
Collector-to-Base Breakdown Voltage (I_C = 0.5 mA, I_E = 0)	$V_{(BR)CBO}$	80 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0.5 A, I_B = 0, t_p = 5 μs, df = 1%	$V_{(BR)CEO}$(sus)	60 min	V
V_{BE} = −1.5 V, I_C = 0.1 mA	$V_{(BR)CEV}$	80 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage (I_C = 2.5 A, I_B = 0.5 A)	V_{CE}(sat)	1 max	V
Collector-Cutoff Current (V_{CB} = 30 V, I_E = 0)	I_{CBO}	0.1 max	μA
Intrinsic Base-Spreading Resistance (V_{CE} = 28 V, I_C = 0.25 A, f = 400 Mc/s)	$r_{bb'}$	6 typ	Ω
RF Power Output, Unneutralized:			
V_{CE} = 28 V, I_C = 0.5 A, P_{IE} = 2 W, f = 50 Mc/s	P_{OE}	10 min	W
V_{CE} = 28 V, I_C = 0.275 A, P_{IE} = 1 W, f = 150 Mc/s	P_{OE}	3 min	W
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 250 mA)	f_T	200 typ	Mc/s
Collector-to-Case Capacitance	C_c	6 max	pF
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 0.14 Mc/s)	C_{obo}	20 max*	pF

* This value applies only to type 2N2876.

SAFE OPERATING REGION



TYPICAL OPERATION CHARACTERISTICS



TRANSISTOR 2N2895

Si **n-p-n** triple-diffused planar type used in a wide variety of small-signal and low-to-medium-power applications in military and industrial equipment. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case. For transfer-characteristics curves, refer to type 2N2102.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	120	V
Collector-to-Emitter Voltage:			
R_{BE} = 10 Ω	V_{CER}	80	V
Base open	V_{CEO}	65	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A

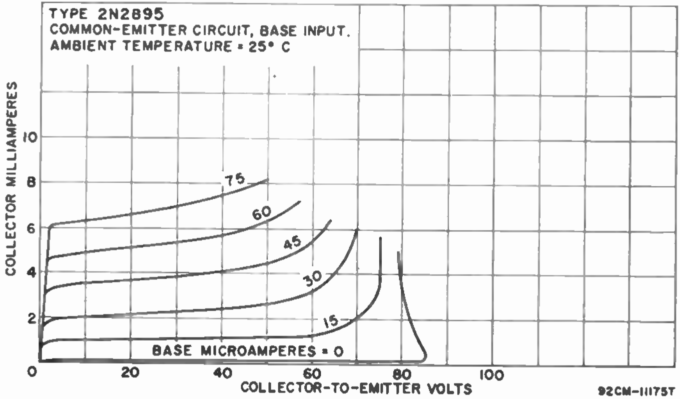
MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_C up to 25°C	P_T	1.8	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	120 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 100 mA, I_B = 0, t_p = 300 μs, df = 2%	V_{CEO}(sus)	65 min	V
I_C = 100 mA, I_B = 0, R_{BE} = 10 Ω, t_p = 300 μs, df = 2%	V_{CER}(sus)	80 min	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p = 300 μs, df = 2%)	V_{CE}(sat)	0.6 max	V
Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p = 300 μs, df = 2%)	V_{BE}(sat)	1.2 max	V
Collector-Cutoff Current:			
V_{CB} = 60 V, I_E = 0, T_A = 25°C	I_{CBO}	0.002 max	μA
V_{CB} = 60 V, I_E = 0, T_A = 150°C	I_{CBO}	2 max	μA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	0.002 max	μA
Pulsed Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 150 mA, t_p = 300 μs, df = 2%	h_{FE}(pulsed)	40 to 120	
V_{CE} = 10 V, I_C = 10 mA, t_p = 300 μs, df = 2%, T_A = −55°C	h_{FE}(pulsed)	20 min	
V_{CE} = 10 V, I_C = 10 mA, t_p = 300 μs, df = 2%	h_{FE}(pulsed)	35 min	
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 0.01 mA)	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 5 mA, f = 1 kc/s	h_{fe}	50 to 200	
V_{CE} = 10 V, I_C = 50 mA, f = 20 Mc/s	h_{fe}	6 min	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 0.14 Mc/s)	C_{ibo}	80 max	pF
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 Mc/s)	C_{obo}	15 max	pF
Noise Figure (V_{CE} = 10 V, I_C = 0.3 mA, f = 1 kc/s, R_G = 510 Ω, circuit bandwidth = 1 c/s)	NF	8 max	dB
Thermal Resistance, Junction-to-Case	θ_{J-C}	97 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	350 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



92CM-11175T

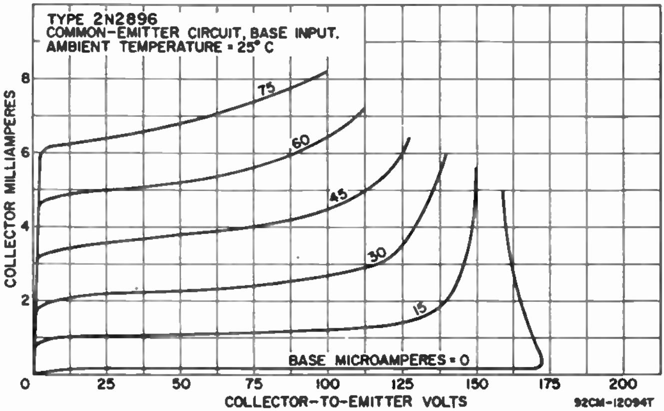
2N2896 TRANSISTOR

Si **n-p-n triple-diffused planar** type used in a wide variety of small-signal and low-to-medium-power applications in military and industrial equipment. JEDEC TO-18, Outline No.9. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. For transfer-characteristics curves, refer to type 2N2102.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	140	V
Collector-to-Emitter Voltage:			
R_{BE} = 10 Ω	V_{CER}	140	V
Base open	V_{CEO}	90	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_C up to 25°C	P_T	1.8	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C
Storage	T_{STG}	—65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

TYPICAL COLLECTOR CHARACTERISTICS



CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	140 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 100 mA, I_B = 0, t_p = 300 μs, df = 2%	V_{CEO}(sus)	90 min	V
I_C = 100 mA, I_B = 0, R_{BE} = 10 Ω, t_p = 300 μs, df = 2%	V_{CER}(sus)	140 min	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p = 300 μs, df = 2%)	V_{CE}(sat)	0.6 max	V
Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p = 300 μs, df = 2%)	V_{BE}(sat)	1.2 max	V
Collector-Cutoff Current:			
V_{CB} = 90 V, I_E = 0, T_A = 25°C	I_{CBO}	0.01 max	μA
V_{CB} = 90 V, I_E = 0, T_A = 150°C	I_{CBO}	10 max	μA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	0.01 max	μA
Pulsed Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 150 mA, t_p = 300 μs, df = 2%, T_A = 25°C	h_{FE}(pulsed)	60 to 200	
V_{CE} = 10 V, I_C = 10 mA, t_p = 300 μs, df = 2%, T_A = 55°C	h_{FE}(pulsed)	20 min	
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 1 mA)	h_{FE}	35 min	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 5 mA, f = 1 kc/s	h_{fe}	50 to 275	
V_{CE} = 10 V, I_C = 50 mA, f = 20 Mc/s	h_{fe}	6 min	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 0.14 Mc/s)	C_{ibo}	80 max	pF
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 Mc/s)	C_{obo}	15 max	pF
Thermal Resistance, Junction-to-Case	Θ_{J-C}	97 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	350 max	°C/W

2N2897 TRANSISTOR

Si n-p-n triple-diffused planar type used in a wide variety of small-signal and low-to-medium-power applications in military and industrial equipment. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

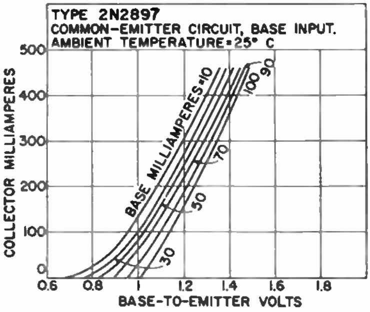
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
R_{BE} = 10 Ω	V_{CER}	60	V
Base open	V_{CEO}	45	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_C up to 25°C	P_T	1.8	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C
Storage	T_{STG}	—65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

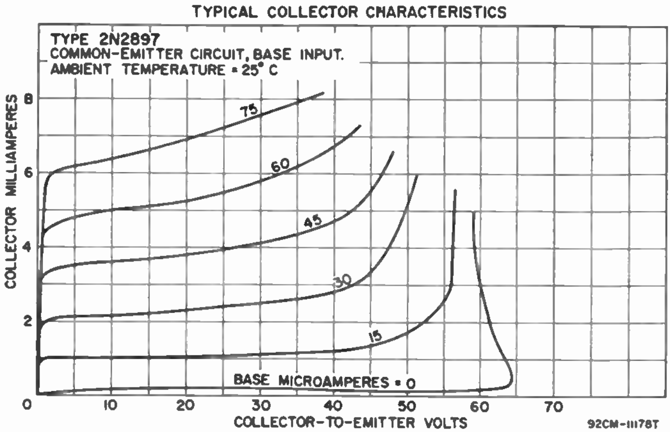
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	60 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 100 mA, I_B = 0, t_p = 300 μs, df = 2%	V_{CEO}(sus)	45 min	V
I_C = 100 mA, I_B = 0, R_{BE} = 10 Ω, t_p = 300 μs, df = 2%	V_{CER}(sus)	60 min	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p = 300 μs, df = 2%)	V_{CE}(sat)	1 max	V
Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p = 300 μs, df = 2%)	V_{BE}(sat)	1.3 max	V
Collector-Cutoff Current:			
V_{CB} = 60 V, I_E = 0, T_A = 25°C	I_{CBO}	0.05 max	μA
V_{CB} = 60 V, I_E = 0, T_A = 150°C	I_{CBO}	50 max	μA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	0.05 max	μA
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 150 mA, t_p = 300 μs, df = 2%)	h_{FE}(pulsed)	50 to 200	
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 0.1 mA)	h_{FE}	35 min	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kc/s	h_{fe}	50 to 275	
V_{CE} = 10 V, I_C = 50 mA, f = 20 Mc/s	h_{fe}	5 min	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 0.14 Mc/s)	C_{ibo}	80 max	pF
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 Mc/s)	C_{obo}	15 max	pF
Thermal Resistance, Junction-to-Case	Θ_{J-C}	97 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	350 max	°C/W

TYPICAL TRANSFER CHARACTERISTICS



92CS-12104T



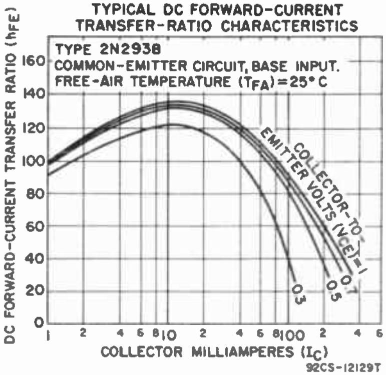
COMPUTER TRANSISTOR

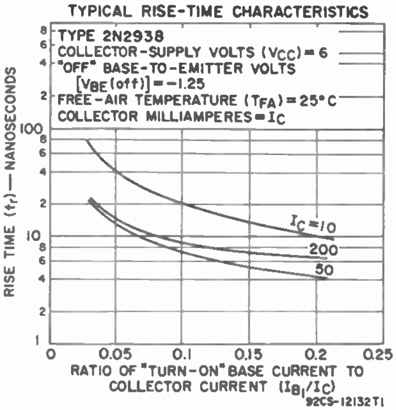
2N2938

Si **n-p-n double-diffused epitaxial planar** type used for high-speed saturated switching in data-processing equipment in industrial and military equipment. JEDEC TO-52, Outline No.18. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

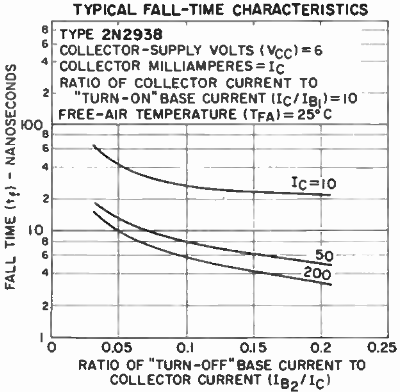
Collector-to-Base Voltage	V_{CBO}	25	V
Collector-to-Emitter Voltage	V_{CEO}	13	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	0.5	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.3	W
T_C up to 25°C	P_T	1	W
T_A or T_C above 25°C	P_T	See curve page 112	
Ambient and Case Temperature Range:			
Operating (T_A — T_C)		—65 to 175	°C
Storage	T_{STG}	—65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C



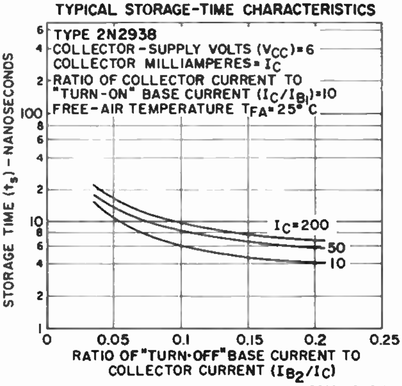


CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage (I_C = 10 mA, I_B = 0)	$V_{(BR)CEO}$	13 min	V
Collector-to-Base Breakdown Voltage (I_C = 0.01 mA, I_E = 0)	$V_{(BR)CBO}$	25 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.01 mA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Saturation Voltage (I_C = 50 mA, I_B = 1.6 mA)	V_{CE}(sat)	0.4 max	V
Base-to-Emitter Saturation Voltage (I_C = 50 mA, I_B = 1.6 mA)	V_{BE}(sat)	0.8 to 0.95	V
Collector-Cutoff Current:			
V_{CE} = 20 V, V_{EB} = 0, T_A = 25°C	I_{CEV}	25 max	nA
V_{CE} = 20 V, V_{EB} = 0, T_A = 150°C	I_{CEV}	25 max	μA
Base-Cutoff Current (V_{CE} = 20 V, V_{EB} = 0)	I_{BEV}	−25 max	nA
Static Forward-Current Transfer Ratio (V_{CE} = 0.35 V, I_C = 10 mA)	h_{FE}	25 min	
Pulsed Static Forward-Current Transfer Ratio:			
V_{CE} = 1 V, I_C = 200 mA, t_p = 50 μs, df = 2%	h_{FE}(pulsed)	10 min	
V_{CE} = 0.4 V, I_C = 50 mA, T_A = −55°C, t_p = 50 μs, df = 2%	h_{FE}(pulsed)	15 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 10 mA, f = 100 Mc/s)	h_{fe}	5 min	
Input Capacitance (V_{EB} = 1 V, I_C = 0, f = 1 Mc/s)	C_{ibo}	5 max	pF
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 1 Mc/s)	C_{obo}	4 max	pF
Storage Time (V_{CC} = 10 V, I_C = 10 mA, I_{B1} = 10 mA, I_{B2} = −10 mA)	t_s	15 max	ns
Turn-On Time (V_{CC} = 6 V, I_C = 50 mA, I_{B1} = 2.5 mA, V_{BB} = −1 V)	t_{on}	30 max	ns
Turn-Off Time (V_{CC} = 6 V, I_C = 50 mA, I_{B1} = 2.5 mA, I_{B2} = −2.5 mA)	t_{off}	30 max	ns



92CS-12337T1



92CS-12135T1

2N2953

TRANSISTOR

Ge **p-n-p alloy-junction** type used in af-driver amplifier applications in consumer and industrial equipment. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage:			
Base open	V_{CBO}	−30	V
V_{BE} = 2 V	V_{CBV}	−30	V
Collector-to-Emitter Voltage (R_{BE} = 10 kΩ)	V_{CER}	−25	V
Emitter-to-Base Voltage	V_{EBO}	−25	V
Collector Current	I_C	−0.15	A
Emitter Current	I_E	0.15	A
Transistor Dissipation:			
T_A up to 55°C	P_T	120	mW
T_C up to 55°C (with practical heat sink, θ = 50°C/W)	P_T	225	mW
T_A or T_C (with practical heat sink) above 55°C	P_T	See curve page 112	

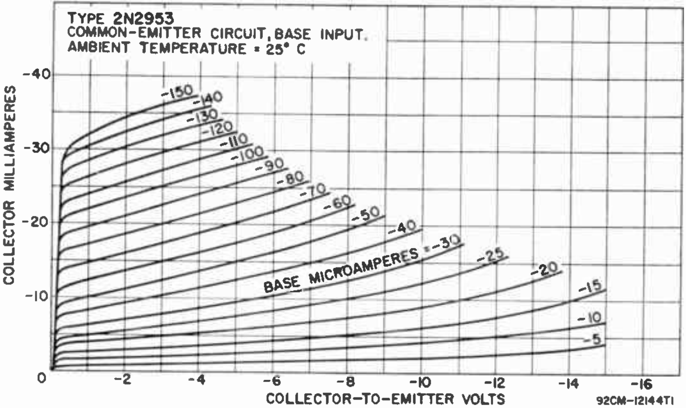
MAXIMUM RATINGS (cont'd)

Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 100	°C
Storage	T_{STG}	−65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

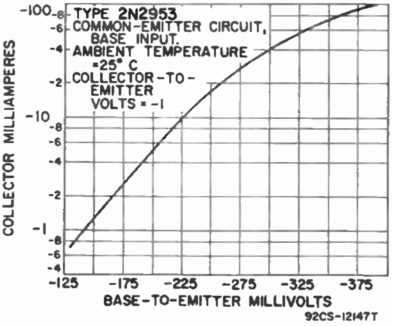
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −0.05 A, V_{BE} = 2 V)	$V_{(BR)CBV}$	−30 min	V
Collector-to-Emitter Breakdown Voltage (I_C = −1 mA, R_{BE} = 10 kΩ)	$V_{(BR)CER}$	−25 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.05 mA, I_C = 0)	$V_{(BR)EBO}$	−25 min	V
Collector-Cutoff Current (V_{CB} = −20 V, I_E = 0)	I_{CBO}	−5 max	µA
Emitter-Cutoff Current (V_{EB} = −20 V, I_C = 0)	I_{EBO}	−7.5 max	µA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −10 V, I_C = −10 mA, f = 1 kc/s)	h_{fe}	200 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = −12 V, I_C = −1 mA)	f_{hfb}	10 typ	Mc/s
Intrinsic Base-Spreading Resistance (V_{CE} = −10 V, I_C = −10 mA, f = 20 Mc/s)	$r_{bb'}$	300 typ	Ω
Collector-to-Base Feedback Capacitance (V_{CE} = −12 V, I_C = −1 mA)	$c_{b'c}$	6.5 typ	pF

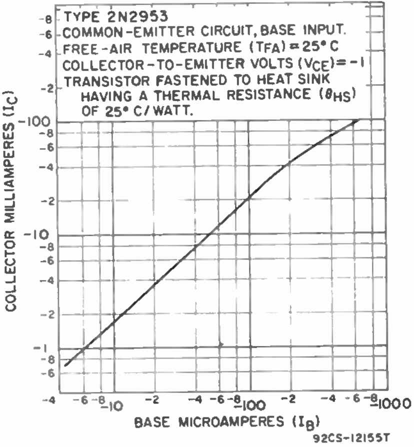
TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC



TYPICAL TRANSFER CHARACTERISTIC



2N3011 COMPUTER TRANSISTOR

Si **n-p-n** epitaxial planar type used for high-speed saturated switching in logic applications. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	30	V
Collector-to-Emitter Voltage	V_{CEO}	12	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.36	W
T_C up to 25°C	P_T	1.2	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J (opr)	—65 to 200	°C
Storage	T_{STG}	—65 to 200	°C
Lead-Soldering Temperature (60 s max)	T_L	300	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage ($I_C = 0.01$ mA, $I_E = 0$)	$V_{(BR)CBO}$	30 min	V
Collector-to-Emitter Breakdown Voltage ($I_C = 0.01$ mA, $R_{BE} = 0$)	$V_{(BR)CES}$	30 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.1$ mA, $I_C = 0$)	$V_{(BB)EBO}$	5 min	V
Collector-to-Emitter Sustaining Voltage ($I_C = 10$ mA, $I_B = 0$, $t_p = 300$ μs, df = 2%)	V_{CEO} (sus)	12 min	V
Collector-to-Emitter Saturation Voltage:			
$I_C = 10$ mA, $I_B = 1$ mA, $T_A = 25$°C	V_{CE} (sat)	0.2 max	V
$I_C = 10$ mA, $I_B = 1$ mA, $T_A = 85$°C	V_{CE} (sat)	0.3 max	V
$I_C = 100$ mA, $I_B = 10$ mA, $T_A = 25$°C	V_{CE} (sat)	0.5 max	V
Base-to-Emitter Saturation Voltage:			
$I_C = 10$ mA, $I_B = 1$ mA	V_{BE} (sat)	0.72 to 0.87	V
$I_C = 100$ mA, $I_B = 10$ mA	V_{BE} (sat)	1.6 max	V
Emitter-Cutoff Current:			
$V_{CE} = 20$ V, $R_{BE} = 0$, $T_A = 85$°C	I_{CES}	10 max	μA
$V_{CE} = 20$ V, $R_{BE} = 0$, $T_A = 25$°C	I_{CES}	0.4 max	μA
Pulsed Static Forward-Current Transfer Ratio:			
$V_{CE} = 0.35$ V, $I_C = 10$ mA, $t_p = 300$ μs, df = 2%	h_{FE} (pulsed)	30 to 120	
$V_{CE} = 1$ V, $I_C = 100$ mA, $t_p = 300$ μs, df = 2%	h_{FE} (pulsed)	12 min	
Small-Signal Forward-Current Transfer Ratio ($V_{CE} = 10$ V, $I_C = 20$ mA, f = 100 Mc/s)	h_{fe}	4 min	
Output Capacitance ($V_{CB} = 5$ V, $I_E = 0$, f = 0.14 Mc/s)	C_{obo}	4 max	pF
Storage Time ($V_{CC} = 10$ V, $I_C = 10$ mA, $I_{B1} = 10$ mA, $I_{B2} = -10$ mA)	t_s	13 max	ns
Turn-On Time ($V_{CC} = 2$ V, $I_C = 10$ mA, $I_{B1} = 3$ mA, V_{BE} (off) $= 0$ V)	$t_d + t_r$	15 max	ns
Turn-Off Time ($V_{CC} = 2$ V, $I_C = 30$ mA, $I_{B1} = 3$ mA, $I_{B2} = -3$ mA)	$t_s + t_f$	20 max	ns

2N3053 POWER TRANSISTOR

Si **n-p-n** triple-diffused planar type used in a wide variety of small signal, medium-power applications (up to 20 Mc/s) in commercial and industrial equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	60	V
$R_{BE} = 10$ Ω	V_{CER}	50	V
Base open (sustaining voltage)	V_{CEO} (sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	0.7	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A or T_C above 25°C	P_T	See curve page 112	

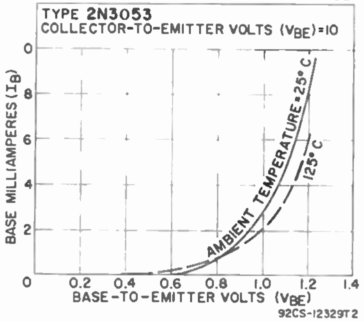
MAXIMUM RATINGS (cont'd)

Temperature Range:			
Operating (T_A-T_C) and Storage (T_{STG})		−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

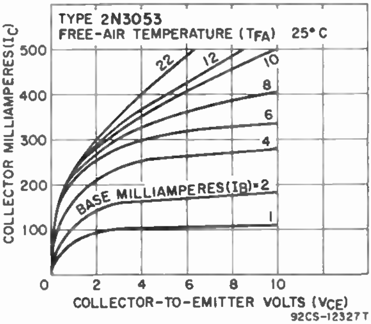
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	60 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 100 mA, R_{BE} = 10 Ω, t_p = 300 μs, df = 2.8%	V_{CER}(sus)	50 min	V
I_C = 100 mA, I_B = 0, t_p = 300 μs, df = 1.8%	V_{CEO}(sus)	40 min	V
Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA)	V_{BE}(sat)	1.7 max	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA)	V_{CE}(sat)	1.4 max	V
Collector-Cutoff Current (V_{CB} = 30 V, I_E = 0)	I_{CBO}	0.25 max	μA
Emitter-Cutoff Current (V_{EB} = 4 V, I_C = 0)	I_{EBO}	0.25 max	μA
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 150 mA, t_p = 300 μs, df = 1.8%)	h_{FE}	50 to 250	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA, f = 20 Mc/s)	h_{fe}	5 min	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0)	C_{ibo}	80 max	pF
Output Capacitance (V_{CB} = 10 V, I_E = 0)	C_{obo}	15 max	pF
Thermal Resistance, Junction-to-Case	$\theta_{J\text{-}C}$	35 max	°C/W

TYPICAL TRANSFER CHARACTERISTICS



TYPICAL COLLECTOR CHARACTERISTICS



POWER TRANSISTOR

2N3054

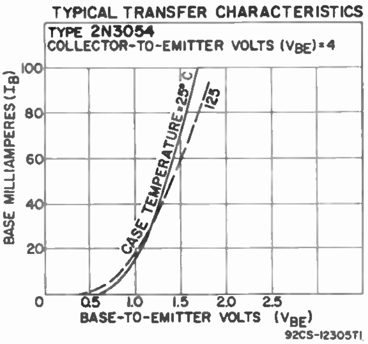
Si **n-p-n diffused-junction** type used in power-switching circuits, series- and shunt-regulator driver and output stages, and high-fidelity amplifiers in commercial and industrial equipment. JEDEC TO-66, **Outline** No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

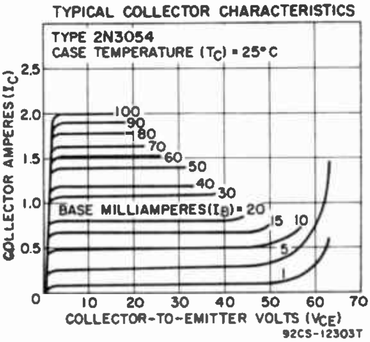
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	90	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	90	V
R_{BE} = 100 Ω	V_{CER}	60	V
Base open (sustaining voltage)	V_{CEO}(sus)	55	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	4	A
Base Current	I_B	2	A
Transistor Dissipation:			
T_C up to 25°C	P_T	29	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_C) and Storage (T_{STG})		−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	235	°C

CHARACTERISTICS (At case temperature = 25°C)

Emitter-to-Base Breakdown Voltage (I_E = 1 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 100 mA, R_{BE} = 100 Ω	V_{CER}(sus)	60 min	V
I_C = 100 mA, I_B = 0	V_{CEO}(sus)	55 min	V
Collector-to-Emitter Saturation Voltage (I_C = 500 mA, I_B = 50 mA)	V_{CE}(sat)	1 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 500 mA)	V_{BE}	1.7 max	V
Collector-Cutoff Current (V_{CE} = 90 V, V_{BE} = −1.5 V)	I_{CEV}	1 max	mA
Emitter-Cutoff Current (V_{EB} = 7 V, I_C = 0)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 500 mA)	h_{FE}	25 to 100	
Thermal Resistance, Junction-to-Case	Θ_{J-C}	6 max	°C/W





2N3055

POWER TRANSISTOR

Si **n-p-n diffused-junction** type used in power-switching circuits, series- and shunt-regulator driver and output stages, and high-fidelity amplifiers in commercial and industrial equipment. JEDEC TO-3, **Outline** No.2. **Terminals**: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

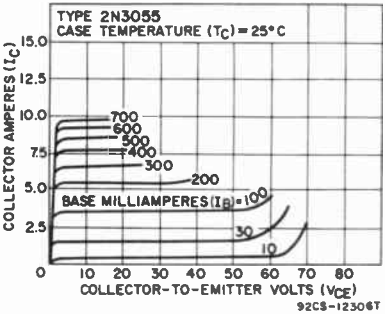
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	100	V
R_{BE} = 100 Ω	V_{CER}	70	V
Base open (sustaining voltage)	V_{CEO}(sus)	60	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	15	A
Base Current	I_B	7	A
Transistor Dissipation:			
T_C up to 25°C	P_T	115	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_C) and Storage (T_{STG})		−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	235	°C

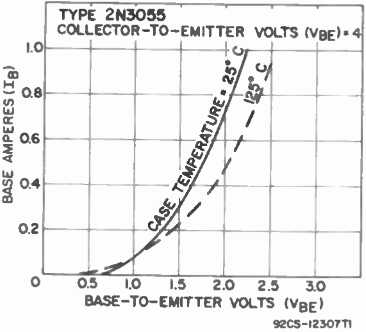
CHARACTERISTICS (At case temperature = 25°C)

Emitter-to-Base Breakdown Voltage (I_E = 5 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 200 mA, R_{BE} = 100 Ω	V_{CER}(sus)	70 min	V
I_C = 200 mA, I_B = 0	V_{CEO}(sus)	60 min	V
Collector-to-Emitter Saturation Voltage (I_C = 4 A, I_B = 400 mA)	V_{CE}(sat)	1.1 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 4 A)	V_{BE}	1.8 max	V
Collector-Cutoff Current (V_{CE} = 100 V, V_{BE} = −1.5 V)	I_{CEV}	5 max	mA
Emitter-Cutoff Current (V_{EB} = 7 V, I_C = 0)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 4 A)	h_{FE}	20 to 70	
Thermal Resistance, Junction-to-Case	Θ_{J-C}	1.5	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



TRANSISTOR 2N3118

Si n-p-n triple-diffused planar type for large-signal vhf class C and small-signal vhf class A amplifier applications in industrial and military communications equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

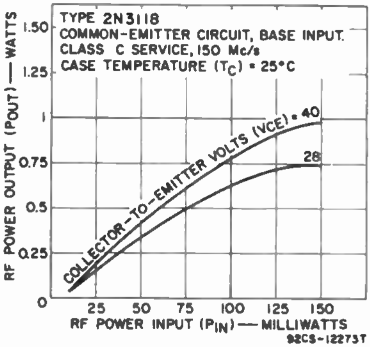
MAXIMUM RATINGS

Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	85	V
Base open	V_{CEO}	60	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	0.5	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	4	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

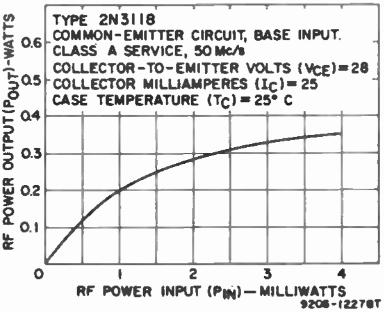
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
$V_{BE} = -1.5$ V, $I_C = 0.1$ mA	$V_{(BR)CEV}$	85 min	V
$I_C = 10$ mA, $I_B = 0$, $t_p = 300$ μs, df = 1.8%	$V_{(BR)CEO}$(sus)	60 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.1$ mA, $I_C = 0$)	$V_{(BR)EBO}$	4 min	V
Collector-Cutoff Current:			
$V_{CB} = 30$ V, $I_E = 0$, $T_A = 25$°C	I_{CBO}	0.1 max	μA
$V_{CB} = 30$ V, $I_E = 0$, $T_A = 150$°C	I_{CBO}	100 max	μA
Small-Signal Short-Circuit Input Impedance, Real Part ($V_{CE} = 28$ V, $I_C = 25$ mA, f = 50 Mc/s)	$R_e(h_{ie})$	25 to 75	Ω

TYPICAL LARGE-SIGNAL CLASS C RF POWER-OUTPUT CHARACTERISTICS



TYPICAL CLASS A RF POWER-OUTPUT CHARACTERISTIC



CHARACTERISTICS (cont'd)

Small-Signal Short-Circuit Output Impedance, Real Part (V_{CE} = 28 V, I_C = 25 mA, f = 50 Mc/s)	$\frac{1}{Y_{22}}$ (real)	500 to 1000	Ω
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = 28 V, I_C = 25 mA, t_p = 300 μs, df ≤ 1.8%)	h_{FE}(pulsed)	50 to 275	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 28 V, I_C = 25 mA, f = 50 Mc/s)	h_{fe}	5 min	
$r_{bb'}C_{b'c}$ Product (V_{CB} = 28 V, I_C = 25 mA, f = 50 Mc/s)	$r_{bb'}C_{b'c}$	60 max	ps
Power Gain, Class A Service (with heat sink) (V_{CE} = 28 V, I_C = 25 mA, P_{oe} = 0.2 W, f = 50 Mc/s)	G_{pe}	18 min	dB
Output Capacitance (V_{CB} = 28 V, I_C = 0, f = 1 Mc/s)	C_{obo}	6 max	pF
Power Output, Class C Oscillator Service (with heat sink):			
V_{CE} = 28 V, P_{ie} = 0.1 W, f = 50 Mc/s	P_{oe}	1 min	W
V_{CE} = 28 V, P_{ie} = 0.1 W, f = 150 Mc/s	P_{oe}	0.4 min	W

TRANSISTOR 2N3119

Si **n-p-n** triple-diffused planar type used in high-voltage, high-frequency pulse-amplifier and high-voltage saturated-switching applications in industrial and military equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

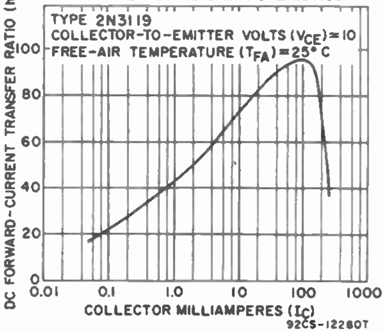
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
V_{BE} = —1.5 V	V_{CEV}	100	V
Base open	V_{CEO}	80	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	0.5	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	4	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C
Storage	T_{STG}	—65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

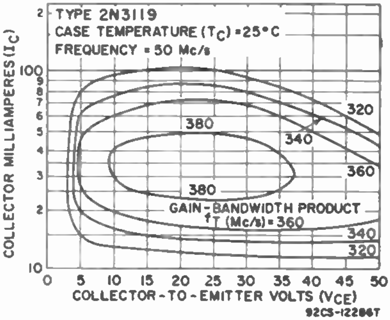
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	100 min	V
Collector-to-Emitter Breakdown Voltage:			
V_{BE} = —1.5 V, I_C = 0.1 mA	$V_{(BR)CEV}$	100 min	V
I_C = 10 mA, I_B = 0, t_p = 300 μs, df = 1.8%	$V_{(BR)CEO}$(sus)	80 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Base-to-Emitter Saturation Voltage (I_C = 100 mA, I_B = 10 mA)	V_{BE}(sat)	1.1 max	V
Collector-to-Emitter Saturation Voltage (I_C = 100 mA, I_B = 10 mA)	V_{CE}(sat)	0.5 max	V
Collector-Cutoff Current:			
V_{CB} = 60 V, I_E = 0, T_A = 25°C	I_{CBO}	50 max	nA
V_{CB} = 60 V, I_E = 0, T_A = 150°C	I_{CBO}	50 max	μA
Emitter-Cutoff Current (V_{BE} = —3 V, I_C = 0, T_A = 25°C)	I_{EBO}	100 max	nA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 10 mA)	h_{FE}	40 min	
Pulsed Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 100 mA, t_p = 300 μs, df = 1.8%	h_{FE}(pulsed)	50 to 200	
V_{CE} = 10 V, I_C = 250 mA, t_p = 300 μs, df = 1.8%	h_{FE}(pulsed)	20 min	
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 25 mA, f = 50 Mc/s)	f_T	250 min	Mc/s
Output Capacitance (V_{CB} = 28 V, I_C = 0, f = 1 Mc/s)	C_{obo}	6 max	pF
Pulsed-Amplifier Rise Time (V_{CC} = 80 V, I_C = 10 mA)		20 max	ns
Saturated Switch Turn-On Time (V_{CC} = 28 V, I_C = 100 mA, I_{B_1} = 10 mA)	$t_d + t_r$	40 max	ns
Saturated Switch Turn-Off Time (V_{CC} = 28 V, I_C = 100 mA, I_{B_2} = —10 mA)	$t_s + t_f$	700 max	ns

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



TYPICAL COLLECTOR-CURRENT CHARACTERISTICS



TRANSISTOR 2N3229

Si n-p-n triple-diffused planar type used in large-signal, high-power AM, FM, and cw applications at vhf frequencies in industrial and military, communications equipment. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, 2 - base, 3 - collector.

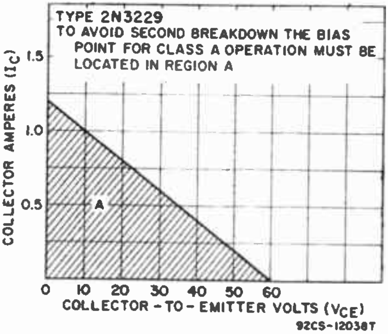
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	105	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	105	V
Base open	V_{CEO}	60	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	2.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	17.5	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

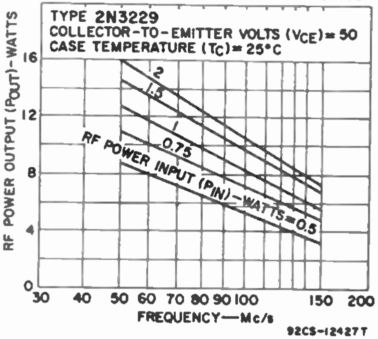
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.5 mA, I_E = 0)	$V_{(BR)CBO}$	105 min	V
Collector-to-Emitter Breakdown Voltage:			
V_{BE} = −1.5 V, I_C = 0.1 mA	$V_{(BR)CEV}$	105 min	V
I_C = 500 mA, I_B = 0, t_p = 5 μs, df = 1%	$V_{(BR)CEO}$(sus)	60 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage (I_C = 2.5 A, I_B = 500 mA)	V_{CE}(sat)	1 max	V
Collector-Cutoff Current (V_{CB} = 30 V, I_E = 0)	I_{CBO}	0.1 max	μA
Intrinsic Base-Spreading Resistance (V_{CE} = 28 V, I_C = 250 mA, f = 400 Mc/s)	$r_{bb'}$	6	Ω

SAFE OPERATING REGION



TYPICAL OPERATION CHARACTERISTICS



CHARACTERISTICS (cont'd)

Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 250 mA)	f_T	200 typ	Mc/s
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 140 kc/s)	C_{obo}	20 max	pF
Collector-to-Case Capacitance	C_c	6 max	pF
RF Power Output, Unneutralized:			
V_{CC} = 50 V, I_C = 500 mA, P_{IE} = 2 W, f = 50 Mc/s	P_{OE}	15 min	W
V_{CC} = 50 V, I_C = 250 mA, P_{IE} = 1 W, f = 150 Mc/s	P_{OE}	5 min	W

2N3230 MULTIUNIT SEMICONDUCTOR DEVICE

Two Si n-p-n epitaxial planar transistors and a commutating diode used in high-speed switching and high-gain linear amplifier applications for aerospace, military, and industrial service. The transistors are internally connected to form an amplifier (Darlington) circuit, and the diode is connected across the output transistor. **Outline No.25. Terminals:** 1 - base 2, 2 - emitter, 3 - collector, 4 - base 1.

MAXIMUM RATINGS

Collector-to-Base 1 Voltage (base 2 and emitter open)	V_{CB_1O}	80	V
Collector-to-Emitter Voltage:			
V_{B_1E} = −1.5 V, R_{B_2E} = 50 Ω	V_{CEV}	80	V
R_{B_1E} and R_{B_2E} ≦ 50 Ω	V_{CER}(sus)	60	V
Base 1 and base 2 open	V_{CEO}(sus)	60	V
Emitter-to-Base 1 Voltage (collector and base 2 open)	V_{EB_1O}	10	V
Collector Current	I_C	7	A
Base 1 Current	I_{B_1}	100	mA
Diode Current	I_F	5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	25	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_C) and (T_{STG})		−55 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	235	°C

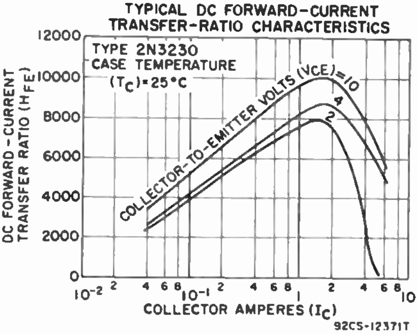
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:	V_F	2 max	V
V_{B_1E} = −1.5 V, R_{B_2E} = 50 Ω	$V_{(BR)CEV}$	80 min	V
R_{B_1E} ≦ 50 Ω, I_C = 50 mA, I_{B_2} = 0	$V_{(BR)CER_1}$(sus)	60 min	V
R_{B_1E} ≦ 50 Ω, R_{B_2E} ≦ 50 Ω, I_C = 50 mA	$V_{(BR)CER_2}$(sus)	80 min	V
I_C = 50 mA, I_{B_1} and I_{B_2} = 0	$V_{(BR)CEO}$(sus)	60 min	V
Collector-to-Emitter Saturation Voltage (I_{B_1} = 3 mA, I_C = 2 A, I_{B_2} = 0)	V_{CE}(sat)	1.4 max	V
Base 1-to-Emitter Saturation Voltage (I_{B_1} = 3 mA, I_C = 2 A, I_{B_2} = 0)	V_{B_1E}(sat)	2 max	V
Base 1-to-Emitter Voltage (V_{CE} = 4 V, I_C = 2 A, I_{B_2} = 0)	V_{B_1E}	1.8 max	V
Collector-Cutoff Current:			
V_{CE} = 50 V, I_{B_1} and I_{B_2} = 0, T_C = 25°C	I_{CEO}	100 max	μA
V_{CE} = 50 V, I_{B_1} and I_{B_2} = 0, T_C = 125°C	I_{CEO}	1.5 max	mA
R_{B_2E} ≦ 50 Ω, V_{CE} = 80 V, V_{B_1E} = −1.5 V	I_{CEV}	2 max	mA
Emitter-Cutoff Current (V_{EB_1} = 10 V, I_{B_2} and I_C = 0)	I_{EB_1O}	50 max	μA
Static Forward-Current Transfer Ratio:			
V_{CE} = 4 V, I_C = 5 A, I_{B_2} = 0	h_{FE}	1000 min	
V_{CE} = 4 V, I_C = 2 A, I_{B_2} = 0	h_{FE}	2000 to 20000	
V_{CE} = 4 V, I_C = 50 mA, I_{B_2} = 0	h_{FE}	1000 min	
Gain-Bandwidth Product (V_{CE} = 10 V, I_C = 1 A, I_{B_2} = 0, f = 20 Mc/s)	f_T	40 min	Mc/s
Collector-to-Base 1 Capacitance (V_{CB_1} = 10 V, I_{B_2} and I_C = 0, f = 1 Mc/s)	C_{ob_1o}	60 max	pF
Collector-to-Base 2 Capacitance (V_{CB_2} = 10 V, I_{B_1} and I_C = 0, f = 1 Mc/s)	C_{ob_2o}	200 max	pF
Turn-On Time, Saturated Switch (V_{CE} = 28 V, I_{B_1}(on) = 4 mA, I_{B_2}(off) = −8 mA, I_C = 2 A)	$t_d + t_r$	350 max	ns
Storage Time (V_{CE} = 28 V, I_{B_1}(on) = 4 mA, I_{B_2}(off) = −8 mA, I_C = 2 A)	t_s	1600 max	ns
Fall Time (V_{CE} = 28 V, I_{B_1}(on) = 4 mA, I_{B_2}(off) = −8 mA, I_C = 2 A)	t_f	550 max	ns

CHARACTERISTICS (cont'd)

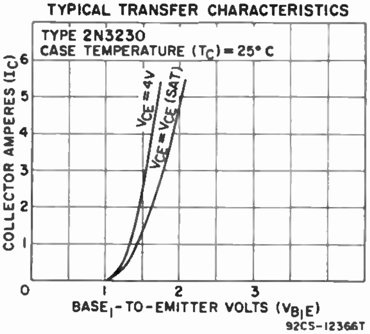
Commutating-Diode Forward Voltage (I_C = 2 A, inverted direction)	V_F	2 max	V
Thermal Resistance, Junction-to-Case	θ_{J-C}	7 max	°C/W

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



92CS-12371T

TYPICAL TRANSFER CHARACTERISTICS



92CS-12366T

MULTIUNIT SEMICONDUCTOR DEVICE 2N3231

Two Si n-p-n epitaxial planar transistors and a commutating diode used in high-speed switching and high-gain linear amplifier applications for aerospace, military, and industrial service. The transistors are internally connected to form an amplifier (Darlington) circuit, and the diode is connected across the output transistor. **Outline** No.25. **Terminals:** 1 - base 2, 2 - emitter, 3 - collector, 4 - base 1. This type is identical with type 2N3230 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage (base 2 and emitter open)	V_{CB_1O}	100	V
Collector-to-Emitter Voltage:			
V_{B_1E} = −1.5 V, R_{B_2E} = 50 Ω	V_{CEV}	100	V
R_{B_1E} and R_{B_2E} ≦ 50 Ω	V_{CER}(sus)	80	V
Base 1 and base 2 open	V_{CEO}(sus)	80	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown (Sustaining):			
V_{B_1E} = −1.5 V, R_{B_2E} = 50 Ω	$V_{(BR)CEV}$	100 min	V
R_{B_1E} ≦ 50 Ω, I_C = 50 mA, I_{B_2} = 0	$V_{(BR)CER_1}$(sus)	80 min	V
R_{B_1E} ≦ 50 Ω, R_{B_2E} ≦ 50 Ω, I_C = 50 mA	$V_{(BR)CER_2}$(sus)	100 min	V
I_C = 50 mA, I_{B_1} and I_{B_2} = 0	$V_{(BR)CEO}$(sus)	80 min	V
Collector-Cutoff Current (R_{B_2E} ≦ 50 Ω, V_{CE} = 100 V, V_{B_1E} = −1.5 V)	I_{CEV}	2 max	mA
Storage Time (V_{CE} = 28 V, I_{B_1}(on) = 4 mA, I_{B_2}(off) = −8 mA, I_C = 2 A)	t_s	1250 max	ns
Fall Time (V_{CE} = 28 V, I_{B_1}(on) = 4 mA, I_{B_2}(off) = −8 mA, I_C = 2 A)	t_f	400 max	ns

TRANSISTOR 2N3241

Si n-p-n planar type for high-gain, low-noise amplifier applications in commercial and industrial equipment. **Outline** No.26 (3-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

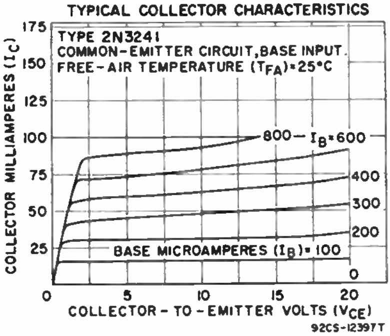
Collector-to-Base Voltage (V_{BE} = −1.5 V)	V_{CBV}	30	V
Collector-to-Emitter Voltage	V_{CEO}	25	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	100	mA
Emitter Current	I_E	−100	mA

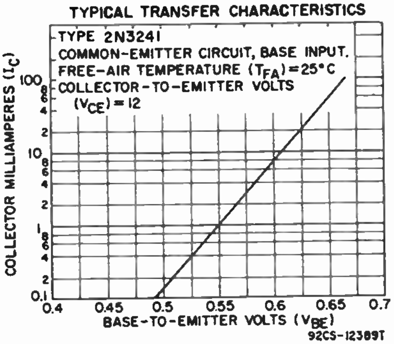
MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_C up to 25°C	P_T	2	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	–65 to 175	°C
Storage	T_{STG}	–65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (V_{BE} = –1 V, I_C = 50 μA)	$V_{(BR)CBV}$	30 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 10 mA, I_B = 0)	$V_{(BR)CEO}$	25 min	V
Emitter-to-Base Breakdown Voltage (I_E = 50 μA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Saturation Voltage (I_C = 50 mA, I_B = 2.5 mA)	V_{CE}(sat)	1 max	V
Base-to-Emitter Saturation Voltage (I_C = 50 mA, I_B = 2.5 mA)	V_{BE}(sat)	0.8	V
Collector-Cutoff Current:			
V_{CB} = 25 V, I_E = 0, T_A = 25°C	I_{CBO}	100 max	nA
V_{CB} = 25 V, I_E = 0, T_A = 85°C	I_{CBO}	10 max	μA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	100 max	nA
Static Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA)	h_{FE}	50 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kc/s)	h_{fe}	70 to 250	
Gain-Bandwidth Product (V_{CE} = 6 V, I_C = 1 mA)	f_T	60	Mc/s
Intrinsic Base-Spreading Resistance (V_{CE} = 60 V, I_C = 1 mA, f = 100 Mc/s)	$r_{bb'}$	20	Ω
Output Capacitance (V_{CB} = 6 V, I_E = 0, f = 1 kc/s)	C_{obo}	22	pF
Noise Figure (V_{CE} = 6 V, R_G = 1000 Ω, I_C = 0.5 mA, f = 1 kc/s, circuit bandwidth = 1 c/s)	NF	10 max	dB
Small-Signal Input Impedance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kc/s)	h_{ie}	600	Ω
Small-Signal Output Admittance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kc/s)	h_{oe}	75	μmhos
Small-Signal Reverse-Voltage Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kc/s)	h_{re}	125 x 10^{-6}	
Thermal Resistance, Junction-to-Case	θ_{J-C}	300 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	50 max	°C/W





2N3242

TRANSISTOR

Si **n-p-n planar** type for high-gain, low-noise amplifier applications in commercial and industrial equipment. It is especially suitable for high-input impedance, direct-coupled amplifier stages. **Outline No.26** (3-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N3241 except for the following items:

MAXIMUM RATINGS

Collector Current	I_C	200	mA
Emitter Current	I_E	−200	mA

CHARACTERISTICS

Collector-Cutoff Current:			
V_{CB} = 25 V, I_E = 0, T_A = 25°C	I_{CBO}	10 max	nA
V_{CB} = 25 V, I_E = 0, T_A = 150°C	I_{CBO}	10 max	µA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	10 max	nA
Static Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA)	h_{FE}	75 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kc/s)	h_{fe}	100 to 375	
Noise Figure (V_{CE} = 6 V, R_G = 1000 Ω, I_C = 0.5 mA, f = 1 kc/s, circuit bandwidth = 1 c/s)	NF	6 max	dB

COMPUTER TRANSISTOR 2N3261

Si **n-p-n epitaxial planar** type used in high-speed switching applications in military and commercial data-processing equipment such as digital-logic circuits, terminated-line-driver service, and as a high-speed-memory driver. JEDEC TO-52, Outline No.18. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

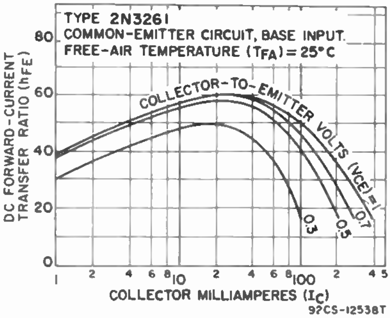
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage	V_{CEO}	15	V
Emitter-to-Base Voltage	V_{EBO}	6	V
Collector Current	I_C	500	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	0.3	W
T_C up to 25°C	P_T	1	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A-T_C)		−65 to 175	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

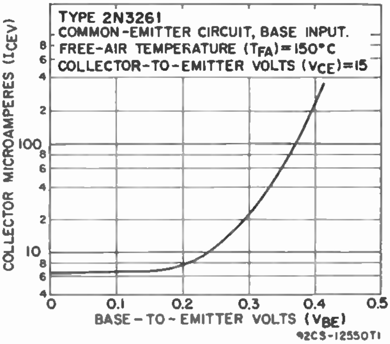
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.01 mA, I_E = 0)	$V_{(BR)CBO}$	40 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 10 mA, I_B = 0, t_p = 100 µs, df ≦ 2%)	$V_{(BR)CEO}$	15 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.01 mA, I_C = 0)	$V_{(BR)EBO}$	6 min	V
Base-to-Emitter Saturation Voltage (I_C = 100 mA, I_B = 10 mA)	V_{BE}(sat)	0.8 to 1.1	V
Collector-to-Emitter Saturation Voltage (I_C = 100 mA, I_B = 10 mA, t_p = 100 µs, df ≦ 2%)	V_{CE}(sat)	0.35 max	V
Base-Cutoff Current (V_{CE} = 15 V, V_{BE} = 0)	I_{BEV}	−25 max	nA
Collector-Cutoff Current:			
V_{CE} = 15 V, V_{BE} = 0, T_A = 15°C	I_{CEV}	25 max	nA
V_{CE} = 15 V, V_{BE} = 0, T_A = 150°C	I_{CEV}	25 max	µA

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



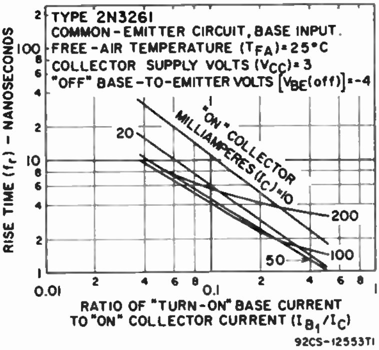
TYPICAL TRANSFER CHARACTERISTICS



CHARACTERISTICS (cont'd)

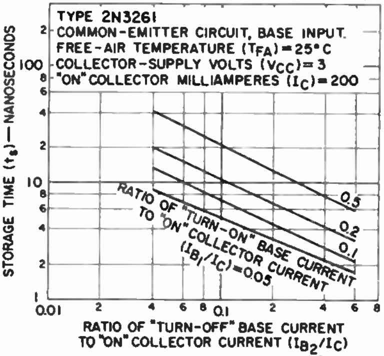
Static Forward-Current Transfer Ratio:			
V_{CE} = 1 V, I_C = 10 mA, T_A = 25°C	h_{FE}	40 to 150	
V_{CE} = 1 V, I_C = 10 mA, T_A = 55°C	h_{FE}	20 min	
Pulsed Static Forward-Current Transfer Ratio:			
V_{CE} = 1 V, I_C = 100 mA, t_p = 300 μs, df $\leqq$ 2%	h_{FE}(pulsed)	30 min	
V_{CE} = 1 V, I_C = 200 mA, t_p = 300 μs, df $\leqq$ 2%	h_{FE}(pulsed)	20 min	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 1 V, I_C = 100 mA, f = 100 Mc/s	h_{fe}	3 min	
V_{CE} = 10 V, I_C = 10 mA, f = 100 Mc/s	h_{fe}	6 min	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 1 Mc/s)	C_{ibo}	4 max	pF
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 1 Mc/s)	C_{obo}	3.5 max	pF
Delay Time (V_{CC} = 6 V, V_{BE}(off) = −4 V, I_{B_1} = 10 mA, I_{CS} = 100 mA, I_{B_2} = −10 mA)	t_d	6 max	ns
Rise Time (V_{CC} = 6 V, V_{BE}(off) = −4 V, I_{B1} = 10 mA, I_{CS} = 100 mA, I_{B2} = −10 mA)	t_r	7 max	ns
Fall Time (V_{CC} = 6 V, I_{B_1} = 10 mA, I_{CS} = 100 mA, I_{B_2} = −10 mA)	t_f	6 max	ns
Storage Time (V_{CC} = 6 V, I_{B_1} = 10 mA, I_{CS} = 100 mA, I_{B_2} = −10 mA)	t_s	10 max	ns

TYPICAL RISE-TIME CHARACTERISTICS



92CS-12553T1

TYPICAL STORAGE-TIME CHARACTERISTICS



92CS-12559T

2N3262 TRANSISTOR

Si **n-p-n triple-diffused planar** type used in high-voltage, high-frequency pulse-amplifier and high-voltage saturated-switching applications in industrial and military equipment. JEDEC TO-39, **Outline** No.12. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	100	V
Base open (sustaining voltage)	V_{CEO}(sus)	80	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	1.5	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	8.75	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A-T_C) and Storage (T_{STG})		−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

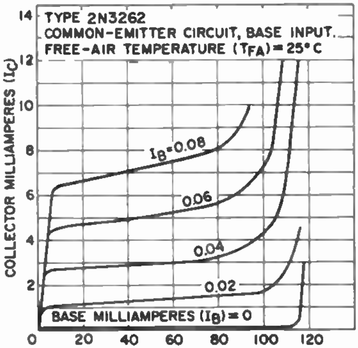
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage (V_{BE} = −1.5 V, I_C = 0.25 mA)	$V_{(BR)CEV}$	100 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 500 mA, R_{BE} = 10 Ω, t_p = 15 μs, df = 1.5%	V_{CER}(sus)	90 min	V
I_C = 500 mA, I_B = 0, t_p = 15 μs, df = 1.5%	V_{CEO}(sus)	80 min	V

CHARACTERISTICS (cont'd)

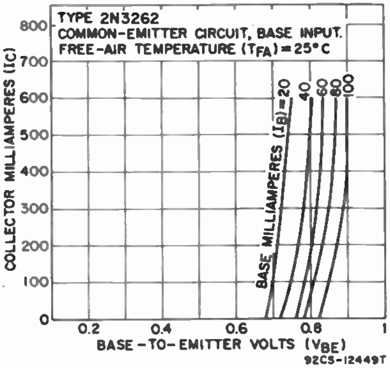
Collector-to-Emitter Saturation Voltage ($I_C = 1$ A, $I_B = 100$ mA)	$V_{CE}(sat)$	0.6 max	V
Base-to-Emitter Saturation Voltage ($I_C = 1$ A, $I_B = 100$ mA)	$V_{BE}(sat)$	1.4 max	V
Collector-Cutoff Current ($V_{CB} = 30$ V, $I_E = 0$, $T_A = 25°C$)	I_{CBO}	0.1 max	µA
Emitter-Cutoff Current ($V_{EB} = 3$ V, $I_C = 0$)	I_{EBO}	100 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = 4$ V, $I_C = 500$ mA)	h_{FE}	40 min	
Small-Signal Forward-Current Transfer Ratio ($V_{CE} = 28$ V, $I_C = 100$ mA, f = 50 Mc/s)	h_{fe}	3 min	
Input Capacitance ($V_{EB} = 3$ V, $I_C = 0$, f = 1 Mc/s)	C_{ibo}	300 max	pF
Output Capacitance ($V_{CB} = 28$ V, $I_C = 0$, f = 1 Mc/s)	C_{obo}	20 max	pF
Pulse-Amplifier Rise Time ($V_{CC} = 80$ V, $I_C = 25$ mA)	t_r	20 max	ns
Turn-On Time, Saturated Switch ($V_{CC} = 28$ V, $I_C = 1$ A, $I_{B_1} = 100$ mA)	$t_d + t_r$	40 max	ns
Turn-Off Time, Saturated Switch ($V_{CC} = 28$ V, $I_C = 1$ A, $I_{B2} = -100$ mA)	$t_s + t_f$	750 max	ns

TYPICAL COLLECTOR CHARACTERISTICS



92CS-12454T

TYPICAL TRANSFER CHARACTERISTICS



92CS-12449T

POWER TRANSISTOR 2N3263

Si n-p-n epitaxial type used in high-power, high-speed, and high-current applications such as switching circuits, amplifiers, and power oscillators in aerospace, military, and industrial applications. Outline No.24. Terminals: B - base, E - emitter, C - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	150	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	150	V
$R_{BE} \leqq 50$ Ω	$V_{CER}(sus)$	110	V
Base open (sustaining voltage)	$V_{CEO}(sus)$	90	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	25	A
Base Current	I_B	10	A
Transistor Dissipation	P_T	See Rating Chart	
Temperature Range:			
Operating (Junction)	$T_J(opr)$	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C

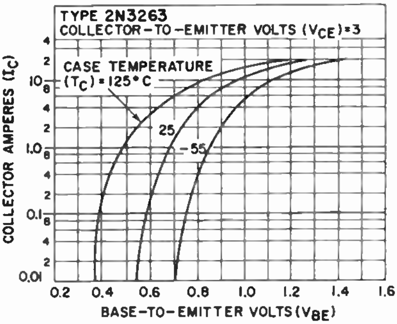
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage:			
$I_C = 0.2$ A, $I_B = 0$	$V_{CEO}(sus)$	90 min	V
$I_C = 0.2$ A, $R_{BE} \leqq 50$ Ω	$V_{CER}(sus)$	110 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 15$ A, $I_B = 1.2$ A, $t_p = 350$ µs, df $\leqq$ 2%)	$V_{CE}(sat)$	0.75 max	V
Base-to-Emitter Saturation Voltage ($I_C = 15$ A, $I_B = 1.5$ A, $t_p = 350$ µs, df $\leqq$ 2%)	$V_{BE}(sat)$	1.6 max	V
Emitter-to-Base Voltage ($I_E = 0.02$ A, $I_C = 0$)	V_{EBO}	7 min	V
Collector-Cutoff Current:			
$V_{CE} = 150$ V, $V_{BE} = -1.5$ V, $T_C = 25°C$	I_{CEV}	20 max	mA
$V_{CB} = 80$ V, $I_E = 0$, $T_C = 25°C$	I_{CBO}	4 max	mA
$V_{CB} = 80$ V, $I_E = 0$, $T_C = 125°C$	I_{CBO}	4 max	mA

CHARACTERISTICS (cont'd)

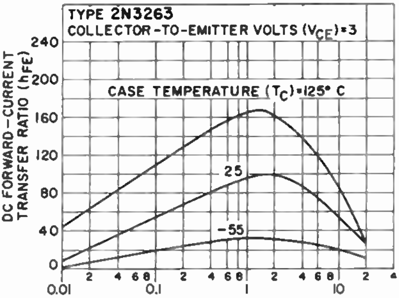
Emitter-Cutoff Current: V_{EB} = 5 V, I_C = 0, T_C = 25°C	I_{EBO}	5 max	mA
V_{EB} = 5 V, I_C = 0, T_C = 125°C	I_{EBO}	5 max	mA
Pulsed Static Forward-Current Transfer Ratio: V_{CE} = 3 V, I_C = 15 A, t_p = 350 µs, df = 2%	h_{FE}(pulsed)	25 to 75	
V_{CE} = 4 V, I_C = 20 A, t_p = 350 µs, df = 2%	h_{FE}(pulsed)	20 min	
Collector-to-Base Feedback Capacitance (V_{CB} = 10 V, I_E = 0, f = 1 Mc/s)	$C_{b'c}$	900 max	pF
Turn-On Time, Saturated Switch (V_{CC} = 30 V, I_C = 15 A, I_{B_1} = 1.2 A, I_{B_2} = −1.2 A)	$t_d + t_r$	0.5 max	µs
Fall Time, Saturated Switch (V_{CC} = 30 V, I_C = 15 A, I_{B_1} = 1.2 A, I_{B_2} = −1.2 A)	t_f	0.5 max	µs
Storage Time, Saturated Switch (V_{CC} = 30 V, I_C = 15 A, I_{B_1} = 1.2 A, I_{B_2} = −1.2 A)	t_s	1.5 max	µs
Gain-Bandwidth Product (V_{CE} = 10 V, I_C = 3 A, f = 5 Mc/s)	f_T	20 min	Mc/s
Second-Breakdown Current, Safe Operating Region (V_{CE} = 75 V)	$I_{S/b}$	350 min	mA
Second-Breakdown Energy, Safe Operating Region (V_{BE} = −6 V, I_C = 10 A, R_{BE} = 20 Ω, L = 40 µH)	$E_{S/b}$	2 min	mJ
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

TYPICAL TRANSFER CHARACTERISTICS



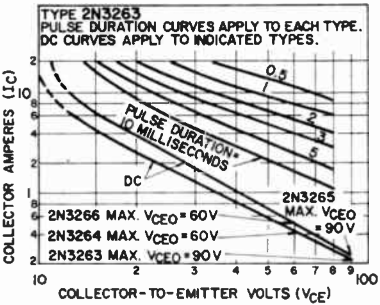
92CS-12437T

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



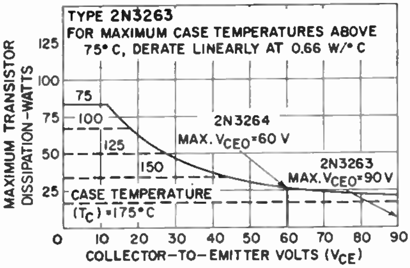
92CS-12443T

SAFE OPERATING REGION



92CS-12428T

RATING CHART



92CS-12433T

2N3264 TRANSISTOR

Si n-p-n epitaxial type used in high-power, high-speed, and high-current applications, such as switching circuits, amplifiers, and power oscillators in aerospace, military, and industrial applications. Outline No.24. Terminals: B - base, E - emitter, C - collector and case. For curves of safe operating region, transfer characteristics, and static forward-current transfer ratio, refer to type 2N3263.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	120	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	120	V
$R_{BE} = 50\ \Omega$	$V_{CER}(sus)$	80	V
Base open (sustaining voltage)	$V_{CEO}(sus)$	60	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	25	A
Base Current	I_B	10	A
Transistor Dissipation	See Rating Chart for type 2N3263		
Temperature Range:			
Operating (Junction)	$T_J(opr)$	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C

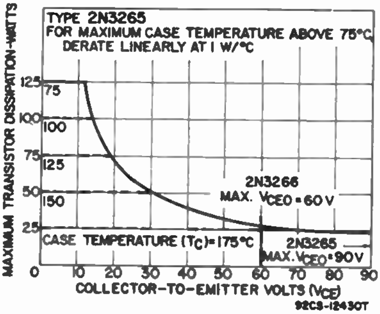
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage:			
$I_C = 0.2$ A, $I_B = 0$	$V_{CEO}(sus)$	60 min	V
$I_C = 0.2$ A, $R_{BE} \leqq 50\ \Omega$	$V_{CER}(sus)$	80 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 15$ A, $I_B = 1.2$ A, $t_p = 350\ \mu s$, df = 2%)	$V_{CE}(sat)$	1.2 max	V
Base-to-Emitter Saturation Voltage ($I_C = 15$ A, $I_B = 1.5$ A, $t_p = 350\ \mu s$, df = 2%)	$V_{BE}(sat)$	1.8 max	V
Emitter-to-Base Voltage ($I_E = 0.02$ A, $I_C = 0$)	V_{EBO}	7 min	V
Collector-Cutoff Current:			
$V_{CE} = 120$ V, $V_{BE} = -1.5$ V, $T_C = 25°C$	I_{CEV}	20 max	mA
$V_{CB} = 60$ V, $I_E = 0$, $T_C = 25°C$	I_{CBO}	10 max	mA
$V_{CB} = 60$ V, $I_E = 0$, $T_C = 125°C$	I_{CBO}	10 max	mA
Emitter-Cutoff Current:			
$V_{EB} = 5$ V, $I_C = 0$, $T_C = 25°C$	I_{EBO}	15 max	mA
$V_{EB} = 5$ V, $I_C = 0$, $T_C = 125°C$	I_{EBO}	15 max	mA
Pulsed Static Forward-Current Transfer Ratio:			
$V_{CE} = 3$ V, $I_C = 15$ A, $t_p = 350\ \mu s$, df = 2%	$h_{FE}(pulsed)$	20 to 80	
$V_{CE} = 4$ V, $I_C = 20$ A, $t_p = 350\ \mu s$, df = 2%	$h_{FE}(pulsed)$	15 min	
Collector-to-Base Feedback Capacitance ($V_{CB} = 10$ V, $I_E = 0$, f = 1 Mc/s)	$C_{b'c}$	900 max	pF
Turn-On Time, Saturated Switch ($V_{CC} = 30$ V, $I_C = 15$ A, $I_{B_1} = 1.2$ A, $I_{B_2} = -1.2$ A)	$t_d + t_r$	0.5 max	µs
Fall Time, Saturated Switch ($V_{CC} = 30$ V, $I_C = 15$ A, $I_{B_1} = 1.2$ A, $I_{B_2} = -1.2$ A)	t_f	0.5 max	µs
Storage Time, Saturated Switch ($V_{CC} = 30$ V, $I_C = 15$ A, $I_{B_1} = 1.2$ A, $I_{B_2} = -1.2$ A)	t_s	1.5 max	µs
Gain-Bandwidth Product ($V_{CE} = 10$ V, $I_C = 3$ A, f = 5 Mc/s)	f_T	20 min	Mc/s
Second-Breakdown Current, Safe Operating Region ($V_{CE} = 75$ V)	$I_{S/b}$	700 min	mA
Second-Breakdown Energy, Safe Operating Region ($V_{BE} = 6$ V, $I_C = 10$ A, $R_{BE} = 20\ \Omega$, L = 40 µH)	$E_{S/b}$	2 min	mJ
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

POWER TRANSISTOR **2N3265**

Si n-p-n epitaxial type used in high-power, high-speed, and high-current applications such as switching circuits, amplifiers, and power oscillators in aerospace, military, and industrial applications. JEDEC TO-63, Outline

RATING CHART



No.21. **Terminals:** C - collector and case, B - base, E - emitter. This type is identical with type 2N3263 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation	P_T	See Rating Chart	

CHARACTERISTICS

Thermal Resistance, Junction-to-Case	θ_{J-C}	1 max	°C/W

2N3266 POWER TRANSISTOR

Si **n-p-n epitaxial** type used in high-power, high-speed, and high-current applications such as switching circuits, amplifiers, and power oscillators in aerospace, military, and industrial applications. JEDEC TO-63, **Outline** No.21. **Terminals:** C - collector and case, B - base, E - emitter. For curves of safe operating region, transfer characteristics, and static forward-current transfer ratio, refer to type 2N3263. This type is identical with type 2N3264 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation	See Rating Chart for Type 2N3265

CHARACTERISTICS

Thermal Resistance, Junction-to-Case	θ_{J-C}	1 max	°C/W

2N3375 TRANSISTOR

Si **n-p-n** "overlay" **epitaxial planar** type used in large-signal, high-power vhf-uhf applications for industrial and military communications equipment in class A, B, or C amplifier, frequency-multiplier, or oscillator operation. JEDEC TO-60, **Outline** No.20. **Terminals:** 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATING

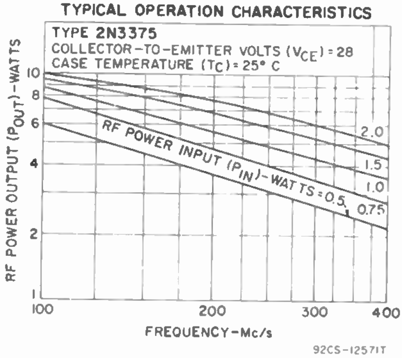
Collector-to-Base Voltage	V_{CBO}	65	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	65	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	1.5	A
Base Current	I_C	0.2	A
Transistor Dissipation:			
T_C up to 25°C	P_T	11.6	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

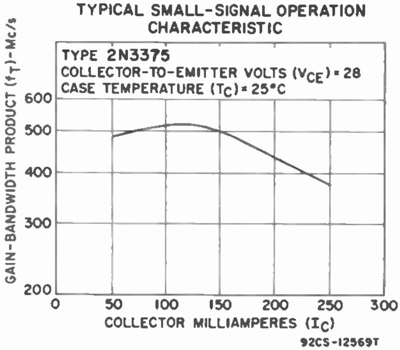
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage			
I_C = 0.1 mA, I_E = 0)	$V_{(BB)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0.2 A, I_B = 0, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	40 min	V
I_C = 0 to 0.2A, V_{BE} = −1.5 V, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	65 min	V
Emitter-to-Base Breakdown Voltage			
(I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 200 mA, I_B = 0	V_{CEO}(sus)	40 min	V
I_C = 200 mA, R_{BE} = 100 Ω	V_{CER}(sus)	40 min	V
Collector-to-Emitter Saturation Voltage			
(I_C = 250 mA, I_B = 50 mA)	V_{CE}(sat)	1 max	V
Emitter-Cutoff Current (V_{EB} = 4 V)	I_{EBO}	0.1 max	mA
Collector-Cutoff Current:			
V_{CE} = 65 V, V_{BE} = −1.5 V, T_C = 25°C	I_{CEV}	1 max	mA
V_{CE} = 30 V, V_{BE} = −1.5 V, T_C = 200°C	I_{CEV}	5 max	mA
V_{CE} = 30 V, I = 0, T_C = 25°C	I_{CEO}	0.1 max	mA

CHARACTERISTICS (cont'd)

RF Power Output:			
Unneutralized Amplifier			
V_{CE} = 28 V, P_{IE} = 1 W, f = 100 Mc/s	P_{OE}	7.5 min	W
V_{CE} = 28 V, P_{IE} = 1 W, f = 400 Mc/s	P_{OE}	3 min	W
Oscillator			
V_{CE} = 28 V, f = 500 Mc/s	P_{OE}	2.5	W
Static Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 250 mA	h_{FE}	10 to 100	
V_{CE} = 5 V, I_C = 125 mA	h_{FE}	200 max	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 28 V, I_C = 125 mA, f = 100 Mc/s	h_{fe}	4 min	
Output Capacitance (V_{CB} = 30 V, I_C = 125 mA, f = 1 Mc/s)	C_{obo}	12 max	pF
Available Amplifier Signal Input Power:			
P_{OE} = 3 W, R_G = 50 Ω, f = 2400 Mc/s	P_{IE}	1 min	W
P_{OE} = 7.5 W, R_G = 50 Ω, f = 100 Mc/s	P_{IE}	1 min	W
Collector Circuit Efficiency:			
P_{IE} = 1 W, R_G = 50 Ω, P_{OE} = 3 W, f = 400 Mc/s	η	40 min	%
P_{IE} = 1 W, R_G = 50 Ω, P_{OE} = 7.5 W, f = 100 Mc/s	η	65 min	%





TRANSISTOR 2N3435

Si **n-p-n** triple-diffused planar type used in vhf large-signal class A amplifier applications. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	80	V
Collector-to-Emitter Voltage	V_{CEO}	60	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	0.25	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	4	W
T_A or T_C above 25°C	P_T	See curve page 112	
Storage-Temperature Range	T_{STG}	—65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	80 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 10 mA, I_B = 0)	$V_{(BR)CEO}$(sus)	60 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-Cutoff Current:			
V_{CB} = 40 V, I_E = 0, T = 25°C	I_{CBO}	0.05 max	µA
V_{CB} = 40 V, I_E = 0, T = 150°C	I_{CBO}	50 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 20 V, I_C = 10 mA)	h_{FE}	50 to 200	
Large-Signal Average Power Gain (V_{CE} = 40 V, I_C = 60 mA, R_G = 50 Ω, P_{IE} = 100 mW, f = 70 Mc/s)	G_{PE}	10 min	dB
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 40 V, I_C = 10 mA, f = 70 Mc/s)	h_{fe}	2 min	

CHARACTERISTICS (cont'd)

Product of Base-Spreading Resistance and Collector-to-Case Capacitance (V_{CE} = 40 V, I_C = 10 mA, f = 70 Mc/s)	$r_{bb'}C_c$	80 max	ps
Output Capacitance (V_{CB} = 40 V, I_E = 0, f = 1 Mc/s)	C_{obo}	5 max	pF

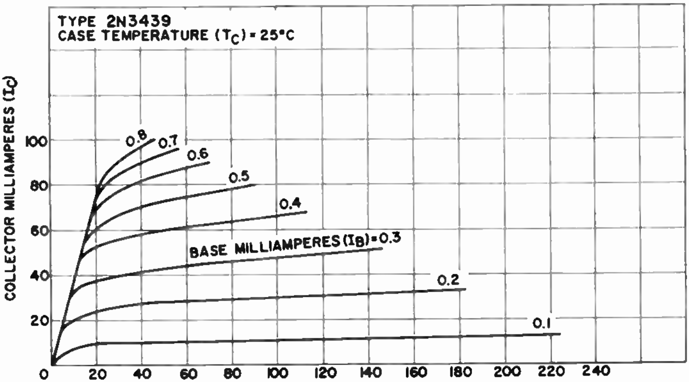
2N3439 TRANSISTOR

Si **n-p-n triple-diffused** type used in high-speed-switching and linear-amplifier applications, such as high-voltage differential and operational amplifiers, high-voltage inverters, and series regulators for industrial and military applications. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

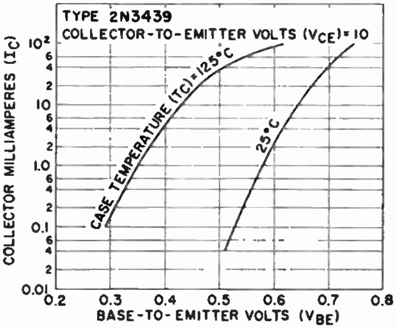
Collector-to-Base Voltage	V_{CBO}	450	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	450	V
Base open (sustaining voltage)	V_{CEO}(sus)	350	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Base Current	I_B	0.5	A
Transistor Dissipation:			
T_A up to 50°C	P_T	1	W
T_C up to 50°C	P_T	5	W
T_A or T_C above 50°C	P_T	See curve page 112	

TYPICAL COLLECTOR CHARACTERISTICS



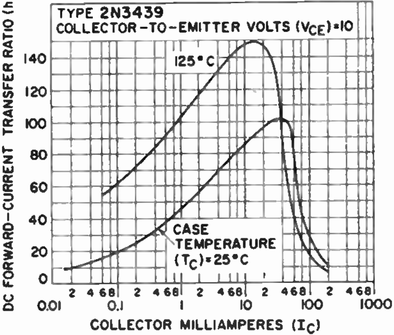
92CM-12617T

TYPICAL TRANSFER CHARACTERISTICS



92CS-12619T

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



92CS-12615T T

MAXIMUM RATINGS (cont'd)

Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C
Storage	T_{STG}	—65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 50 mA, I_B = 0)	V_{CEO}(sus)	350 min	V
Collector-to-Emitter Saturation Voltage (I_C = 50 mA, I_B = 4 mA)	V_{CE}(sat)	0.5 max	V
Base-to-Emitter Saturation Voltage (I_C = 50 mA, I_B = 4 mA)	V_{BE}(sat)	1.3 max	V
Collector-Cutoff Current:			
V_{CE} = 300 V, I_B = 0	I_{CEO}	20 max	µA
V_{CE} = 450 V, V_{BE} = —1.5 V	I_{CEV}	500 max	µA
Emitter-Cutoff Current (V_{EB} = 6 V, I_C = 0)	I_{EBO}	20 max	µA
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 20 mA	h_{FE}	40 to 160	
V_{CE} = 10 V, I_C = 2 mA	h_{FE}	30* min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 10 mA, f = 5 Mc/s)	h_{fe}	3 min	
Second-Breakdown Current, Safe Operating Region (V_{CE} = 200 V)	$I_{S/b}$	50 min	mA
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 1 Mc/s)	C_{obo}	10 max	pF
Thermal Resistance, Junction-to-Case (P_{oe} = 2 to 4 W, I_E = 100 mA)	θ_{J-C}	30 max	°C/W

* This value does not apply to type 2N3440.

TRANSISTOR 2N3440

Si **n-p-n triple-diffused** type used in high-speed-switching and linear-amplifier applications such as high-voltage differential and operational amplifiers, high-voltage inverters, and series regulators for industrial and military applications. JEDEC TO-5, **Outline No.3. Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N3439 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	300	V
Collector-to-Emitter Voltage:			
V_{BE} = —1.5 V	V_{CEV}	300	V
Base open (sustaining voltage)	V_{CEO}(sus)	250	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 50 mA, I_B = 0)	V_{CEO}(sus)	250	V
Collector-Cutoff Current:			
V_{CE} = 200 V, I_B = 0	I_{CEO}	50 max	µA
V_{CE} = 300 V, V_{BE} = —1.5 V	I_{CEV}	500 max	µA

POWER TRANSISTOR 2N3441

Si **n-p-n diffused** type for high-voltage applications in power-switching circuits, series- and shunt-regulator driver and output stages, and in dc-to-dc converters in military, industrial, and commercial equipment. JEDEC TO-66, **Outline No.22. Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

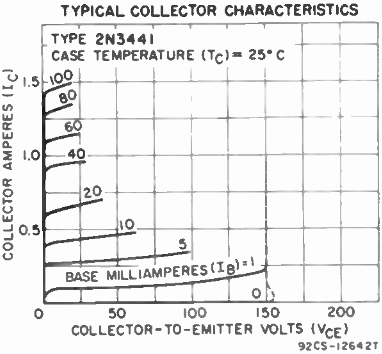
Collector-to-Base Voltage	V_{CBO}	160	V
Collector-to-Emitter Voltage:			
V_{BE} = —1.5 V	V_{CEV}	160	V
Base open (sustaining voltage)	V_{CEO}(sus)	140	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	3	A
Base Current	I_B	2	A
Transistor Dissipation:			
T_C up to 25°C	P_T	29	W
T_C above 25°C	P_T	See curve page 112	

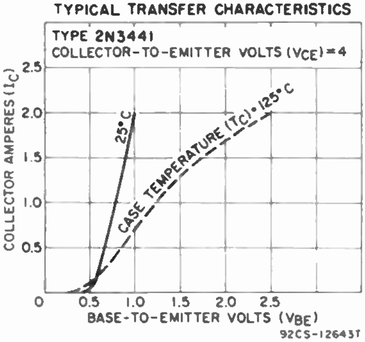
MAXIMUM RATINGS (cont'd)

Temperature Range:			
Operating (Junction)	T_J	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	255	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
$I_C = 100$ mA, $I_B = 0$	$V_{(BR)CEO}$(sus)	140 min	V
$I_C = 50$ mA, $V_{BE} = -1.5$ V	$V_{(BR)CEV}$	160 min	V
$I_C = 50$ mA, $R_{BE} = 100\ \Omega$	$V_{(BR)CER}$	150 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 0.5$ A, $I_B = 50$ mA)	V_{CE}(sat)	1 max	V
Base-to-Emitter Voltage ($V_{CE} = 4$ V, $I_C = 0.5$ A)	V_{BE}	1.7 max	V
Collector-Cutoff Current:			
$V_{CE} = 140$ V, $V_{BE} = -1.5$ V, $T_C = 25$°C	I_{CEV}	5 max	mA
$V_{CE} = 140$ V, $V_{BE} = -1.5$ V, $T_C = 150$°C	I_{CEV}	6 max	mA
$V_{CE} = 140$ V, $I_E = 0$, $T = 25$°C	I_{CBO}	5 max	mA
Emitter-Cutoff Current ($V_{EB} = 7$ V, $I_C = 0$)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = 4$ V, $I_C = 0.5$ A)	h_{FE}	20 to 80	
Thermal Resistance, Junction-to-Case	θ_{J-C}	6 max	°C/W

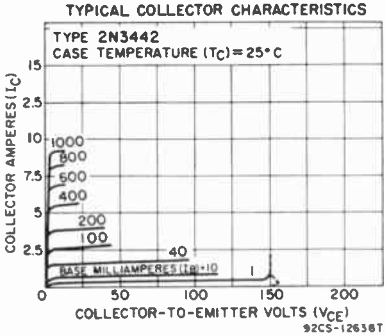


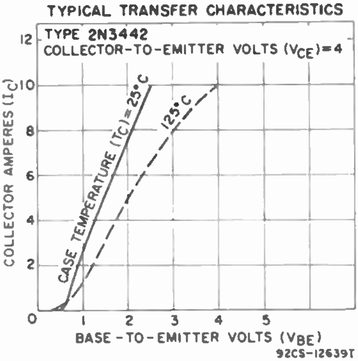


2N3442

POWER TRANSISTOR

Si **n-p-n diffused** type for high-voltage applications in power-switching circuits, series- and shunt-regulator driver and output stages, and in dc-to-dc converters in military, industrial, and commercial equipment. JEDEC TO-3, **Outline** No.2. **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N3441 except for the following items:





MAXIMUM RATINGS

Collector Current	I_C	10	A
Base Current	I_B	7	A
Transistor Dissipation:			
T_C up to 25°C	P_T	117	W
T_C up to 25°C	P_T	See curve page 112	

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
I_C = 200 mA, I_B = 0	$V_{(BR)CEO}$(sus)	140 min	V
I_C = 100 mA, V_{BE} = −1.5 V	$V_{(BR)CEV}$	160 min	V
I_C = 100 mA, R_{BE} = 100 Ω	$V_{(BR)CER}$	150 min	V
Collector-to-Emitter Saturation Voltage (I_C = 3 A, I_B = 300 mA)	V_{CE}(sat)	1 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 3 A)	V_{BE}	1.7 max	V
Collector-Cutoff Current (V_{CE} = 140 V, V_{BE} = −1.5 V, T_C = 150°C)	I_{CEV}	30 max	mA
Emitter-Cutoff Current (V_{EB} = 7 V, I_C = 0)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 3 A)	h_{FE}	20 to 70	
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

TRANSISTOR 2N3478

Si n-p-n epitaxial planar type for vhf-uhf applications at frequencies up to 470 Mc/s in industrial and commercial equipment. Outline No.26 (4 lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

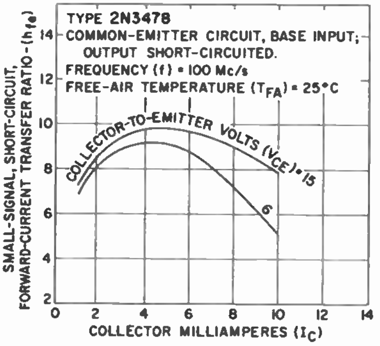
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	30	V
Collector-to-Emitter Voltage	V_{CEO}	15	V
Emitter-to-Base Voltage	V_{EBO}	2	V
Collector Current	I_C	Limited by Power Dissipation	
Transistor Dissipation:			
T_A up to 25°C	P_T	200	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

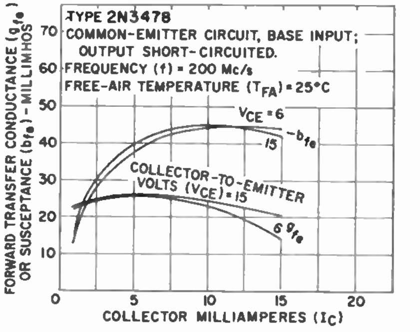
Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	30 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 0.001 mA, I_B = 0)	$V_{(BR)CEO}$	15 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.001 mA, I_C = 0)	$V_{(BR)EBO}$	2 min	V
Collector-Cutoff Current (V_{CB} = 1 V, I_E = 0)	I_{CBO}	0.02 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 8 V, I_C = 2 mA)	h_{FE}	25 to 150	

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



92CS-12756T1

TYPICAL FORWARD TRANSFER CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



92CS-12759T

CHARACTERISTICS (cont'd)

Small-Signal Forward-Current Transfer Ratio* (V_{CE} = 8 V, I_C = 2 mA, f = 100 Mc/s)	h_{fe}	9	
Output Capacitance:			
V_{CB} = 8 V, I_E = 0, f = 1 Mc/s	C_{obo}†	0.95 max	pF
V_{CB} = 8 V, I_E = 0, f = 1 Mc/s	C_{obo}*	0.65 max	pF
Small-Signal Power Gain:			
Unneutralized Amplifier Circuit* V_{CE} = 8 V, I_C = 2 mA, f = 200 Mc/s	G_{pe}	11.5 to 17	dB
Neutralized Amplifier Circuit† R_S = 50 Ω, I_C = 1.5 mA, V_{CE} = 6 V, f = 470 Mc/s	G_{pe}	12	dB
Noise Figure*			
UHF—R_S = 50 Ω, V_{CE} = 6 V, I_C = 1.5 mA, f = 470 Mc/s	NF	5	dB
VHF—V_{CE} = 8 V, I_C = 2 mA, f = 200 Mc/s	NF	4.5 max	dB

* Lead 4 (case) grounded. † Lead 4 (case) floating.

2N3512

COMPUTER TRANSISTOR

Si n-p-n double-diffused epitaxial planar type used for core-driver and line-driver service in high-performance computers and in other critical applications requiring considerable output power. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

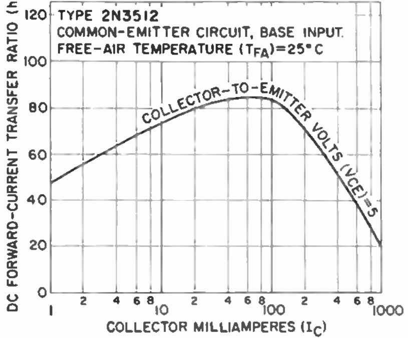
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage	V_{CEO}	35	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	Limited by Power Dissipation	
Transistor Dissipation:			
T_A up to 25°C	P_T	0.8	W
T_C up to 25°C (with heat sink)	P_T	4	W
T_A or T_C (with heat sink) above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

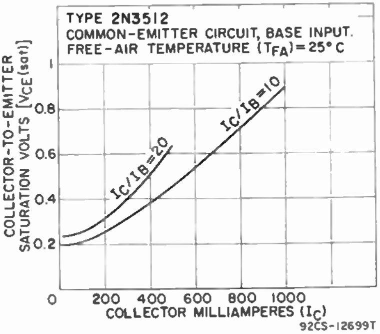
Collector-to-Base Breakdown Voltage (I_C = 0.01 mA, I_E = 0)	$V_{(BR)CBO}$	60 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 50 mA, I_B = 0)	$V_{(BR)CEO}$	35 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = 150 mA, I_B = 7.5 mA	V_{CE}(sat)	0.4 max	V
I_C = 500 mA, I_B = 50 mA	V_{CE}(sat)	1 max	V

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC



92CS-12698T

TYPICAL SATURATION CHARACTERISTICS



92CS-12699T

CHARACTERISTICS (cont'd)

Base-to-Emitter Voltage (I_C = 150 mA, I_B = 7.5 mA)	V_{BE}	1 max	V
Base-Cutoff Current (V_{CE} = 30 V, V_{BE} = —0.3 V)	I_{BEV}	0.5 max	μA
Collector-Cutoff Current:			
V_{CE} = 30 V, V_{BE} = —0.3 V, T_A = 25°C	I_{CEV}	0.5 max	μA
V_{CE} = 30 V, V_{BE} = —0.3 V, T_A = 100°C	I_{CEV}	100 max	μA
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = 1 V, I_C = 0.5 A, t_p = 400 μs, df ≦ 3%)	h_{FE}(pulsed)	10 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA, f = 100 Mc/s)	h_{fe}	2.5 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 Mc/s)	C_{obo}	10 max	pF
Storage Time (V_{CC} = 6.4 V, V_{BB} = 15.9 V, I_C = 150 mA, I_B = 15 mA)	t_s	30 max	ns
Turn-On Time (V_{CC} = 6.4 V, I_C = 150 mA, I_{B_1} = 15 mA, I_{B_2} = —15 mA)	$t_d + t_r$	30 max	ns
Turn-Off Time (V_{CC} = 6.4 V, V_{BB} = 15.9 V, I_C = 150 mA, I_{B_2} = —15 mA, I_{B_1} = 15 mA)	$t_s + t_f$	45 max	ns

TRANSISTOR 2N3553

Si n-p-n "overlay" epitaxial planar type used in class A, B, and C amplifiers, frequency multipliers, or oscillators in vhf-uhf applications for industrial and military communications. JEDEC TO-39, Outline No.12. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	65	V
Collector-to-Emitter Voltage:			
V_{BE} = —1.5 V	V_{CEV}	65	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	1	A
Transistor Dissipation:			
T_C up to 25°C	P_T	7	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C
Storage	T_{STG}	—65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

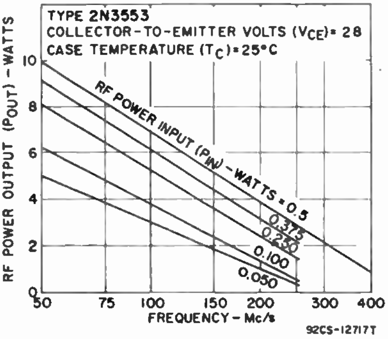
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.3 mA, I_E = 0)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0.2 A, I_B = 0, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	40 min	V
I_C = 0 to 0.2 A, V_{BE} = —1.5 V, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	65 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage (I_C = 250 mA, I_B = 50 mA)	V_{CE}(sat)	1 max	V
Collector-Cutoff Current (V_{CE} = 30 V, I_B = 0)	I_{CEO}	0.1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 5 V, I_C = 250 mA)	h_{FE}	10 to 100	
Intrinsic Base-Spreading Resistance (V_{CE} = 28 V, I_C = 100 mA, f = 100 Mc/s)	$r_{bb'}$	12	Ω
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 28 V, I_C = 125 mA, f = 100 Mc/s)	h_{fe}	4 min	
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 100 mA)	f_T	500	Mc/s
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 Mc/s)	C_{obo}	10 max	pF
RF Power Output:			
Unneutralized Amplifier—V_{CC} = 28 V, P_{IE} = 0.25 W, R_G & R_L = 50 Ω, f = 175 Mc/s	P_{OE}	2.5* min	W
Oscillator—V_{CC} = 28 V, f = 500 Mc/s	P_{OE}	1.5†	W

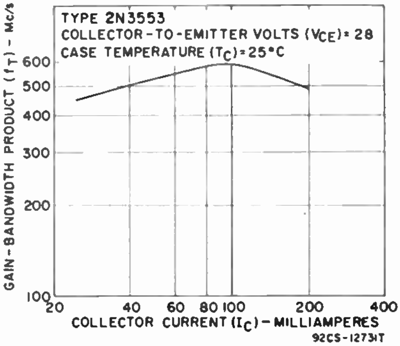
* For conditions given, minimum efficiency = 50 per cent.

† For conditions given, typical efficiency = 30 per cent.

TYPICAL OPERATION CHARACTERISTICS



TYPICAL SMALL-SIGNAL OPERATION CHARACTERISTIC



2N3583 TRANSISTOR

Si **n-p-n triple-diffused** type used in high-speed-switching and linear-amplifier applications such as high-voltage operational amplifiers, high-voltage switches, switching regulators, converters, inverters, deflection and high-fidelity amplifiers in military, industrial and commercial equipment. JEDEC TO-66, **Outline** No.22. **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

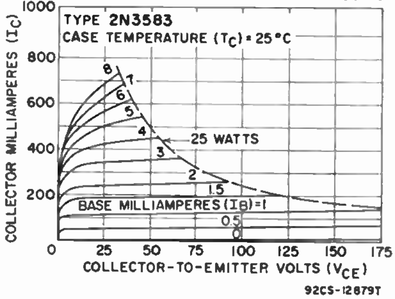
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	250	V
Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	175	V
Emitter-to-Base Voltage	V_{EBO}	6	V
Collector Current	I_C	2	A
Peak Collector Current	i_C	5	A
Base Current	I_B	1	A
Transistor Dissipation	P_T	See Rating Chart	
Operating Temperature Range	T_C(opr)	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	255	°C

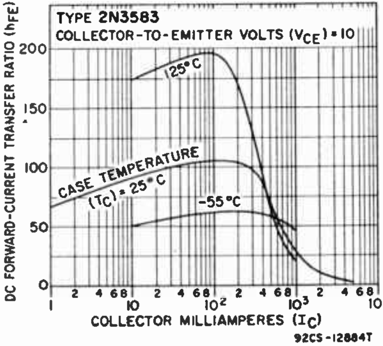
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage:			
I_C = 200 mA, I_B = 0	V_{CEO}(sus)	175 min	V
R_{BE} = 50 Ω, I_C = 500 mA	V_{CER}(sus)	250 min	V
Base-to-Emitter Saturation Voltage (I_C = 1 A, I_B = 100 mA)	V_{BE}(sat)	1.4 max	V
Collector-Cutoff Current:			
V_{CE} = 150 V, I_B = 0, T_C = 25°C	I_{CEO}	10 max	mA
V_{BE} = −1.5 V, V_{CE} = 225 V, T_C = 25°C	I_{CEV}	1 max	mA
V_{BE} = −1.5 V, V_{CE} = 225 V, T_C = 200°C	I_{CEV}	5 max	mA
Emitter-Cutoff Current (V_{EB} = 6 V, I_C = 0)	I_{EBO}	5 max	mA

TYPICAL COLLECTOR CHARACTERISTICS

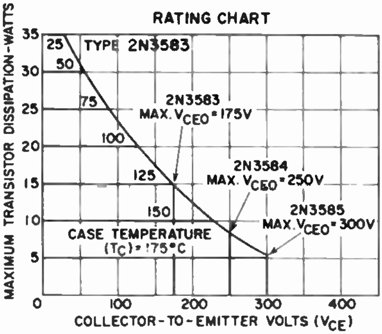


TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



CHARACTERISTICS (cont'd)

Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 100 mA	h_{FE}	40 min	
V_{CE} = 10 V, I_C = 1 A	h_{FE}	10 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 200 mA, f = 50 Mc/s)	h_{fe}	2 min	
Second-Breakdown Collector Current (Base forward-biased from zero up, V_{CE} = 100 V)	$I_{S/b}$	250 min	mA
Second-Breakdown Energy (Base reverse-biased, R_{BE} = 20 Ω, L = 100 μH, V_{BE} = 4 V)	$E_{S/b}$	50 min	μJ
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 1 Mc/s)	C_{obo}	120 max	pF
Thermal Resistance, Junction-to-Case (I_C = 500 mA)	θ_{J-C}	5 max	°C/W



92CS-12878T

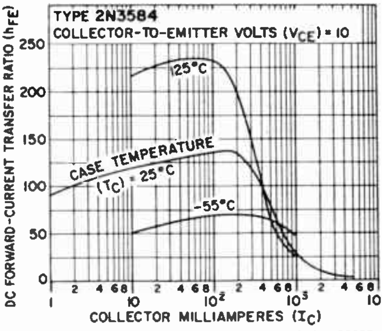
TRANSISTOR 2N3584

Si n-p-n triple-diffused type used in high-speed-switching and linear-amplifier applications such as high-voltage operational amplifiers, high-voltage switches, switching regulators, converters, inverters, deflection and high-fidelity amplifiers in military, industrial and commercial equipment. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N3583 except for the following:

MAXIMUM RATINGS

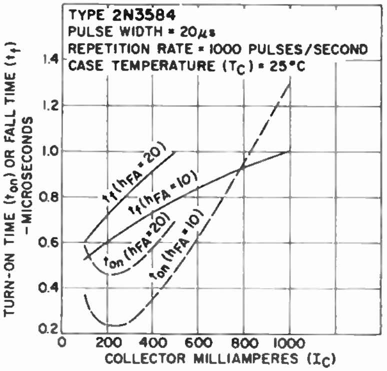
Collector-to-Base Voltage	V_{CBO}	375	V
Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	250	V

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



92CS-12883T

TYPICAL TURN-ON TIME AND FALL-TIME CHARACTERISTICS



92CS-12872T

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage:			
$I_C = 200$ mA, $I_B = 0$	V_{CEO}(sus)	250 min	V
$R_{BE} = 50\ \Omega$, $I_C = 500$ mA	V_{CER}(sus)	300 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 1$ A, $I_B = 125$ mA)	V_{CE}(sat)	0.75 max	V
Collector-Cutoff Current:			
$V_{CE} = 150$ V, $I_B = 0$, $T_C = 25°C$	I_{CEO}	5 max	mA
$V_{BE} = -1.5$ V, $V_{CE} = 300$ V, $T_C = 25°C$	I_{CEV}	1 max	mA
$V_{BE} = -1.5$ V, $V_{CE} = 300$ V, $T_C = 200°C$	I_{CEV}	5 max	mA
Emitter-Cutoff Current ($V_{EB} = 6$ V, $I_C = 0$)	I_{EBO}	0.5 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = 10$ V, $I_C = 1$ A)	h_{FE}	25 to 100	
Second-Breakdown Energy (Base reverse-biased, $R_{BE} = 20\ \Omega$, $L = 100\ \mu$H, $V_{BE} = -4$ V)	$E_{S/b}$	200 min	
Turn-On Time, Saturated Switch ($V_{CC} = 30$ V, $I_C = 1$ A, $I_B = 100$ mA)	$t_d + t_r$	3 max	μs
Storage Time ($V_{CC} = 30$ V, $I_C = 1$ A, $I_B = 100$ mA)	t_s	4 max	μs
Fall Time ($V_{CC} = 30$ V, $I_C = 1$ A, $I_B = 100$ mA)	t_f	3 max	μs

2N3585 TRANSISTOR

Si n-p-n triple-diffused type used in high-speed-switching and linear-amplifier applications such as high-voltage operational amplifiers, high-voltage switches, switching regulators, converters, inverters, deflection and high-fidelity amplifiers in military, industrial and commercial equipment. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N3583 except for the curves of static forward-current transfer ratio and turn-on and fall time, which are the same as for type 2N3584, and the following:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	500	V
Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	300	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage:			
$I_C = 200$ mA, $I_B = 0$	V_{CEO}(sus)	300 min	V
$R_{BE} = 50\ \Omega$, $I_C = 500$ mA	V_{CER}(sus)	400 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 1$ A, $I_B = 125$ mA)	V_{CE}(sat)	0.75 max	V
Collector-Cutoff Current:			
$V_{CE} = 150$ V, $I_B = 0$, $T_C = 25°C$	I_{CEO}	5 max	mA
$V_{BE} = -1.5$ V, $V_{CE} = 400$ V, $T_C = 25°C$	I_{CEV}	1 max	mA
$V_{BE} = -1.5$ V, $V_{CE} = 300$ V, $T_C = 200°C$	I_{CEV}	5 max	mA
Emitter-Cutoff Current ($V_{EB} = 6$ V, $I_C = 0$)	I_{EBO}	0.5 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = 10$ V, $I_C = 1$ A)	h_{FE}	25 to 100	
Second-Breakdown Energy (Base reverse-biased, $R_{BE} = 20\ \Omega$, $L = 100\ \mu$H, $V_{BE} = -4$ V)	$E_{S/b}$	200 min	μJ
Turn-On Time, Saturated Switch ($V_{CC} = 30$ V, $I_C = 1$ A, $I_B = 100$ mA)	$t_d + t_r$	3 max	μs
Storage Time ($V_{CC} = 30$ V, $I_C = 1$ A, $I_B = 100$ mA)	t_s	4 max	μs
Fall Time ($V_{CC} = 30$ V, $I_C = 1$ A, $I_B = 100$ mA)	t_f	3 max	μs

2N3600 TRANSISTOR

Si n-p-n epitaxial planar type used in low-noise amplifier, oscillator, and converter applications at vhf frequencies in military, communications, and industrial equipment. JEDEC TO-72, Outline No.23. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

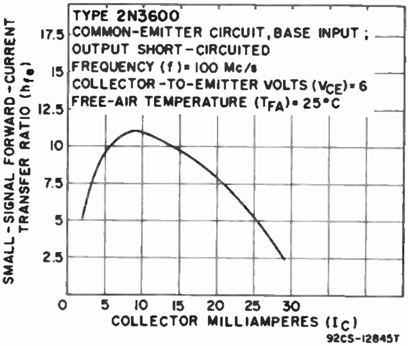
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	30	V
Collector-to-Emitter Voltage	V_{CEO}	15	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	Limited by Power Dissipation	

MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_A up to 25°C	P_T	200	mW
T_C up to 25°C (with heat sink)	P_T	300	mW
T_A or T_C (with heat sink) above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (60 s max)	T_L	300	°C

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC

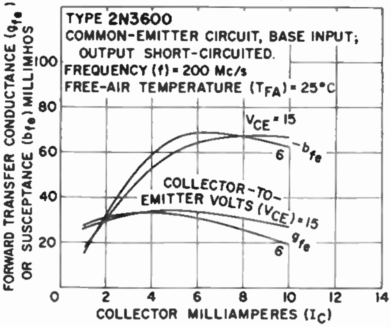


92CS-12845T

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	30 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.01 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V
Collector-to-Emitter Sustaining Voltage (I_C = 3 mA, I_B = 0)	$V_{(BR)CEO}$(sus)	15 min	V
Collector-to-Emitter Saturation Voltage (I_C = 10 mA, I_B = 1 mA)	V_{CE}(sat)	0.4 max	V
Base-to-Emitter Saturation Voltage (I_C = 10 mA, I_B = 1 mA)	V_{BE}(sat)	1 max	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_A = 25°C	I_{CBO}	0.01 max	µA
V_{CB} = 15 V, I_E = 0, T_A = 150°C	I_{CBO}	1 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 1 V, I_C = 3 mA)	h_{FE}	20 to 150▲	
Small-Signal Forward-Current Transfer Ratio:*			
V_{CE} = 6 V, I_C = 5 mA, f = 100 Mc/s	h_{fe}	8.5 to 15▲	
V_{CE} = 6 V, I_C = 2 mA, f = 1 kc/s	h_{fe}	40 to 200▲	

TYPICAL FORWARD TRANSFER CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



92CS-12759T1

CHARACTERISTICS (cont'd)

Input Capacitance† (V_{EB} = 0.5 V, I_C = 0, f = 0.1 to 1 Mc/s)	C_{ibo}	1.4 typ	pF
Output Capacitance† (V_{CB} = 10 V, I_E = 0, f = 0.1 to 1 Mc/s)	C_{obo}	1.7 max	pF
Collector-to-Base Time Constant* (V_{CB} = 6 V, I_C = 5 mA, f = 31.9 Mc/s)	$r_b'C_c$	4 to 15	ps
Small-Signal Power Gain, Amplifier Circuit, Neutralized* (V_{CE} = 6 V, I_C = 5 mA, f = 200 Mc/s)	G_{pe}	17 to 24▲	dB
Power Output, Oscillator Circuit† (V_{CB} = 10 V, I_E = 12 mA, f = 500 Mc/s)	P_{oe}	20 min	mW
Noise Figure:*			
V_{CE} = 6 V, I_C = 1.5 mA, f = 200 Mc/s	NF	4.5 max▲	dB
V_{CE} = 6 V, I_C = 1 mA, f = 60 Mc/s	NF	3 typ	dB

* Lead 4 (case) grounded.
† Lead 4 (case) floating.
▲ This value does not apply to type 2N918.

2N3632 TRANSISTOR

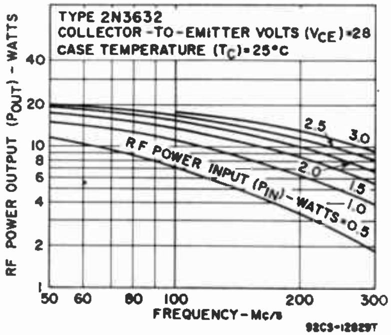
Si n-p-n "overlay" epitaxial planar type used in class A, B, and C amplifiers, frequency multipliers, or oscillators in vhf-uhf applications for industrial and military communications. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	65	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	65	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	3	A
Transistor Dissipation:			
T_C up to 25°C	P_T	23	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.5 mA, I_E = 0)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0.2 A, I_B = 0, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	40 min	V
I_C = 0 to 0.2 A, V_{BE} = −1.5 V, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	65 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.25 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage (I_C = 0.5 A, I_B = 0.1 A)	V_{CE}(sat)	1 max	V

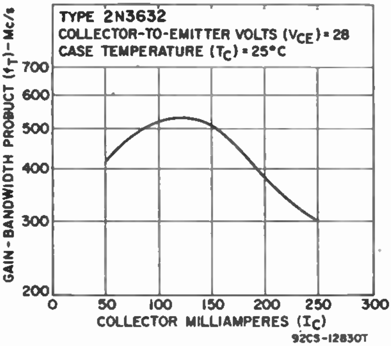

TYPICAL OPERATION CHARACTERISTICS

CHARACTERISTICS (cont'd)

Collector-Cutoff Current (V_{CE} = 30 V, I = 0)	I_{CEO}	0.25 max	mA
Intrinsic Base-Spreading Resistance (V_{CE} = 28 V, I_C = 250 mA, f = 200 Mc/s)	$r_{bb'}$	6.5 typ	Ω
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 150 mA)	f_T	400 typ	Mc/s
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 Mc/s)	C_{obo}	20 max	pF
RF Power Output, Unneutralized:			
V_{CC} = 28 V, P_{IE} = 3.5 W, R_G & R_L = 50 Ω, f = 175 Mc/s	P_{OE}	13.5* min	W
V_{CC} = 28 V, P_{IE} = 3 W, R_G & R_L = 50 Ω, f = 260 Mc/s	P_{OE}	10† typ	W

* For conditions given, minimum efficiency = 70 per cent.
† For conditions given, minimum efficiency = 60 per cent.

TYPICAL SMALL-SIGNAL OPERATION CHARACTERISTIC



POWER TRANSISTOR

2N3730

Ge p-n-p diffused-collector graded-base type used in 114-degree 18-kV TV deflection systems as a vertical-deflection output amplifier. This type, together with types 2N3731 (horizontal output), 2N3732 (horizontal driver), and 1N4785 (damper) make up a complete transistor/damper-diode complement. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage:			
Peak	v_{CBO}	—200	V
Continuous	V_{CBO}	—60	V
Emitter-to-Base Voltage	V_{EBO}	—0.5	V
Collector Current	I_C	—3	A
Base Current	I_B	±0.5	A
Transistor Dissipation:			
T_{MF} up to 55°C	P_T	10	W
T_{MF} above 55°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 85	°C
Storage	T_{STG}	—65 to 85	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (V_{BE} = 0.5 V, I_C = 5 mA)	$V_{(BR)CBV}$	—200 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = —0.7 A, I_B = —0.02 A	V_{CE}(sat)	—2 max	V
I_C = —0.05 A, I_B = —0.005 A	V_{CE}(sat)	—1 max	V
Base-to-Emitter Voltage (I_C = —0.7 A, I_B = —0.02 A)	V_{BE}	0.5 typ	V
Collector-Cutoff Current (V_{CB} = —10 V, I_E = 0)	I_{CBO}	—200 max	µA
Thermal Resistance, Junction-to-Case	Θ_{J-C}	1.5 max	°C/W

2N3731 POWER TRANSISTOR

Ge p-n-p diffused-collector graded-base type used in 114-degree 18-kV TV deflection systems as a horizontal output amplifier. This type, together with types 2N3730 (vertical output), 2N3732 (horizontal driver), and 1N4785 (damper) make up a complete transistor/damper-diode complement. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage:			
Peak	v_{CBO}	−320	V
Continuous	V_{CBO}	−60	V
Emitter-to-Base Voltage	V_{EBO}	−2	V
Collector Current	I_C	−10	A
Base Current	I_B	+4, −1	A
Transistor Dissipation:			
T_{MF} up to 55°C	P_T	5	W
T_{MF} above 55°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 185	°C
Storage	T_{STG}	−65 to 185	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (V_{BE} = 0.5 V, I_C = −0.25 A)	$V_{(BR)CBV}$	−320 min	V
Emitter-to-Base Breakdown Voltage (I_E = 100 mA, I_C = 0)	$V_{(BR)EBO}$	−2 min	V
Collector-to-Emitter Saturation Voltage (I_C = −6 A, I_B = −0.4 A)	V_{CE}(sat)	−1.5 max	V
Base-to-Emitter Voltage (I_C = −6 A, I_B = −0.4 A)	V_{BE}	0.7	V
Collector-Cutoff Current (V_{CB} = −10 V, I_E = 0)	I_{CBO}	−200 max	µA
Turn-off Time	t(off)	1.2 max	µs
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

TYPICAL OPERATION IN HORIZONTAL-DEFLECTION AND HIGH-VOLTAGE CIRCUIT

DC Supply Voltage	45	V
Average Supply Current	0.55	A
Input Power:		
Oscillator and driver circuits	1.5	W
Output Circuit:		
At beam current = 0	18	W
At beam current = 200 µA	22	W
DC High-Voltage Output:		
At beam current = 0	18	kV
At beam current = 200 µA	17	kV
Yoke Current (peak-to-peak)	10	A
Peak Yoke Energy	2.5	mJ
Retrace Time	11.5	µs

2N3732 POWER TRANSISTOR

Ge p-n-p diffused-collector graded-base type used in 114-degree 18-kV TV deflection systems as a horizontal driver. This type, together with types 2N3730 (vertical output), 2N3731 (horizontal output), and 1N4785 (damper) make up a complete transistor/damper-diode complement. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. For typical operation in horizontal-deflection and high-voltage circuit, refer to type 2N3731.

MAXIMUM RATINGS

Collector-to-Base Voltage:			
Peak	v_{CBO}	−100	V
Continuous	V_{CBO}	−60	V
Emitter-to-Base Voltage	V_{EBO}	−0.5	V
Collector Current	I_C	−3	A

MAXIMUM RATINGS (cont'd)

Base Current	I_B	±0.5	A
Transistor Dissipation:			
T_{MF} up to 55°C	P_T	3	W
T_{MF} above 55°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 185	°C
Storage	T_{STG}	−65 to 185	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (V_{BE} = 0.5 V, I_C = −5 mA)	$V_{(BR)CBV}$	−100 min	V
Collector-to-Emitter Saturation Voltage (I_C = −0.7 A, I_B = −0.02 A)	V_{CE}(sat)	−2 max	V
Base-to-Emitter Voltage (I_C = −0.7 A, I_B = −0.02 A)	V_{BE}	0.5	V
Collector-Cutoff Current (V_{CB} = −10 V, I_E = 0)	I_{CBO}	−200 max	μA
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

TRANSISTOR **2N3733**

Si n-p-n "overlay" epitaxial planar type used in large-signal, high-power vhf-uhf applications in military and industrial communications equipment. Intended for class A, B, C amplifier, frequency-multiplier, or oscillator service. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, 2 - base, 3 - collector.

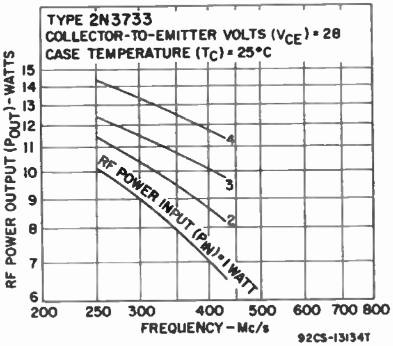
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	65	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	65	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Peak Collector Current	i_C	3	A
Transistor Dissipation:			
T_C up to 25°C	P_T	23	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

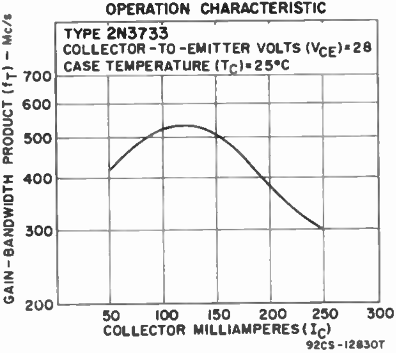
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.5 mA, I_E = 0)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0 to 200 mA, V_{BE} = −1.5 V, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	65 min	V
I_C = 0 to 200 mA, I_B = 0, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	40 min	V

TYPICAL OPERATION CHARACTERISTICS



TYPICAL SMALL-SIGNAL OPERATION CHARACTERISTIC



CHARACTERISTICS (cont'd)

Emitter-to-Base Breakdown Voltage (I_E = 0.25 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage (I_C = 0.5 A, I_B = 100 mA)	$V_{CE}(sat)$	1 max	V
Collector-Cutoff Current (V_{CE} = 30 V, I_B = 0)	I_{CEO}	0.25 max	mA
Intrinsic Base-Spreading Resistance (V_{CE} = 28 V, I_C = 250 mA, f = 200 Mc/s)	$r_{bb'}$	6.5	Ω
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 150 mA)	f_T	400	Mc/s
Collector-to-Case Capacitance	C_c	6 max	pF
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 Mc/s)	C_{obo}	20 max	pF
RF Power Output Amplifier, Unneutralized:			
V_{CE} = 28 V, P_{IE} = 4 W, R_G & R_L = 50 Ω, f = 260 Mc/s	P_{OE}	14.5*	W
V_{CE} = 28 V, P_{IE} = 4 W, R_G & R_L = 50 Ω, f = 400 Mc/s	P_{OE}	10† min	W

* For conditions given, minimum efficiency = 60 per cent.
† For conditions given, minimum efficiency = 45 per cent.

2N3771

POWER TRANSISTOR

Si n-p-n type with high collector-current rating (30 A max) for intermediate- and high-power applications such as public-address amplifiers, power supplies, and low-speed switching regulators and inverters. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

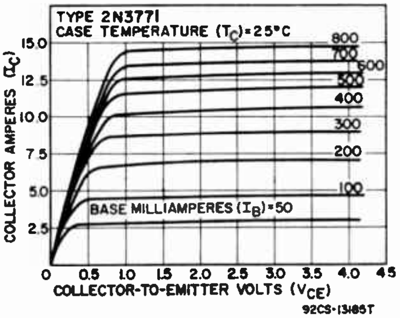
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	50	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	50	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	30	A
Transistor Dissipation:			
T_C up to 25°C	P_T	150	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

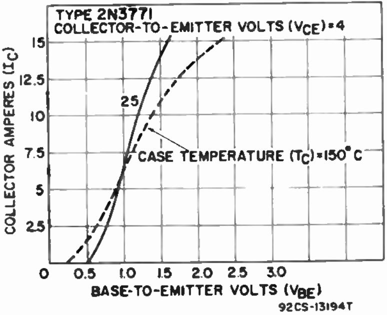
CHARACTERISTICS (At case temperature = 25°C)

Emitter-to-Base Breakdown Voltage (I_E = 5 mA, I_C = 0)	$V_{(BR)EBO}$	5 max	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = −1.5 V, I_C = 3 A	V_{CEV}(sus)	50 min	V
I_C = 0.2 A, I_B = 0	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Saturation Voltage (I_B = 1.5 A, I_C = 15 A, t_p = 300 µs, p/s = 60 c/s)	V_{CE}(sat)	2 max	V

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



CHARACTERISTICS (cont'd)

Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 15 A, t_p = 300 μs, p/s = 60 c/s)	V_{BE}	2.7 max	V
Collector-Cutoff Current:			
V_{CB} = 50 V, I_E = 0, T_C = 25°C	I_{CBO}	2 max	mA
V_{CB} = 30 V, I_E = 0, T_C = 150°C	I_{CBO}	10 max	mA
V_{CE} = 50 V, V_{BE} = —1.5 V, T_C = 25°C	I_{CEV}	2 max	mA
V_{CE} = 30 V, V_{BE} = —1.5 V, T_C = 150°C	I_{CEV}	10 max	mA
V_{CE} = 30 V, I_B = 0, T_C = 25°C	I_{CEO}	10 max	mA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	5 max	mA
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 15 A, t_p = 300 μs, p/s = 60 c/s)	h_{FE}(pulsed)	15 to 60	
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.7 max	°C/W

POWER TRANSISTOR 2N3772

Si **n-p-n** type with high collector-current rating (30 A max) for intermediate- and high-power applications such as public-address amplifiers, power supplies, and low-speed switching regulators and inverters. JEDEC TO-3, **Outline** No.2. **Terminals**: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

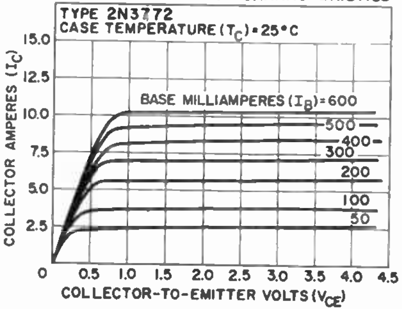
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
V_{BE} = —1.5 V	V_{CEV}	100	V
Base open	V_{CEO}	60	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	30	A
Transistor Dissipation:			
T_C up to 25°C	P_T	150	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C
Storage	T_{STG}	—65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

CHARACTERISTICS (At case temperature = 25°C)

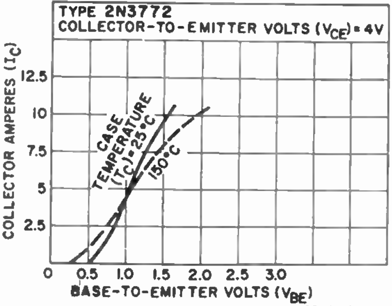
Emitter-to-Base Breakdown Voltage (I_E = 5 mA, I_C = 0)	$V_{(BR)EBO}$	7 max	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = —1.5 V, I_C = 3 A	V_{CEV}(sus)	100 min	V
I_C = 0.2 A, I_B = 0	V_{CEO}(sus)	60 min	V
Collector-to-Emitter Saturation Voltage (I_B = 1 A, I_C = 10 A, t_p = 300 μs, p/s = 60 c/s)	V_{CE}(sat)	1.4 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 10 A, t_p = 300 μs, p/s = 60 c/s)	V_{BE}	2.2 max	V

TYPICAL COLLECTOR CHARACTERISTICS



92CS-13184T

TYPICAL TRANSFER CHARACTERISTICS



92CS-13188T

CHARACTERISTICS (cont'd)

Collector-Cutoff Current:			
V_{CB} = 100 V, I_E = 0, T_C = 25°C	I_{CBO}	5 max	mA
V_{CB} = 30 V, I_E = 0, T_C = 150°C	I_{CBO}	10 max	mA
V_{CE} = 100 V, V_{BE} = −1.5 V, T_C = 25°C	I_{CEV}	5 max	mA
V_{CE} = 30 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	10 max	mA
V_{CE} = 50 V, I_B = 0, T_C = 25°C	I_{CEO}	10 max	mA
Emitter-Cutoff Current (V_{EB} = 7 V, I_C = 0)	I_{EBO}	5 max	mA
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 10 A, t_p = 300 μs, p/s = 60 c/s)	h_{FE}(pulsed)	15 to 60	
Thermal Resistance, Junction-to-Case	Θ_{J-C}	1.7 max	°C/W

2N3773 POWER TRANSISTOR

Si n-p-n type with high collector-current rating (30 A max) for intermediate- and high-power applications such as public-address amplifiers, power supplies, and low-speed switching regulators and inverters. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

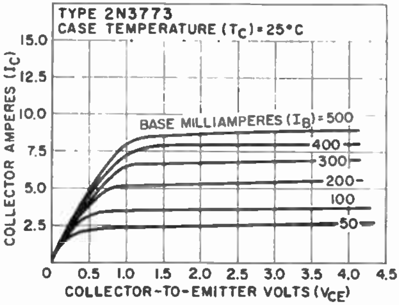
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	160	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	160	V
Base open	V_{CEO}	140	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	30	A
Transistor Dissipation:			
T_C up to 25°C	P_T	150	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

CHARACTERISTICS (At case temperature = 25°C)

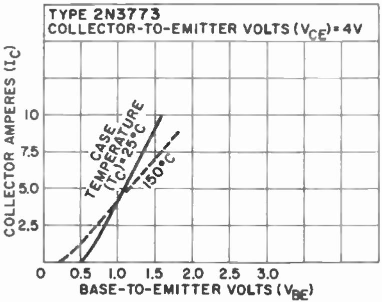
Emitter-to-Base Breakdown Voltage (I_E = 5 mA, I_C = 0)	$V_{(BR)EBO}$	7 max	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = −1.5 V, I_C = 3 A	V_{CEV}(sus)	160 min	V
I_C = 0.2 A, I_B = 0	V_{CEO}(sus)	140 min	V
Collector-to-Emitter Saturation Voltage (I_B = 0.8 A, I_C = 8 A, t_p = 300 μs, p/s = 60 c/s)	V_{CE}(sat)	1.4 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 8 A, t_p = 300 μs, p/s = 60 c/s)	V_{BE}	2.2 max	V
Collector-Cutoff Current:			
V_{CB} = 140 V, I_E = 0, T_C = 25°C	I_{CBO}	2 max	mA
V_{CB} = 30 V, I_E = 0, T_C = 150°C	I_{CBO}	10 max	mA
V_{CE} = 140 V, V_{BE} = −1.5 V, T_C = 25°C	I_{CEV}	2 max	mA
V_{CE} = 30 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	10 max	mA
V_{CE} = 120 V, I_B = 0, T_C = 25°C	I_{CEO}	10 max	mA

TYPICAL COLLECTOR CHARACTERISTICS



92CS-13196T

TYPICAL TRANSFER CHARACTERISTICS



92CS-13199T

CHARACTERISTICS (cont'd)

Emitter-Cutoff Current (V_{EB} = 7 V, I_C = 0)	I_{EBO}	5 max	mA
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 8 A, t_p = 300 μs, p/s = 60 c/s)	h_{FE}(pulsed)	15 to 60	
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.7 max	°C/W

TRANSISTOR 2N3866

Si **n-p-n** "overlay" epitaxial planar type for vhf-uhf applications in class A, B, and C amplifiers, frequency multipliers, and oscillators in military and industrial communications equipment. JEDEC TO-39, **Outline** No.12. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

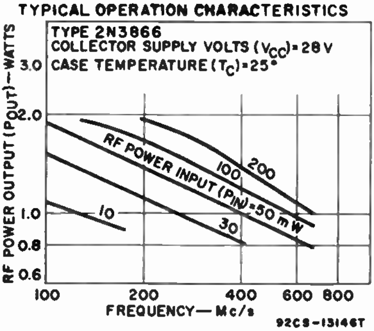
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	55	V
Collector-to-Emitter Voltage:			
R_{BE} = 10 Ω	V_{CER}	55	V
Base open	V_{CEO}	30	V
Emitter-to-Base Voltage	V_{EBO}	3.5	V
Collector Current	I_C	0.4	A
Transistor Dissipation:			
T_C up to 25°C	P_T	5	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

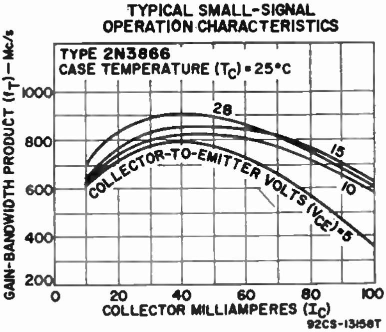
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	55 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	3.5 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 5 mA, R_{BE} = 10 Ω	V_{CER}(sus)	55 min	V
I_C = 5 mA, I_B = 0	V_{CEO}(sus)	30 min	V
Collector-to-Emitter Saturation Voltage (I_C = 100 mA, I_B = 20 mA)	V_{CE}(sat)	1 max	V
Collector-Cutoff Current (V_{CE} = 28 V, I_B = 0)	I_{CEO}	20 max	μA
Gain-Bandwidth Product (V_{CE} = 15 V, I_C = 25 mA)	f_T	800	Mc/s
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 Mc/s)	C_{obo}	3 max	pF
RF Power-Output Class C Amplifier, Unneutralized:			
V_{CC} = 28 V, P_{IE} = 0.05 W, f = 100 Mc/s	P_{OE}	1.8*	W
V_{CC} = 28 V, P_{IE} = 0.1 W, f = 400 Mc/s	P_{OE}	1† min	W

* For conditions given, minimum efficiency = 60 per cent.
† For conditions given, minimum efficiency = 45 per cent.



92CS-13146T



92CS-13158T

2N3878

POWER TRANSISTOR

Si n-p-n epitaxial type used in af, rf, and ultrasonic applications such as low-distortion power amplifiers, oscillators, switching regulators, series regulators, converters, and inverters. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

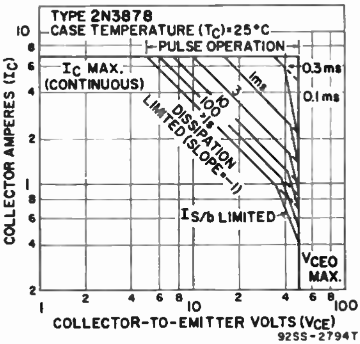
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	120	
Collector-to-Emitter Voltage:			V
R_{BE} = 50 Ω	V_{CER}(sus)	65	V
Base open (sustaining voltage)	V_{CEO}(sus)	50	V
Emitter-to-Base Voltage	V_{EBO}	7	A
Collector Current	I_C	7	A
Base Current	I_B	5	V
Transistor Dissipation:			
T_C up to 25°C	P_T	35	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	255	°C

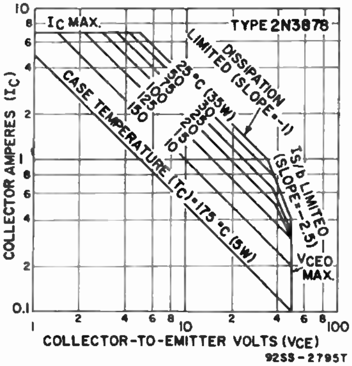
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage:			
I_C = 0.2 A, I_B = 0	V_{CEO}(sus)	50 min	V
I_C = 0.2 A, R_{BE} = 50 Ω	V_{CER}(sus)	65 min	V
Collector-to-Emitter Saturation Voltage (I_C = 4 A, I_B = 0.5 A)	V_{CE}(sat)	2 max	V
Base-to-Emitter Voltage (V_{CE} = 2 V, I_C = 4 A)	V_{BE}	2.5 max	V
Collector-Cutoff Current:			
V_{CE} = 40 V, I_B = 0, T_C = 25°C	I_{CEO}	5 max	mA

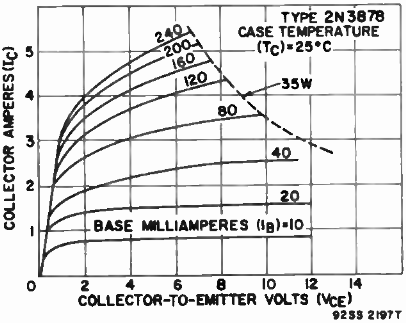
MAXIMUM PULSE OPERATING AREAS



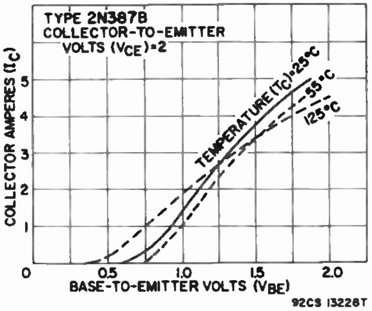
MAXIMUM DC OPERATING AREAS



TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



CHARACTERISTICS (cont'd)

V_{CE} = 100 V, V_{BE} = −1.5 V, T_C = 25°C	I_{CEV}	4 max	mA
V_{CE} = 100 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	4 max	mA
Emitter-Cutoff Current (V_{EB} = 4 V, I_C = 0)	I_{EBO}	4 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 0.5 A	h_{FE}	50 to 200	
V_{CE} = 5 V, I_C = 4 A	h_{FE}	20 min	
V_{CE} = 2 V, I_C = 4 A	h_{FE}	8 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 0.5 A, f = 10 Mc/s)	h_{fe}	4 min	
Second-Breakdown Collector Current (V_{CE} = 40 V, base forward-biased)	$I_{S/b}$	750 min	mA
Second-Breakdown Energy (R_{BE} = 50 Ω, L = 125 μH, V_{BE} = −4 V, base reverse-biased)	$E_{S/b}$	1 min	mJ
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 1 Mc/s)	C_{obo}	175 max	pF
Thermal Resistance, Junction-to-Case	θ_{J-C}	5 max	°C/W

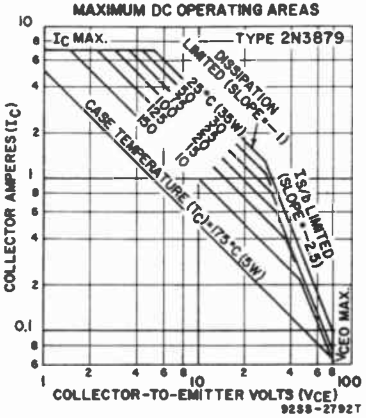
POWER TRANSISTOR

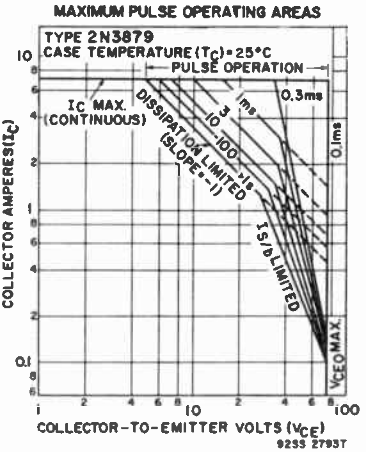
2N3879

Si **n-p-n** epitaxial type used in af, rf, and ultrasonic applications such as low-distortion power amplifiers, oscillators, switching regulators, series regulators, converters and inverters. JEDEC TO-66, **Outline** No.22. **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N3878 except for collector-to-emitter voltages of V_{CER}(sus) = 90 V and V_{CEO}(sus) = 75 V, and the following items:

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Saturation Voltage (I_C = 4 A, I_B = 0.4 A)	V_{CE}(sat)	1.2 max	V
Base-to-Emitter Voltage (V_{CE} = 2 V, I_C = 4 A)	V_{BE}	1.8 max	V
Emitter-Cutoff Current (V_{EB} = 4 V, I_C = 0)	I_{EBO}	2 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 0.5 A	h_{FE}	40 min	
V_{CE} = 5 V, I_C = 4 A	h_{FE}	20 to 80	
V_{CE} = 2 V, I_C = 4 A	h_{FE}	12 min	
Second-Breakdown Collector Current (V_{CE} = 40 V, base forward-biased)	$I_{S/b}$	500 min	mA
Delay Time (V_{CC} = 30 V, I_C = 4 A, I_{B_1} = 0.4 A, I_{B_2} = −0.4 A)	t_d	40 max	ns
Rise Time (V_{CC} = 30 V, I_C = 4 A, I_{B_1} = 0.4 A, I_{B_2} = −0.4 A)	t_r	400 max	ns
Storage Time (V_{CC} = 30 V, I_C = 4 A, I_{B_1} = 0.4 A, I_{B_2} = −0.4 A)	t_s	800 max	ns
Fall Time (V_{CC} = 30 V, I_C = 4 A, I_{B_1} = 0.4 A, I_{B_2} = −0.4 A)	t_f	400 max	ns





2N3932 TRANSISTOR

Si n-p-n epitaxial planar type for general purpose vhf-uhf applications in rf amplifiers. Outline No.27 (4-lead). Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - case.

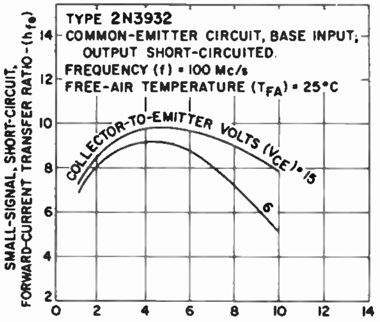
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	30	V
Collector-to-Emitter Voltage	V_{CEO}	20	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	Limited by Power Dissipation	
Transistor Dissipation:			
T_A up to 25°C	P_T	175	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 175	°C
Storage	T_{STG}	−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

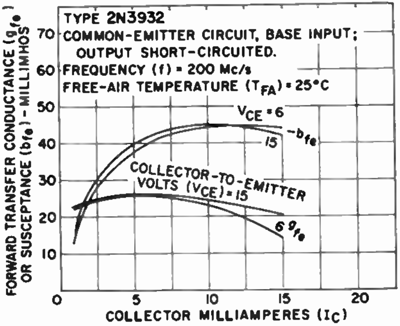
Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	30 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 1 mA, I_B = 0)	$V_{(BR)CEO}$	20 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.001 mA, I_C = 0)	$V_{(BR)EBO}$	2.5 min	V
Collector-Cutoff Current (V_{CB} = 15 V, I_E = 0)	I_{CBO}	0.01 max	μA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 8 V, I_C = 2 mA, f = 100 Mc/s, lead No. 4 grounded)	h_{fe}	7.5 to 16	
Gain-Bandwidth Product	f_T	750 min	Mc/s
Collector-to-Base Time Constant (V_{CB} = 8 V, I_E = 2 mA, f = 31.9 Mc/s)	$r_b'C_c$	1 to 8	ps
Output Capacitance (V_{CB} = 8 V, I_E = 0, f = 0.1 to 1 Mc/s, lead Nos. 1 and 4 connected to guard terminal)	C_{obo}	0.55 max	pF
Static Forward-Current Transfer Ratio (V_{CE} = 8 V, I_C = 2 mA)	h_{FE}	40 to 150	
Small-Signal Power Gain, Unneutralized Amplifier (V_{CB} = 8 V, I_C = 2 mA, f = 200 Mc/s, lead No. 4 grounded)	G_{pe}	11.5 to 17	dB
Noise Figure:			
V_{CE} = 8 V, I_C = 2 mA, R_S = 200 Ω, f = 200 Mc/s	NF	4.5 max	dB
V_{CE} = 6 V, I_C = 1.5 mA, R_S = 100 Ω, f = 450 Mc/s	NF	5	dB

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



92CS-12756T1

TYPICAL FORWARD TRANSFER CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



92CS-12759T

2N3933 TRANSISTOR

Si n-p-n epitaxial planar type for general purpose vhf and uhf applications in rf amplifiers. Outline No.27 (4-lead). Terminals: 1 - emitter, 2 - base, 3 -

collector, 4 - case. This type is identical with type 2N3932 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage	V_{CEO}	30	V

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	40 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 1 mA, I_B = 0)	$V_{(BR)CEO}$	30 min	V
Static Forward-Current Transfer Ratio (V_{CE} = 8 V, I_C = 2 mA)	h_{FE}	60 to 200	
Small-Signal Power Gain, Unneutralized Amplifier (V_{CB} = 8 V, I_C = 2 mA, f = 200 Mc/s, lead No. 4 grounded)	G_{pe}	14 to 18	
Collector-to-Base Time Constant (V_{CB} = 8 V, I_E = 2 mA, f = 31.9 Mc/s)	$r_b'C_c$	1 to 6	ps
Noise Figure (V_{CB} = 8 V, I_C = 2 mA, R_S = 200 Ω, f = 200 Mc/s)	NF	4 max	dB

TRANSISTOR 2N4012

Si **n-p-n** "overlay" epitaxial planar type designed to provide high power as a frequency multiplier into the uhf or L-band frequency region in military and industrial communications equipment. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	65	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	65	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	1.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	11.6	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

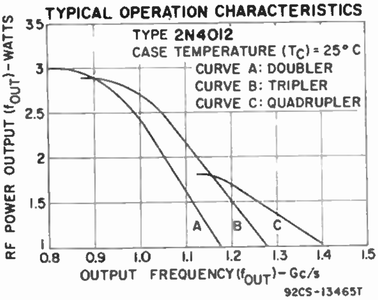
CHARACTERISTICS

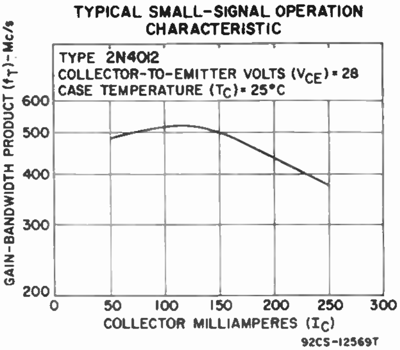
Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0 to 200 mA, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	40 min	V
V_{BE} = −1.5 V, I_C = 0 to 200 mA, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	65 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage (I_C = 500 mA, I_B = 100 mA)	V_{CE}(sat)	1 max	V
Collector-Cutoff Current (V_{CE} = 30 V, I_B = 0)	I_{CEO}	0.1 max	mA
Intrinsic Base-Spreading Resistance (V_{CE} = 28 V, I_C = 250 mA, f = 400 Mc/s)	$r_{bb'}$	10	Ω
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 150 mA)	f_T	500	Mc/s
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 Mc/s)	C_{obo}	10 max	pF
Collector-to-Base Cutoff Frequency* (V_{CE} = 28 V, I_C = 0)	f_c	25	Gc/s
RF Power Output, Multiplier:			
Tripler-V_{CE} = 28 V, f = 1002 Mc/s, P_{IE} = 1 W at 334 Mc/s	P_{OE}	2.5† min	W
Doubler-V_{CE} = 28 V, f = 800 Mc/s, P_{IE} = 1 W at 400 Mc/s	P_{OE}	3■	W

* Cutoff frequency is determined from Q measurement at 210 Mc/s. The cutoff frequency of the collector-to-base junction of the transistor, f_c = Q x 210 Mc/s.

† For conditions given, minimum efficiency = 25 per cent.

■ For conditions given, minimum efficiency = 35 per cent.





2N4036

POWER TRANSISTOR

Si **p-n-p** double-diffused **epitaxial planar** type used in a wide variety of small-signal, medium-power, and high-speed saturated switching applications in military, industrial, and commercial equipment. The p-n-p construction permits complementary operation with a matching n-p-n type such as the 2N2102. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

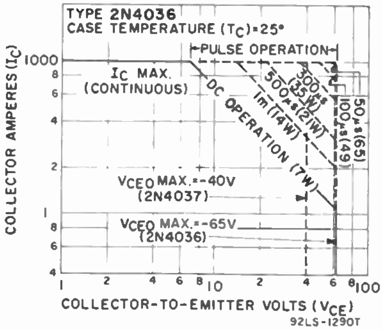
Collector-to-Base Voltage	V_{CBO}	−90	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = 1.5 V	V_{CEV}(sus)	−85	V
$R_{BE} \leqq 200\ \Omega$	V_{CER}(sus)	−85	V
Base open	V_{CEO}(sus)	−65	V
Emitter-to-Base Voltage	V_{EBO}	−7	V
Collector Current	I_C	−1	A
Base Current	I_B	−0.5	A
Transistor Dissipation:*			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	7	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

* See curve for maximum pulse operating areas.

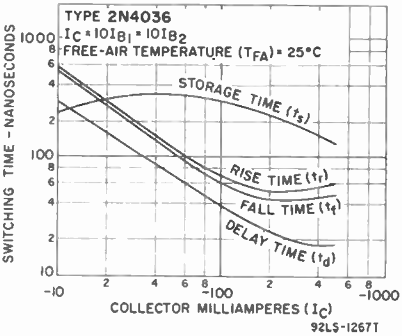
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	−90 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.1 mA, I_C = 0)	$V_{(BR)EBO}$	−7 min	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = 1.5 V, I_C = −100 mA	V_{CEV}(sus)	−85 min	V
$R_{BE} \leqq 200\ \Omega$, I_C = −100 mA	V_{CER}(sus)	−85 min	V
I_C = −100 mA, I_B = 0	V_{CEO}(sus)	−65 min	V
Collector-to-Emitter Saturation Voltage (I_C = −150 mA, I_B = −15 mA)	V_{CE}(sat)	−0.65 max	V
Collector-Cutoff Current:			
V_{CB} = −60 V, I_E = 0	I_{CBO}	−0.002 max	μA
V_{CE} = −30 V, I_B = 0	I_{CEO}	−0.5 max	μA
Emitter-Cutoff Current (V_{EB} = −5 V, I_C = 0)	I_{EBO}	−0.02 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = −10 V, I_C = −0.1 mA)	h_{FE}	20 min	
Pulsed Static Forward-Current Transfer Ratio:			
V_{CE} = −10 V, I_C = −150 mA, t_p = 300 μs, df $\leqq$ 2%	h_{FE}(pulsed)	40 to 120	
V_{CE} = −10 V, I_C = −500 mA, t_p = 300 μs, df $\leqq$ 2%	h_{FE}(pulsed)	20 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −10 V, I_C = −50 mA, f = 20 Mc/s)	h_{fe}	3 min	
Input Capacitance (V_{EB} = −0.5 V, I_C = 0)	C_{ibo}	90 max	pF
Output Capacitance (V_{CB} = −10 V, I_E = 0)	C_{obo}	30 max	pF
Saturated Switching Turn-On Time (V_{CE} = −30 V, I_C = −150 mA, I_{B_1} = −15 mA, $V_{BB} \approx$ 4 V)	$t_d + t_r$	110 max	ns
Saturated Switching Turn-Off Time (V_{CE} = −30 V, I_C = −150 mA, I_{B_2} = 15 mA, $V_{BB} \approx$ 4 V)	$t_s + t_f$	700 max	ns
Thermal Resistance, Junction-to-Case	θ_{J-C}	25 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	165 max	°C/W

MAXIMUM OPERATING AREAS



TYPICAL SWITCHING-TIME CHARACTERISTICS



POWER TRANSISTOR

2N4037

Si **p-n-p double-diffused epitaxial planar** type used in a wide variety of small-signal, medium-power applications in military, industrial, and commercial equipment. The p-n-p construction permits complementary operation with a matching n-p-n type such as the 2N3053. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

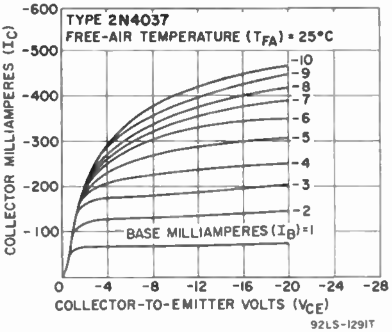
Collector-to-Base Voltage	V_{CBO}	−60	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = 1.5 V	V_{CEV}(sus)	−60	V
R_{BE} ≦ 200 Ω	V_{CER}(sus)	−60	V
Base open	V_{CEO}(sus)	−40	V
Emitter-to-Base Voltage	V_{EBO}	−7	V
Collector Current	I_C	−1	A
Base Current	I_B	−0.5	A
Transistor Dissipation:*			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	7	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

* See curve for maximum pulse operating areas.

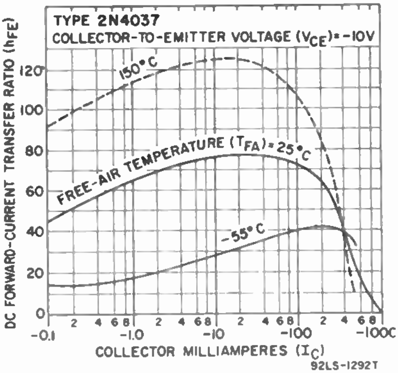
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = −0.1 mA, I_E = 0)	$V_{(BR)CBO}$	−60 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.1 mA, I_C = 0)	$V_{(BR)EBO}$	−7 min	V
Collector-to-Emitter Sustaining Voltage:			V
V_{BE} = 1.5 V, I_C = −100 mA	V_{CEV}(sus)	−60 min	
R_{BE} ≦ 200 Ω, I_C = −100 mA	V_{CER}(sus)	−60 min	V
I_C = −100 mA, I_B = 0	V_{CEO}(sus)	−40 min	V
Collector-to-Emitter Saturation Voltage (I_C = −150 mA, I_B = −15 mA)	V_{CE}(sat)	−1.4 max	V
Collector-Cutoff Current:			
V_{CB} = −60 V, I_E = 0	I_{CBO}	−0.25 max	µA
V_{CE} = −30 V, I_B = 0	I_{CEO}	−5 max	µA
Emitter-Cutoff Current (V_{EB} = −5 V, I_C = 0)	I_{EBO}	−1 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = −10 V, I_C = −1 mA)	h_{FE}	15 min	
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = −10 V, I_C = −150 mA, t_p = 300 µs, df ≦ 2%)	h_{FE}(pulsed)	20 to 100	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −10 V, I_C = −50 mA, f = 20 Mc/s)	h_{fe}	3 min	
Input Capacitance (V_{EB} = −0.5 V, I_C = 0)	C_{ibo}	90 max	pF
Output Capacitance (V_{CB} = −10 V, I_E = 0)	C_{obo}	30 max	pF
Thermal Resistance, Junction-to-Case	θ_{J-C}	25 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	165 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



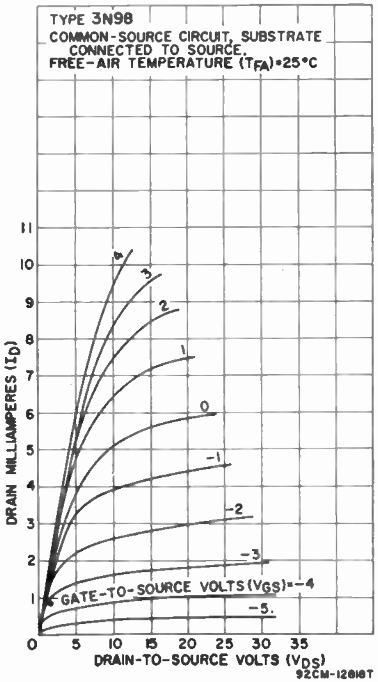
TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



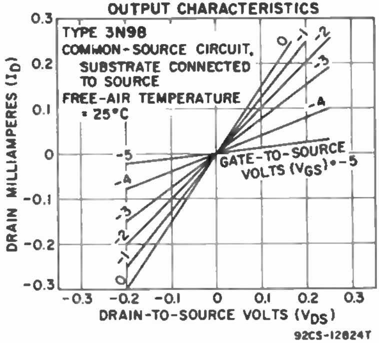
3N98 FIELD-EFFECT TRANSISTOR

Si insulated-gate field-effect (MOS) n-channel depletion type for low-power af and rf applications in which high-input resistance (10^{15} Ω) is required at frequencies to 60 Mc/s and conservation of battery power is a primary consideration. Similar to JEDEC TO-72, Outline No.23. Terminals: 1 - source, 2 - gate, 3 - drain, 4 - substrate and case.

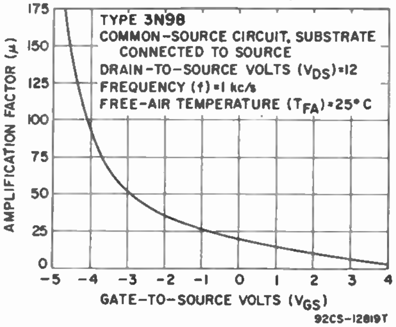
TYPICAL DRAIN CHARACTERISTICS



TYPICAL LOW-LEVEL BIDIRECTIONAL OUTPUT CHARACTERISTICS



TYPICAL AMPLIFICATION-FACTOR CHARACTERISTIC



MAXIMUM RATINGS

Drain-to-Source Voltage	V_{DS}	32	V
DC Gate-to-Source Voltage	V_{GS}	—6 to 2	V
Peak Gate-to-Source Voltage	V_{GS}	±15	V
DC Gate-to-Substrate Voltage	V_{GB}	—1 to 2	V
Peak Gate-to-Substrate Voltage	V_{GB}	±15	V
Drain-to-Substrate Voltage	V_{DB}	—0.3 to 32	V
Drain Current	I_D	15	mA
Transistor Dissipation (T_A up to 85°C	P_T	150	mW
Ambient-Temperature Range: Operating (T_A) and Storage (T_{STG})		—65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

Gate-to-Source Cutoff Voltage (V_{DS} = 12 V, I_D = 50 μA)	V_{GS}(OFF)	6 max	V
Gate Leakage Current (V_{DS} = 0, V_{GS} = —6 to 2 V)	I_{GSS}	0.1	pA
Drain-to-Source OFF Current (V_{DS} = 6 V, V_{GS} = —9 V)	I_{DS}(OFF)	50	pA
Drain Current (V_{DS} = 12 V, V_{GS} = 0)	I_D	3.5	mA
Drain-to-Source ON Resistance (V_{DS} = 6 V, V_{GS} = 9 V)	r_{DS}(ON)	900	Ω
Forward Transconductance (V_{DS} = 12 V, V_{GS} = 0, f = 1 kc/s)	g_{fs}	1000 to 3000	μmhos
Forward Transadmittance (V_{DS} = 12 V, V_{GS} = 0, f = 60 Mc/s)	Y_{fs}	1000 min	μmhos
Input Conductance (V_{DS} = 12 V, V_{GS} = 0, f = 60 Mc/s)	g_{is}	80	μmhos
Output Conductance (V_{DS} = 12 V, V_{GS} = 0, f = 60 Mc/s)	g_{os}	200	μmhos
Small-Signal Short-Circuit Reverse Transfer Capacitance (V_{DS} = 12 V, V_{GS} = 0, f = 1 kc/s)	C_{rss}	0.5* max	pF
Small-Signal Short-Circuit Input Capacitance (V_{DS} = 12 V, V_{GS} = 0, f = 1 kc/s)	C_{iss}	7* max	pF
Spot Noise Figure (R_G = 1 MΩ, V_{DS} = 12 V, V_{GS} = 0, f = 1 kc/s)	NF	7	dB

* Maximum values shown for C_{rss} and C_{iss} are for devices with 5/16-inch leads.

FIELD-EFFECT TRANSISTOR 3N99

Si **insulated-gate field-effect (MOS) n-channel depletion** type for low-power af and rf applications in which high-input resistance (10^{15} Ω) is required at frequencies to 60 Mc/s and conservation of battery power is a primary consideration. Similar to JEDEC TO-72, Outline No.23. Terminals: 1 - source, 2 - gate, 3 - drain, 4 - substrate and case. This type is identical with type 3N98 except for the following items:

CHARACTERISTICS

Drain Current (V_{DS} = 12 V, V_{GS} = 0)	I_D	5 to 10.5	mA
Drain-to-Source ON Resistance (V_{DS} = 6 V, V_{GS} = 9 V)	r_{DS}(ON)	800	Ω
Forward Transconductance (V_{DS} = 12 V, V_{GS} = 0, f = 1 kc/s)	g_{fs}	1000 to 4000	μmhos

POWER TRANSISTOR 40022

Ge **p-n-p alloy** type used in class A and push-pull class B service in high-fidelity af power-amplifier applications. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	—32	V
Collector-to-Emitter Voltage (R_{BE} = 30 Ω)	V_{CER}	—32	V
Emitter-to-Base Voltage	V_{EBO}	—5	V
Collector Current	I_C	—5	A
Base Current	I_B	—1	A

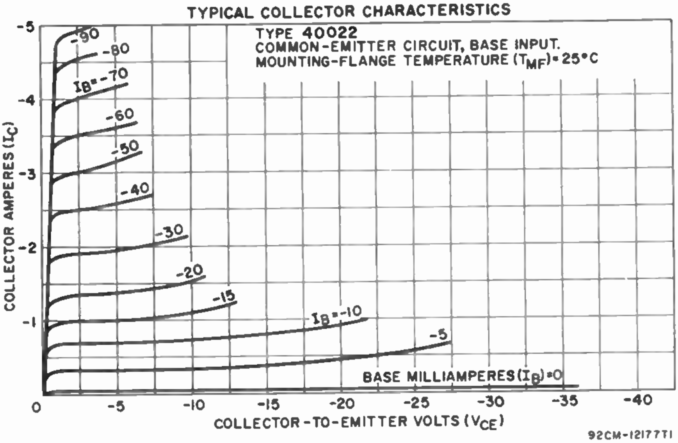
MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_{MF} up to 81°C	P_T	12.5	W
T_{MF} above 81°C	P_T	Derate linearly 0.66	W/°C
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 100	°C
Storage	T_{STG}	−65 to 100	°C
Pin-Soldering Temperature (10 s max)	T_P	255	°C

CHARACTERISTICS (At mounting-flange temperature = 25°C)

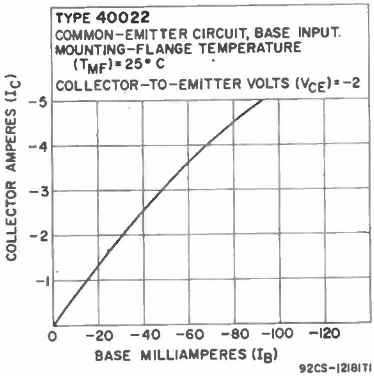
Collector-to-Base Breakdown Voltage (I_C = −0.005 A, I_E = 0)	$V_{(BR)CBO}$	−32 min	V
Collector-to-Emitter Breakdown Voltage (I_C = −0.2 A, R_{BE} = 33 Ω)	$V_{(BR)CER}$	−32 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.002 A, I_C = 0)	$V_{(BR)EBO}$	−5 min	V
Base-to-Emitter Voltage* (V_{CB} = −10 V, I_C = −0.05 A)	V_{BE}	−0.18	V
Collector-Cutoff Current (V_{CB} = −30, I_E = 0)	I_{CBO}	−1 max	mA
Collector-Cutoff Saturation Current (V_{CB} = −0.5 V, I_E = 0)	I_{CBO}(sat)	−0.1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = −2 V, I_C = −1 A)	h_{FE}	38 min	
Gain-Bandwidth Product (V_{CE} = −5 V, I_C = −0.5 A)	f_T	300	kc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



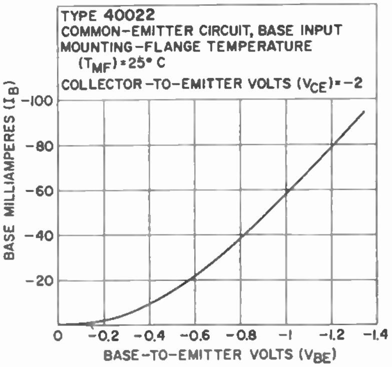
92CM-12177T1

TYPICAL TRANSFER CHARACTERISTIC



92CS-12181T1

TYPICAL INPUT CHARACTERISTIC



92CS-12179T1

TYPICAL OPERATION IN CLASS B AF-AMPLIFIER CIRCUIT

Unless otherwise specified, values are for 2 transistors.

DC Collector-Supply Voltage	V_{CC}	—14	V
Zero-Signal Base-Bias Voltage		—0.18	V
Zero-Signal DC Collector Current	I_C	—0.05	A
Maximum-Signal DC Collector Current	I_C	—0.716	A
Peak Collector Current	i_C(peak)	—2.25	A
Input Impedance of Stage (Per base)	R_S	43	Ω
Load Impedance (Speaker voice-coil)	R_L	4	Ω
Maximum Collector Dissipation (Per transistor under worst-case conditions)		5	W
Music Power Output		18	W
Power Gain	G_{PE}	24	dB
Total Harmonic Distortion		5	%
Maximum-Signal Power Output	P_{OE}	10	W

* This characteristic does not apply to type 40254.

POWER TRANSISTOR 40050

Ge p-n-p alloy type for high-fidelity amplifiers and other commercial af amplifier applications. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

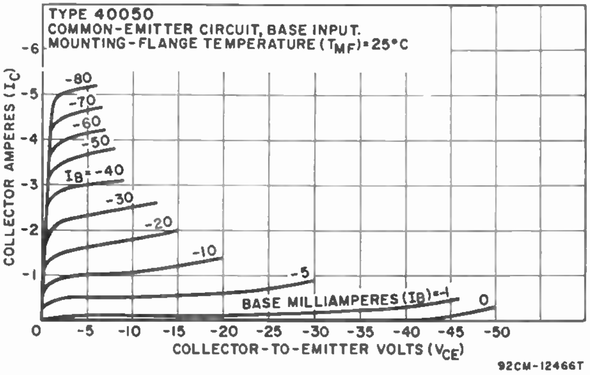
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	—40	V
Collector-to-Emitter Voltage	V_{CEO}	—40	V
Emitter-to-Base Voltage	V_{EBO}	—5	V
Collector Current	I_C	—5	A
Base Current	I_B	—1	A
Transistor Dissipation:			
T_{MF} up to 81°C	P_T	12.5	W
T_{MF} above 81°C	P_T	Derate linearly 0.66	W/°C
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 100	°C
Storage	T_{STG}	—65 to 100	°C
Pin-Soldering Temperature (10 s max)	T_P	255	°C

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = —5 mA, I_E = 0)	$V_{(BR)CBO}$	—40 min	V
Collector-to-Emitter Breakdown Voltage (I_C = —0.6 A, R_{BE} = 68 Ω)	$V_{(BR)CER}$	—40 min	V
Emitter-to-Base Breakdown Voltage (I_E = —2 mA, I_C = 0)	$V_{(BR)EBO}$	—5 min	V
Base-to-Emitter Voltage (V_{CE} = —10 V, I_C = —0.5 A)	V_{BE}	—0.17	V
Collector-Cutoff Current (V_{CB} = —30 V, I_E = 0)	I_{CBO}	—0.5 max	mA

TYPICAL COLLECTOR CHARACTERISTICS



CHARACTERISTICS (cont'd)

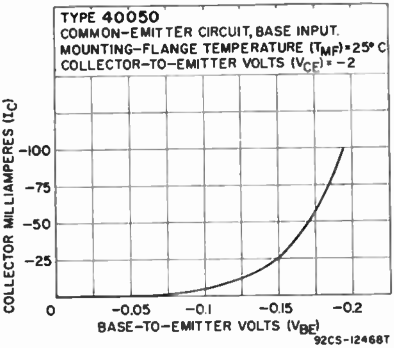
Collector-Cutoff Saturation Current (V_{CB} = −0.5 V, I_E = 0)	I_{CBO}(sat)	−0.1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = −2 V, I_C = −1 A)	h_{FE}	50 min	
Gain-Bandwidth Product (V_{CE} = −5 V, I_C = −0.5 A)	f_T	500	kc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

TYPICAL OPERATION IN CLASS B AF-AMPLIFIER CIRCUIT

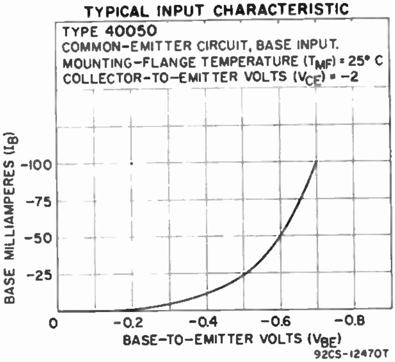
Unless otherwise specified, values are for 2 transistors.

DC Collector-Supply Voltage	V_{CC}	−18	V
Zero-Signal Base-Bias Voltage		−0.17	V
Zero-Signal DC Collector Current	I_C	−0.05	A
Maximum-Signal DC Collector Current	I_C	−0.8	A
Peak Collector Current	i_c(peak)	−2.8	A
Input Impedance of Stage (Per base)	R_S	32	Ω
Load Impedance (Speaker voice-coil)	R_L	4	Ω
Maximum Collector Dissipation (Per transistor under worst-case conditions)		7.5	W
Power Gain	G_{PE}	28	dB
Total Harmonic Distortion		5	%
Music Power Output		25	W
Maximum-Signal Power Output	P_{OE}	15	W

TYPICAL TRANSFER CHARACTERISTIC



TYPICAL INPUT CHARACTERISTIC



40051 POWER TRANSISTOR

Ge p-n-p alloy type for high-fidelity amplifiers and other commercial af amplifier applications. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 40050 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−50	V
Collector-to-Emitter Voltage	V_{CEO}	−50	V

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = −5 mA, I_E = 0)	$V_{(BR)CBO}$	−50 min	V
Collector-to-Emitter Breakdown Voltage (I_C = −0.6 A, R_{BE} = 68 Ω)	$V_{(BR)CER}$	−50 min	V

TYPICAL OPERATION IN CLASS B AF-AMPLIFIER CIRCUIT

Unless otherwise specified, values are for 2 transistors.

DC Collector-Supply Voltage	V_{CC}	−22	V
Zero-Signal Base-Bias Voltage		−0.17	V
Zero-Signal DC Collector Current	I_C	−0.05	A
Maximum-Signal DC Collector Current	I_C	−1.1	A
Peak Collector Current	i_c(peak)	−3.5	A

TYPICAL OPERATION (cont'd)

Input Impedance of Stage (Per base)	R_S	31	Ω
Load Impedance (Speaker voice-coil)	R_L	4	Ω
Maximum Collector Dissipation (Per transistor under worst-case conditions)		12.5	W
Power Gain	G_{PE}	28	dB
Total Harmonic Distortion		5	%
Music Power Output		45	W
Maximum-Signal Power Output	P_{OE}	25	W

TRANSISTOR 40080

Si n-p-n triple-diffused planar type designed for oscillator applications, in conjunction with transistor types 40081 (driver) and 40082 (power amplifier) in a 5-watt input, 27-megacycle citizens-band transmitter. JEDEC TO-39, Outline No.12. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Emitter Voltage	V_{CEO}	30	V
Peak Collector Current	i_C	0.25	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 175	°C
Storage	T_{STG}	−65 to 175	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage (I_C = 10 mA, I_E = 0)	$V_{(BR)CEO}$	30 min	V
Collector-Cutoff Current (V_{CB} = 15 V, I_E = 0)	I_{CBO}	10 max	μA
RF Power Output (V_{CC} = 12 V, I_C = 32 mA max, f = 27 Mc/s)	P_{oe}	100 min	mW

TYPICAL OPERATION IN A CITIZENS-BAND TRANSMITTER

DC Collector-Supply Voltage	V_{CC}	13.8	V
DC Collector Current:			
No modulation	I_C	15	mA
100% modulation	I_C	15	mA

TRANSISTOR 40081

Si n-p-n triple-diffused planar type designed for driver applications, in conjunction with transistor types 40080 (oscillator) and 40082 (power amplifier), in a 5-watt input, 27-megacycle citizens-band transmitter, JEDEC TO-39, Outline No.12. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Emitter Voltage (V_{BE} = −0.5 V)	V_{CEV}	60	V
Emitter-to-Base Voltage	V_{EBO}	2	V
Peak Collector Current	i_C	0.25	A
Transistor Dissipation:			
T_C up to 25°C	P_T	2	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 175	°C
Storage	T_{STG}	−65 to 175	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage (V_{BE} = −0.5 V, I_C = 100 μA)	$V_{(BR)CEV}$	60 min	V
Emitter-to-Base Breakdown Voltage (I_E = 500 μA, I_C = 0)	$V_{(BR)EBO}$	2 min	V
Collector-Cutoff Current (V_{CB} = 15 V, I_E = 0)	I_{CBO}	10 max	μA
RF Power Output (V_{CC} = 12 V, I_C = 85 mA max, P_{ie} = 75 mW, f = 27 Mc/s)	P_{oe}	400 min	mW

TYPICAL OPERATION IN A CITIZENS-BAND TRANSMITTER

DC Collector-Supply Voltage	V_{CC}	13.8	V
DC Collector Current:			
No modulation	I_C	55	mA
100% modulation	I_C	50	mA

40082 POWER TRANSISTOR

Si n-p-n triple-diffused planar type designed for power-amplifier applications, in conjunction with transistor types 40080 (oscillator) and 40081 (driver), in a 5-watt, 27-megacycle citizens-band transmitter. JEDEC TO-39, Outline No.12. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Emitter Voltage (V_{BE} = —0.5 V)	V_{CEV}	60	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Peak Collector Current	i_C	1.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	5	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 175	°C
Storage	T_{STG}	—65 to 175	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage (V_{BE} = —0.5 V, I_C = 500 μA)	$V_{(BR)CEV}$	60 min	V
Emitter-to-Base Breakdown Voltage (I_E = 500 μA, I_C = 0)	$V_{(BR)EBO}$	2.5 min	V
Collector-Cutoff Current (V_{CB} = 15 V, I_E = 0)	I_{CBO}	10 max	μA
RF Power Output (V_{CC} = 12 V, I_C = 415 mA max, P_{IE} = 350 mW, f = 27 Mc/s)	P_{OE}	3 min	W

TYPICAL OPERATION IN A CITIZENS-BAND TRANSMITTER

DC Collector-Supply Voltage	V_{CC}	13.8	V
DC Collector Current:			
No modulation	I_C	330	mA
100% modulation	I_C	330	mA
Power Output:			
No modulation (adjusted for legal maximum-power output)	P_{OE}	3.5	W
100% modulation	P_{OE}	4.8	W

40084 TRANSISTOR

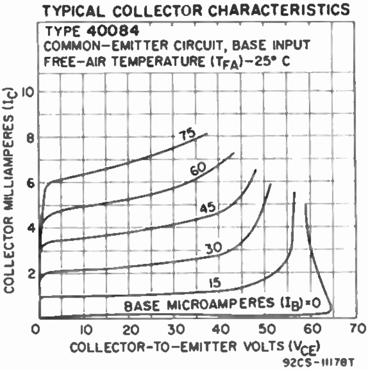
Si n-p-n triple-diffused planar type used in a wide variety of small and medium-power applications (up to 20 Mc/s) in industrial equipment. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

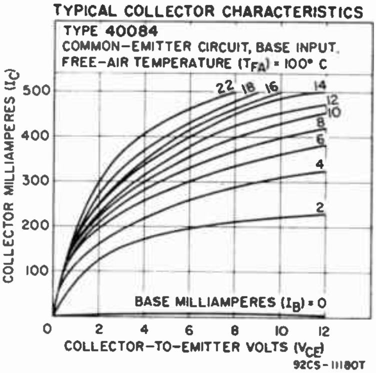
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
R_{BE} = 10 Ω	V_{CER}	50	V
Base open (sustaining voltage)	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	0.7	A
Transistor Dissipation:			
T_C up to 25°C	P_T	1.8	W
T_A up to 25°C	P_T	0.5	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C
Storage	T_{STG}	—65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	60 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 100 mA, R_{BE} = 10 Ω, t_p = 300 μs, df = 1.8%	$V_{CER}(sus)$	50 min	V
I_C = 100 mA, I_B = 0, t_p = 300 μs, df = 1.8%	$V_{CEO}(sus)$	40 min	V
Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA)	$V_{BE}(sat)$	1.7 max	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA)	$V_{CE}(sat)$	1.4 max	V
Collector-Cutoff Current (V_{CB} = 30 V, I_E = 0)	I_{CBO}	0.25 max	μA
Emitter-Cutoff Current (V_{EB} = 4 V, I_C = 0)	I_{EBO}	0.25 max	μA
Input Capacitance (V_{EB} = 0.5 V, I_C = 0)	C_{ibo}	80 max	pF
Output Capacitance (V_{CB} = 10 V, I_E = 0)	C_{obo}	15 max	pF
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 150 mA, t_p = 300 μs, df = 1.8%)	h_{FE}	50 to 250	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA, f = 20 Mc/s)	h_{fe}	5 min	
Noise Figure (R_G = 500 Ω, circuit bandwidth = 15 kc/s, V_{CE} = 10 V, I_C = 0.3 mA, f = 1 kc/s)	NF	8 max	dB
Thermal Resistance:			
Junction-to-Case	θ_{J-C}	97 max	°C/W
Junction-to-Ambient	θ_{J-A}	350 max	°C/W





COMPUTER TRANSISTOR 40217

Si n-p-n epitaxial planar type used in switching applications in data-processing equipment. JEDEC TO-52, **Outline** No.18. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is electrically identical with type 2N706 except for the following items:

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	25 min	V
Collector-to-Emitter Breakdown Voltage (R_{BE} = 10 Ω, I_C = 50 mA)	$V_{(BR)CER}$	20 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V

COMPUTER TRANSISTOR 40218

Si n-p-n epitaxial planar type used in switching applications in data-processing equipment. JEDEC TO-52, **Outline** No.18. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is electrically identical with type 2N706A except for the following items:

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.01 mA, I_E = 0)	$V_{(BR)CBO}$	25 min	V
Collector-to-Emitter Breakdown Voltage (R_{BE} = 10 Ω, I_C = 50 mA)	$V_{(BR)CER}$	20 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.01 mA, I_C = 0)	$V_{(BR)EBO}$	5 min	V

40219 COMPUTER TRANSISTOR

Si **n-p-n** epitaxial planar type used in switching applications in data-processing equipment. JEDEC TO-52, **Outline** No.18. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is electrically identical with type 2N708.

40220 COMPUTER TRANSISTOR

Si **n-p-n** epitaxial planar type used in switching applications in data-processing equipment requiring high reliability. JEDEC TO-52, **Outline** No.18. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is electrically identical with type 2N834.

40221 COMPUTER TRANSISTOR

Si **n-p-n** epitaxial planar type used in switching applications in data-processing equipment. JEDEC TO-52, **Outline** No.18. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is electrically identical with type 2N914.

40222 COMPUTER TRANSISTOR

Si **n-p-n** epitaxial planar type used in switching applications in data-processing equipment. JEDEC TO-52, **Outline** No.18. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is electrically identical to type 2N2205.

40231 TRANSISTOR

Si **n-p-n** planar type used in low-to-intermediate-signal-level af amplifier circuits, such as preamplifiers, "voltage amplifiers", and driver stages in consumer and industrial equipment. **Outline** No.26 (3-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	18	V
Collector-to-Emitter Voltage	V_{CEO}	18	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	100	mA
Emitter Current	I_E	−100	mA
Base Current	I_B	25	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_A above 25°C	P_T	See curve page 112	
T_C up to 125°C	P_T	1	W
T_C above 125°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 175	°C
Storage	T_{STG}	−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 50 μA, I_E = 0)	$V_{(BR)CBO}$	18 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 10 mA, I_B = 0)	$V_{(BR)CEO}$	18 min	V
Emitter-to-Base Breakdown Voltage (I_E = 50 μA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-Cutoff Current:			
V_{CB} = 12 V, I_E = 0, T_A = 25°C	I_{CBO}	0.5 max	μA
V_{CB} = 12 V, I_E = 0, T_A = 85°C	I_{CBO}	10 max	μA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	0.5 max	μA
Small-Signal Forward-Current Transfer Ratio (I_C = 2 mA, V_{CE} = 10 V, f = 1 kc/s)	h_{fe}	55 to 180	
Gain-Bandwidth Product (V_{CE} = 6 V, I_C = 1 mA)	f_T	60	Mc/s
Intrinsic Base-Spreading Resistance (V_{CE} = 6 V, I_C = 1 mA, f = 100 Mc/s)	r_{bb}'	20	Ω
Output Capacitance (V_{CB} = 6 V, I_E = 0, f = 1 Mc/s)	C_{obo}	22	pF
Noise Figure (R_G = 1000 Ω, V_{CE} = 6 V, I_C = 0.1 mA, circuit bandwidth = 1 c/s, f = 10 kc/s)	NF	2.8	dB
Thermal Resistance, Junction-to-Case (T_J = 175°C)	Θ_{J-C}	50 max	°C/W
Thermal Resistance, Junction-to-Ambient (T_J = 175°C)	Θ_{J-A}	300 max	°C/W

TRANSISTOR 40232

Si **n-p-n planar** type used in low-to-intermediate-signal-level af amplifier circuits, such as preamplifiers, "voltage amplifiers", and driver stages in consumer and industrial equipment. **Outline** No.26 (3-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 40231 except for the following item:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (I_C = 2 mA, V_{CE} = 10 V, f = 1 kc/s)	h_{fe}	90 to 300	

TRANSISTOR 40233

Si **n-p-n planar** type used in low-to-intermediate-signal-level af amplifier circuits, such as preamplifiers, "voltage amplifiers", and driver stages in consumer and industrial equipment. **Outline** No.26 (3-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 40231 except for the following items:

CHARACTERISTICS

Collector-Cutoff Current (V_{CB} = 12 V, I_E = 0, T_A = 25°C)	I_{CBO}	0.25 max	μA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	0.25 max	μA
Small-Signal Forward-Current Transfer Ratio (I_C = 2 mA, V_{CE} = 10 V, f = 1 kc/s)	h_{fe}	90 to 300	
Noise Figure:			
R_G = 1000 Ω, V_{CE} = 6 V, I_C = 0.1 mA, circuit bandwidth = 1 c/s, f = 10 kc/s	NF	2	dB
R_G = 1000 Ω, V_{CE} = 6 V, I_C = 0.5 mA, circuit bandwidth = 1 c/s, f = 1 kc/s	NF	6 max	dB

TRANSISTOR 40234

Si **n-p-n planar** type used in low-to-intermediate-signal-level af amplifier circuits, such as preamplifiers, "voltage amplifiers", and driver stages in consumer and industrial equipment. **Outline** No.26 (3-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 40231 except for the following item:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (I_C = 2 mA, V_{CE} = 10 V, f = 1 kc/s)	h_{fe}	35 to 470	

40235 TRANSISTOR

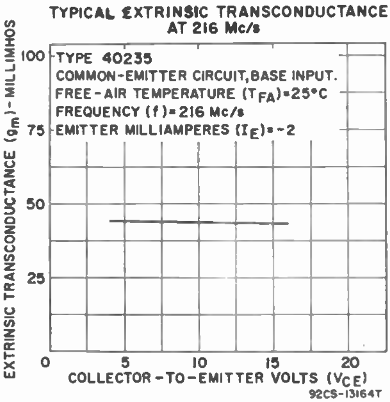
Si **n-p-n** type used as rf amplifier in television tuners covering channels 2 through 13. **Outline** No.27. **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

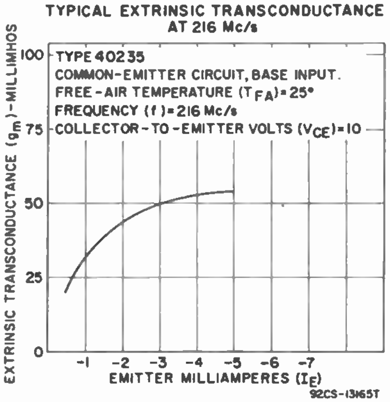
MAXIMUM RATINGS

Collector-to-Base Voltage:			
$V_{BE} = -1$ V	V_{CBV}	35	V
Emitter open	V_{CBO}	35	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	50	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	180	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 175	°C
Lead Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-Cutoff Current:			
$V_{CB} = 1$ V, $I_E = 0$	I_{CBO}	0.02 max	µA
$V_{CB} = 35$ V, $I_E = 0$	I_{CBO}	1 max	µA
Emitter-Cutoff Current ($V_{EB} = 3$ V, $I_C = 0$)	I_{EBO}	1 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = 6$ V, $I_E = -1$ mA)	h_{FE}	40 to 170	
Gain-Bandwidth Product ($V_{CE} = 6$ V, $I_E = -1$ mA, f = 100 Mc/s)	f_T	1200	Mc/s
Collector-to-Base Feedback Capacitance ($V_{CE} = 10$ V, $I_E = -2$ mA, f = 216 Mc/s)	C_{cb}	0.5	pF
Input Resistance ($V_{CE} = 10$ V, $I_E = -2$ mA, f = 216 Mc/s)	R_{ie}	190	Ω
Output Resistance ($V_{CE} = 10$ V, $I_E = -2$ mA, f = 216 Mc/s)	R_{oe}	8.9	kΩ
Extrinsic Transconductance ($V_{CE} = 10$ V, $I_E = -2$ mA, f = 216 Mc/s)	g_m	43.7	mmhos
Noise Figure ($V_{CE} = 10$ V, $I_E = -2$ mA, R_G & $R_L = 50$ Ω, f = 216 Mc/s)	NF	3.3	dB
Maximum Available Amplifier Gain ($V_{CE} = 10$ V, $I_E = -2$ mA, f = 216 Mc/s)	MAG	29.1	dB
Maximum Usable Amplifier Gain, Neutralized ($V_{CE} = 10$ V, $I_E = -2$ mA, R_G & $R_L = 50$ Ω, f = 216 Mc/s)	MUG	18.1	dB





40236 TRANSISTOR

Si **n-p-n** type used as rf mixer in television tuners covering channels 2 through 13. **Outline** No.27 (4-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case. The maximum ratings for this type are identical with type 40235.

CHARACTERISTICS

Collector-Cutoff Current:			
V_{CB} = 1 V, I_E = 0	I_{CBO}	0.02 max	µA
V_{CB} = 35 V, I_E = 0	I_{CBO}	1 max	µA
Emitter-Cutoff Current (V_{EB} = 1 V, I_C = 0)	I_{CBO}	1 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	40 to 275	
Gain-Bandwidth Product (V_{CE} = 6 V, I_E = −1 mA, f = 100 Mc/s)	f_T	1200	Mc/s
Collector-to-Base Feedback Capacitance (V_{CE} = 12 V, I_E = 1.5 mA, f = 216 Mc/s)	C_{cb}	0.5	pF
Input Resistance (V_{CE} = 12 V, I_E = −1.5 mA, f = 216 Mc/s)	R_{ie}	230	Ω
Output Resistance (V_{CE} = 12 V, I_E = −1.5 mA, f = 45 Mc/s)	R_{oe}	65	kΩ
Maximum Available Conversion Gain (V_{CE} = 12 V, I_E = −1.5 mA, f = 216 to 45 Mc/s)	MAG_c	19	dB

TRANSISTOR 40237

Si n-p-n type used as rf local oscillator in television tuners covering channels 2 through 13. Outline No.27 (4-lead). Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case. The maximum ratings for this type are identical with type 40235.

CHARACTERISTICS

Collector-Cutoff Current:			
V_{CB} = 1 V, I_E = 0	I_{CBO}	0.02 max	µA
V_{CB} = 35 V, I_E = 0	I_{CBO}	1 max	µA
Emitter-Cutoff Current (V_{EB} = 1 V, I_C = 0)	I_{EBO}	1 max	µA
Output Capacitance (V_{CB} = 12 V, I_C = 2.5 mA, f = 257 Mc/s)	C_{obo}	0.6 max	pF
Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	27 to 275	
Gain-Bandwidth Product (V_{CE} = 6 V, I_E = −1 mA, f = 100 Mc/s)	f_T	1200	Mc/s

TRANSISTOR 40238

Si n-p-n type used as 45-Mc/s if amplifier in television receivers. Outline No.27 (4-lead). Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

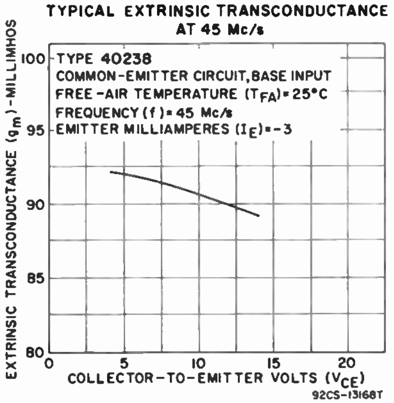
Collector-to-Base Voltage:			
V_{BE} = −1 V	V_{CBV}	35	V
Emitter open	V_{CBO}	35	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	50	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	180	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

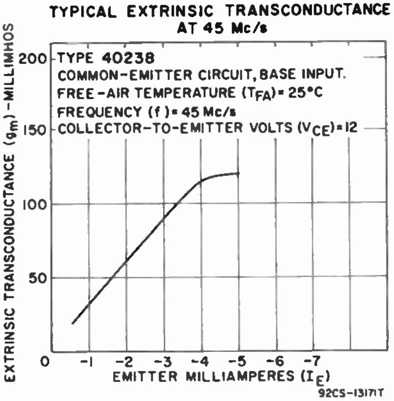
CHARACTERISTICS

Collector-Cutoff Current:			
V_{CB} = 1 V, I_E = 0	I_{CBO}	0.02 max	µA
V_{CB} = 35 V, I_E = 0	I_{CBO}	1 max	µA
Emitter-Cutoff Current (V_{EB} = 1 V, I_C = 0)	I_{CBO}	1 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	40 to 170	
Gain-Bandwidth Product (V_{CE} = 6 V, I_E = −1 mA, f = 100 Mc/s)	f_T	900	Mc/s
Collector-to-Base Feedback Capacitance (V_{CE} = 12 V, I_E = −3 mA, f = 216 Mc/s)	C_{cb}	0.5	pF
Input Resistance (V_{CE} = 12 V, I_E = −3 mA, f = 45 Mc/s)	R_{ie}	480	Ω
Output Resistance (V_{CE} = 12 V, I_E = −3 mA, f = 45 Mc/s)	R_{oe}	35	kΩ

CHARACTERISTICS (cont'd)

Extrinsic Transconductance (V_{CE} = 12 V, I_E = −3 mA, f = 45 Mc/s)	g_m	90	mmhos
Maximum Available Amplifier Gain For 1, 2, or 3 Stages (V_{CE} = 12 V, I_E = −3 mA, f = 45 Mc/s)	MAG	45.3	dB
Maximum Usable Amplifier Gain, Unneutralized (V_{CE} = 12 V, I_E = −3 mA, f = 45 Mc/s):			
For 1 stage	MUG	22.9	dB
For 2 stages	MUG	20.7	dB
For 3 stages	MUG	19	dB
Maximum Usable Amplifier Gain, Neutralized (V_{CE} = 12 V, I_E = −3 mA, f = 45 Mc/s):			
For 1 stage	MUG	28	dB
For 2 stages	MUG	25.8	dB
For 3 stages	MUG	24.1	dB





40239 TRANSISTOR

Si **n-p-n** type used as 45-Mc/s if amplifier in television receivers. **Outline** No.27 (4-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case. This type is identical with type 40238 except for the following item:

CHARACTERISTICS

Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	27 to 100

40240 TRANSISTOR

Si **n-p-n** type used as 45-Mc/s if amplifier in television receivers. **Outline** No.27 (4-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case. This type is identical with type 40238 except for the following item:

CHARACTERISTICS

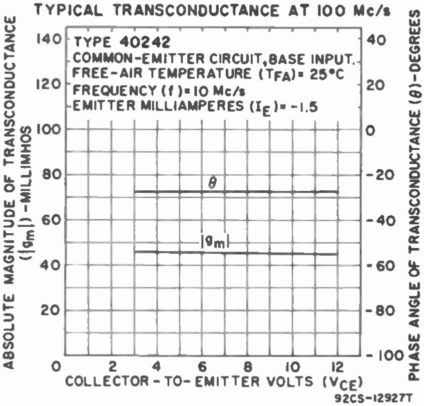
Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	27 to 275

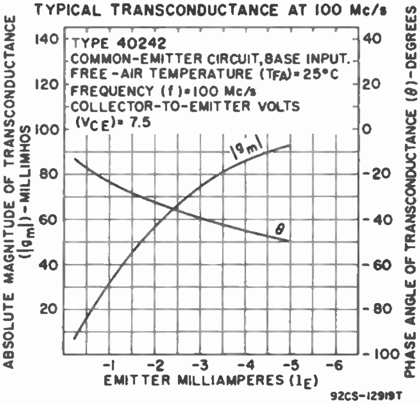
40242 TRANSISTOR

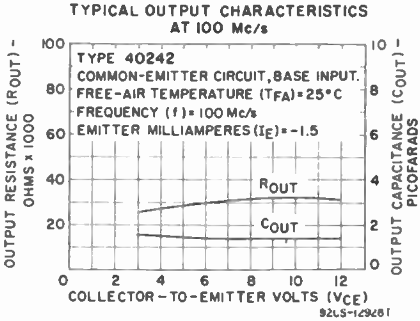
Si **n-p-n** planar type used in rf-amplifier applications in conjunction with types 40243 (mixer), 40244 (rf oscillator), and 40245 and 40246 (if amplifiers) to make up a "front-end" and if complement for FM and AM/FM receivers. **Outline** No.27 (4-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

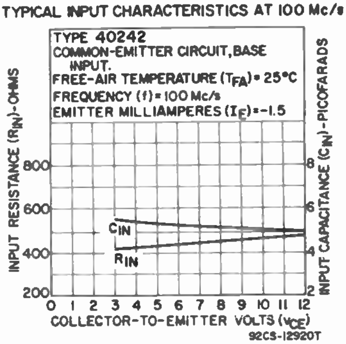
MAXIMUM RATINGS

Collector-to-Base Voltage:			
Emitter open	V_{CBO}	35	V
V_{BE} = −1 V	V_{CBV}	35	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	50	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	180	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C









CHARACTERISTICS

Collector-to-Base Breakdown Voltage:			
I_C = 0.001 mA, I_E = 0	$V_{(BR)CBO}$	35 min	V
V_{BE} = −1 V, I_C = 0.001 mA	$V_{(BR)CBV}$	35 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.001 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V
Collector-Cutoff Current (V_{CE} = 1 V, I_E = 0)	I_{CBO}	0.02 max	μA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	1 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	40 to 170	
Extrinsic Transconductance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 Mc/s)	g_m	45	mmhos
Maximum Available Amplifier Gain* (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 Mc/s)	MAG	38.3	dB
Maximum Usable Amplifier Gain*:			
Neutralized—V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 Mc/s	MUG	21.5	dB
Unneutralized—V_{CC} = 15 V, f = 100 Mc/s	MUG	16.4	dB
Input Capacitance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 Mc/s)	C_{ie}	5.2	pF
Feedback Capacitance (V_{CB} = 8 V, I_E = 0, f = 1 Mc/s)	C_{cb}	0.65 max	pF

CHARACTERISTICS (cont'd)

Input Resistance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 Mc/s)	R_{ie}	450	Ω
Output Resistance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 Mc/s)	R_{oe}	30	kΩ
Output Capacitance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 Mc/s)	C_{oe}	1.35	pF
Noise Figure* (V_{CC} = 15 V, R_G = 50 Ω, f = 100 Mc/s)	NF	2.5	dB

* This characteristic applies only to type 40242.

40243 TRANSISTOR

Si **n-p-n planar** type used in mixer applications in conjunction with types 40242 (rf amplifier), 40244 (rf oscillator), and 40245 and 40246 (if amplifiers) to make up a "front-end" and if complement for FM and AM/FM receivers. **Outline** No.27 (4-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - case. This type is identical with type 40242 except for the following items:

MAXIMUM RATINGS

Emitter-to-Base Voltage	V_{EBO}	3	V

CHARACTERISTICS

Emitter-Cutoff Current (V_{EB} = 3 V, I_C = 0)	I_{EBO}	1 max	µA
Extrinsic Transconductance (V_{CE} = 7.5 V, I_E = −1 mA, f = 100 Mc/s)	g_m	32	mmhos
Maximum Available Conversion Gain (V_{CE} = 7.5 V, I_E = −1 mA, f = 10.7 to 100 Mc/s)	MAG_c	37.64	dB
Input Capacitance (V_{CE} = 7.5 V, I_E = −1 mA, f = 100 Mc/s)	C_{ie}	4.5	pF
Input Resistance (V_{CE} = 7.5 V, I_E = −1 mA, f = 100 Mc/s)	R_{ie}	650	Ω
Output Resistance (V_{CE} = 7.5 V, I_E = −1 mA, f = 100 Mc/s)	R_{oe}	30	kΩ
Output Capacitance (V_{CE} = 7.5 V, I_E = −1 mA, f = 100 Mc/s)	C_{oe}	1.35	pF

40244 TRANSISTOR

Si **n-p-n planar** type used in rf-oscillator applications in conjunction with types 40242 (rf amplifier), 40243 (mixer), and 40245 and 40246 (if amplifiers) to make up a "front-end" and if complement for FM and AM/FM receivers. **Outline** No.27 (4-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

Collector-to-Base Voltage:			
Emitter open	V_{CBO}	35	V
V_{BE} = −1 V	V_{CEV}	35	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	50	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	180	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage:			
I_C = 0.001 mA, I_E = 0	$V_{(BR)CBO}$	35 min	V
V_{BE} = −1 V, I_C = 0.001 mA	$V_{(BR)CBV}$	35 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.001 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V
Collector-Cutoff Current (V_{CE} = 1 V, I_E = 0)	I_{CBO}	0.02 max	µA
Emitter-Cutoff Current (V_{EB} = 3 V, I_C = 0)	I_{EBO}	1 max	µA

CHARACTERISTICS (cont'd)

Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	27 to 170	
Oscillator Output Voltage, Common Base Circuit (V_{CC} = 6 V, R_L = 50 Ω, f = 120 Mc/s)	V_{ob}	55	mV
Feedback Capacitance (V_{CE} = 8 V, I_E = 0, f = 1 Mc/s)	C_{cb}	0.8 max	pF

TRANSISTOR 40245

Si n-p-n planar type used in if-amplifier applications in conjunction with types 40242 (rf amplifier), 40243 (mixer), 40244 (rf oscillator), and 40246 (if amplifier) to make up a "front-end" and if complement for FM and AM/FM receivers. Outline No.27 (4-lead). Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

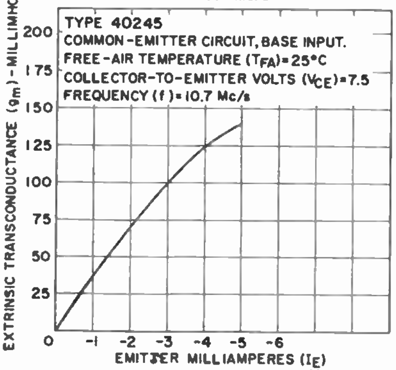
MAXIMUM RATINGS

Collector-to-Base Voltage:			
Emitter open	V_{CBO}	35	V
V_{BE} = −1 V	V_{CBV}	35	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	50	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	180	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage:			
I_C = 0.001 mA, I_E = 0	$V_{(BR)CBO}$	35 min	V
V_{BE} = −1 V, I_C = 0.001 mA	$V_{(BR)CBV}$	35 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.001 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V
Collector-Cutoff Current (V_{CB} = 1 V, I_E = 0)	I_{CBO}	0.02 max	µA
Emitter-Cutoff Current (V_{EB} = 3 V, I_C = 0)	I_{EBO}	1 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	70 to 170	
Feedback Capacitance (V_{CE} = 8 V, I_E = 0, f = 1 Mc/s)	C_{cb}	0.65 max	pF
Extrinsic Transconductance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 Mc/s)	g_m	70	mmhos
Maximum Available Amplifier Gain (V_{CB} = 7.5 V, I_E = −2 mA, f = 10.7 Mc/s)	MAG	51.4	dB
Maximum Usable Amplifier Gain:			
Neutralized—V_{CC} = 12 V, f = 10.7 Mc/s	MUG	33.2	dB
Unneutralized—V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 Mc/s	MUG	28.1	dB

TYPICAL EXTRINSIC TRANSCONDUCTANCE AT 10.7 Mc/s



92CS-12929T

CHARACTERISTICS (cont'd)

Input Capacitance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 Mc/s)	C_{ie}	8.2	pF
Input Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 Mc/s)	R_{ie}	1400	Ω
Output Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 Mc/s)	R_{oe}	80	kΩ
Output Capacitance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 Mc/s)	C_{oe}	1.5	pF

40246 TRANSISTOR

Si **n-p-n planar** type used in if-amplifier applications in conjunction with types 40242 (rf amplifier), 40243 (mixer), 40244 (if oscillator), and 40245 (if amplifier) to make up a "front-end" and if complement for FM and AM/FM receivers. Outline No.27 (4-lead). Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to the case. This type is identical with type 40245 except for the following items:

CHARACTERISTICS

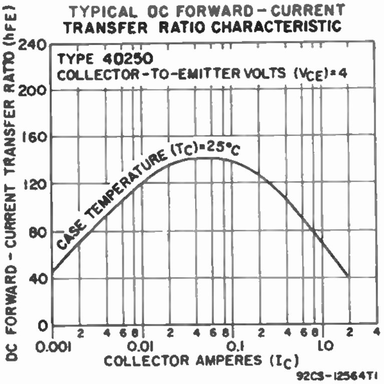
Input Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 Mc/s)	R_{ie}	1200	Ω
Output Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 Mc/s)	R_{oe}	90	kΩ

40250 POWER TRANSISTOR

Si **n-p-n diffused-junction** type used in audio and inverter circuits in 12-volt mobile radio and portable communications equipment and in a wide variety of intermediate- and high-power applications. JEDEC TO-66, **Outline** No.22. **Terminals**: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

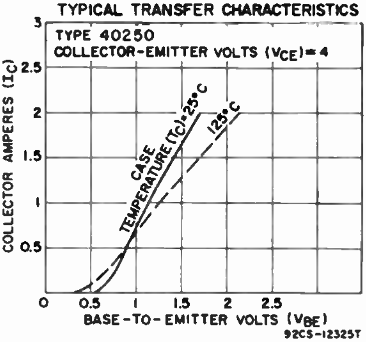
Collector-to-Base Voltage	V_{CBO}	50	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	50	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	4	A
Base Current	I_B	2	A
Transistor Dissipation:			
T_C up to 25°C	P_T	29	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	235	°C



CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage ($I_C = 0.05$ A, $I_E = 0$)	$V_{(BR)CBO}$	50 min	V
Collector-to-Emitter Breakdown Voltage ($I_C = 0.05$ A, $V_{BE} = -1.5$ V)	$V_{(BR)CEV}$	50 min	V
Collector-to-Emitter Sustaining Voltage ($I_C = 0.1$ A)	$V_{CEO}(sus)$	40 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.005$ A, $I_C = 0$)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 1.5$ A, $I_B = 0.15$ A)	$V_{CE}(sat)$	1.5 max	V
Base-to-Emitter Voltage ($V_{CE} = 4$ V, $I_C = 1.5$ A)	V_{BE}	2.2 max	V
Collector-Cutoff Current:			
$V_{CB} = 30$ V, $I_E = 0$, $T_C = 25°C$	I_{CBO}	1 max	mA
$V_{CB} = 30$ V, $I_E = 0$, $T_C = 150°C$	I_{CBO}	5 max	mA
Emitter-Cutoff Current ($V_{EB} = 5$ V, $I_C = 0$)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = 4$ V, $I_C = 1.5$ A)	h_{FE}	25 to 100	
Thermal Resistance, Junction-to-Case	θ_{J-C}	6* max	°C/W

* This value does not apply to type 40250V1.



TRANSISTOR 40250V1

Si **n-p-n diffused-junction** type used in audio and inverter circuits in 12-volt mobile radio and portable communications equipment and in a wide variety of intermediate- and high-power applications. This type has an attached heat radiator for mounting on printed-circuit-board applications. JEDEC TO-66 (with heat radiator), Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case (with heat radiator). This type is identical with type 40250 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	5.8	W

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	30 max	°C/W

POWER TRANSISTOR 40251

Si **n-p-n diffused-junction** type used in audio and inverter circuits in 12-volt mobile radio and portable communications equipment and in a wide variety of intermediate- and high-power applications. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

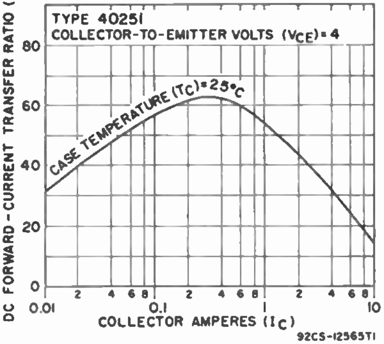
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	50	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	50	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	15	A
Base Current	I_B	7	A
Transistor Dissipation:			
T_C up to 25°C	P_T	117	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	235	°C

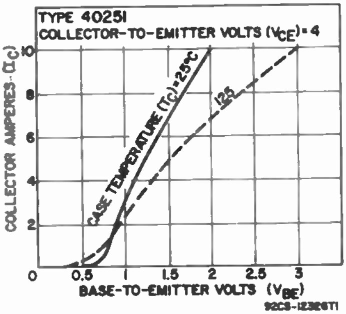
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 A, I_E = 0)	$V_{(BR)CBO}$	50 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 0.1 A, V_{BE} = −1.5 V)	$V_{(BR)CEV}$	50 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.01 A, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Sustaining Voltage (I_C = 0.2 A)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Saturation Voltage (I_C = 8 A, I_B = 0.8 A)	V_{CE}(sat)	1.5 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 8 A)	V_{BE}	2.2 max	V
Collector-Cutoff Current:			
V_{CE} = 30 V, V_{BE} = −1.5 V, T_C = 25°C	I_{CEV}	2 max	mA
V_{CE} = 40 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	10 max	mA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	10 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 8 A)	h_{FE}	15 to 60	
Thermal Resistance, Junction-to-Case	Θ_{J-C}	1.5 max	°C/W

TYPICAL OC FORWARD-CURRENT TRANSFER RATIO CHARACTERISTIC



TYPICAL TRANSFER CHARACTERISTICS



40253 TRANSISTOR

Ge p-n-p alloy-junction type used in class B audio amplifier applications in consumer product and industrial equipment. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−25	V
Collector-to-Emitter Voltage	V_{CEO}	−25	V
Emitter-to-Base Voltage	V_{EBO}	−2.5	V
Collector Current	I_C	−500	mA
Emitter Current	I_E	500	mA
Base Current	I_B	−100	mA

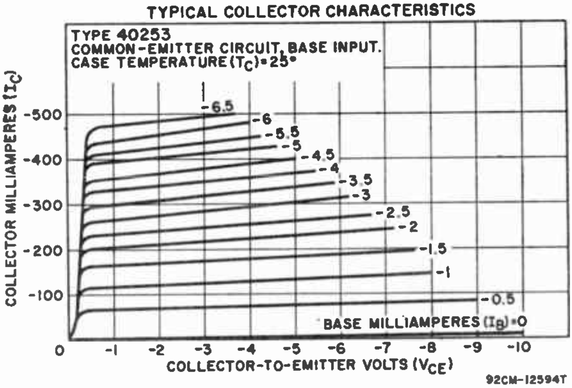
MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_A up to 55°C	P_T	125	mW
T_A above 55°C	P_T	See curve page 112	
T_C up to 64°C	P_T	650	mW
T_C above 64°C	P_T	Derate linearly 25	mW/°C
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 90	°C
Storage	T_{STG}	−65 to 90	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

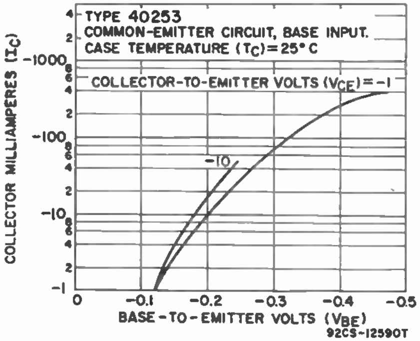
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = −0.05 mA, I_E = 0)	$V_{(BR)CBO}$	−25 min	V
Collector-to-Emitter Breakdown Voltage (I_C = −2 mA, I_B = 0)	$V_{(BR)CEO}$	−25 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.014 mA, I_C = 0)	$V_{(BR)EBO}$	−2.5 min	V
Collector-to-Emitter Saturation Voltage (I_C = −400 mA, I_B = −20 mA)	V_{CE}(sat)	−0.5	V
Base-to-Emitter Voltage:			
V_{CE} = −10 V, I_C = −5 mA	V_{BE}	−0.15	V
V_{CE} = −1 V, I_C = −400 mA	V_{BE}	−0.45	V
Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−14 max	µA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	−14 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = −1 V, I_C = −400 mA)	h_{FE}	50 min	
Gain-Bandwidth Product	f_T	1	Mc/s
Thermal Resistance, Junction-to-Case (T_C = 64°C)	θ_{J-C}	40 max	°C/W

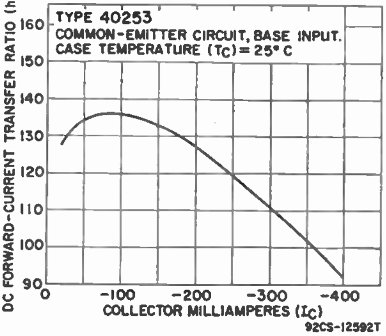
TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC



40254 POWER TRANSISTOR

Ge **p-n-p** alloy type for class A af power-amplifier service in driver- and output-stage applications. JEDEC TO-3, **Outline** No.2. **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 40022 except for the following items:

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-Cutoff Current ($V_{CB} = -30$ V, $I_E = 0$)	I_{CBO}	−3 max	mA
Collector-Cutoff Saturation Current ($V_{CB} = -0.5$ V, $I_E = 0$)	$I_{CBO}(sat)$	−0.16 max	mA

TYPICAL OPERATION IN CLASS A AF-AMPLIFIER CIRCUIT

DC Collector-Supply Voltage	V_{CC}	−16	V
DC Collector-to-Emitter Voltage	V_{CE}	−13.2	V
DC Collector Current	I_C	−0.9	A
Peak Collector Current	$i_c(peak)$	−1.8	A
Input Impedance	R_S	15	Ω
Collector Load Impedance	R_L	15	Ω
Maximum Collector Dissipation		12	W
Power Gain	G_{PE}	36	dB
Total Harmonic Distortion ($P_{OE} = 5$ W)		5	%
Maximum-Signal Power Output	P_{OE}	5	W

40255 TRANSISTOR

Si **n-p-n triple-diffused** type used in switching and linear amplifiers, differential and operational amplifiers, high-voltage inverters, and series regulators for industrial and military applications. JEDEC TO-5 (with flange), **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with flange). This type is identical with type 2N3439 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation T_C up to 50°C	P_T	10	W

CHARACTERISTICS

Thermal Resistance, Junction-to-Case ($P_{oe} = 2$ to 4 W, $I_E = 100$ mA)	θ_{J-C}	15 max	°C/W

40256 TRANSISTOR

Si **n-p-n triple-diffused** type used in switching and linear amplifiers, differential and operational amplifiers, high-voltage inverters, and series regulators for industrial and military applications. JEDEC TO-5 (with flange), **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with flange). This type is identical with type 2N3440 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation: T_C up to 50°C	P_T	10	W

CHARACTERISTICS

Thermal Resistance, Junction-to-Case ($P_{oe} = 2$ to 4 W, $I_E = 100$ mA)	θ_{J-C}	15 max	°C/W

40261 TRANSISTOR

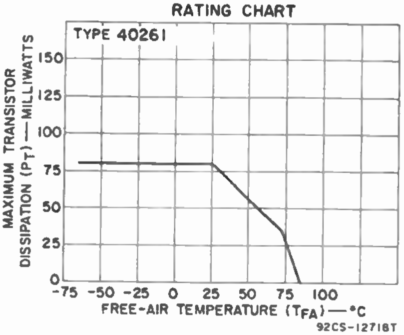
Ge **p-n-p drift-field** type used in converter service in conjunction with types 40262 (if amplifier), 40263 (af amplifier and driver), 40264 (power output), and 40265 (line rectifier) to provide a complement for line-operated AM broadcast-band receivers and phonographs in entertainment equipment. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

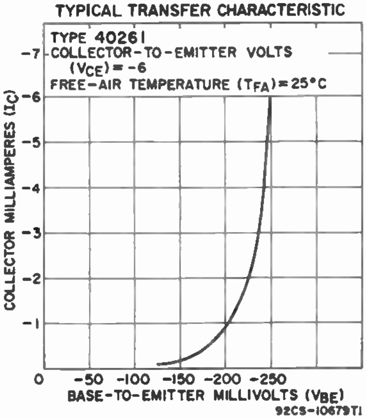
MAXIMUM RATINGS

Collector-to-Base Voltage:			
Emitter open	V_{CBO}	−34	V
V_{BE} = 0.5 V, I_C = −50 μA	V_{CBV}	−50	V
Emitter-to-Base Voltage	V_{EBO}	−0.5	V
Collector Current	I_C	−10	mA
Emitter Current	I_E	10	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	80	mW
T_A above 25°C		See Rating	Chart
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage:			
I_C = −0.05 mA, I_E = 0	V_{CBO}	−50	V
V_{BE} = 0.5 V, I_C = −0.05 mA	V_{CBV}	−34	V
Emitter-to-Base Breakdown Voltage (I_E = −0.012 mA, I_C = 0)	$V_{(BR)EBO}$	−0.5 min	V
Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−12 max	μA
Emitter-Cutoff Current (V_{EB} = 0.5 V, I_C = 0)	I_{EBO}	−12 max	μA
Intrinsic Base-Spreading Resistance (V_{CE} = −12 V, I_C = −1 mA, f = 100 Mc/s)	$r_{bb'}$	25	Ω
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_C = −1 mA, f = 1 kc/s)	h_{fe}	27 to 170	
Gain-Bandwidth Product (V_{CE} = −12 V, I_C = −1 mA)	f_T	40	Mc/s
Output Capacitance (V_{CB} = −12 V, I_E = 0, f = 1.5 Mc/s)	C_{obo}	3.7 max	pF





TRANSISTOR 40262

Ge p-n-p drift-field type used in if-amplifier service in conjunction with types 40261 (converter), 40263 (af amplifier and driver), 40264 (power output), and 40265 (line rectifier) to provide a complement for line-operated AM broadcast-band receivers and phonographs in entertainment equipment. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector. This type is identical with type 40261 except for the following items:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_C = −1 mA, f = 1 kc/s)	h_{fe}	82 to 350	
Gain-Bandwidth Product (V_{CE} = −12 V, I_C = −1 mA)	f_T	30	Mc/s
Output Capacitance (V_{CB} = −12 V, I_E = 0, f = 1.5 Mc/s)	C_{obo}	3.4 max	pF

40263 TRANSISTOR

Ge **p-n-p alloy-junction** type used in low-level af-amplifier and driver service in conjunction with types 40261 (converter), 40262 (if amplifier), 40264 (power output), and 40265 (line rectifier) to provide a complement for line-operated AM broadcast-band receivers and phonographs in entertainment equipment. JEDEC TO-1, **Outline** No.1. **Terminals:** 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−20	V
Collector-to-Emitter Voltage (R_{BE} = 10 kΩ)	V_{CER}	−18	V
Emitter-to-Base Voltage	V_{EB}	−2.5	V
Collector Current	I_C	−50	mA
Emitter Current	I_E	50	mA
Transistor Dissipation:			
T_A up to 55°C	P_T	120	mW
T_A above 55°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A—T_C) and Storage (T_{STG})		−65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage (I_C = −1 mA, R_{BE} = 10 kΩ)	$V_{(BR)CER}$	18 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.05 mA, I_C = 0)	$V_{(BR)EBO}$	−2.5 min	V
Collector-Cutoff Current (V_{CB} = −20 V, I_E = 0)	I_{CBO}	−12 max	μA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	−12 max	μA
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = −6 V, I_C = −1 mA)	f_{hfb}	10	Mc/s
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_C = −1 mA, f = 1 kc/s)	h_{fe}	100 to 325	
Intrinsic Base-Spreading Resistance (V_{CE} = −6 V, I_C = −1 mA, f = 100 Mc/s)	$r_{bb'}$	200	Ω

40264 POWER TRANSISTOR

Si **n-p-n diffused-junction** type used in class A output-amplifier service in conjunction with types 40261 (converter), 40262 (if amplifier), 40263 (af amplifier and driver), and 40265 (line rectifier) to provide a complement for line-operated AM broadcast-band receivers and phonographs in entertainment equipment. **Outline** No.28. **Terminals:** 1 - emitter, 2 - base, 3 - collector and mounting flange.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	300	V
Collector-to-Emitter Voltage (I_C = 1 mA, I_B = 5 μA)	V_{CEX}	300	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	100	mA
Emitter Current	I_E	−100	mA
Transistor Dissipation:			
T_{MF} up to 70°C	P_T	4	W
T_{MF} above 70°C	P_T	Derate linearly 0.05	W/°C
Temperature Range:			
Operating (T_A-T_{MF}) and Storage (T_{STG})		−65 to 150	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

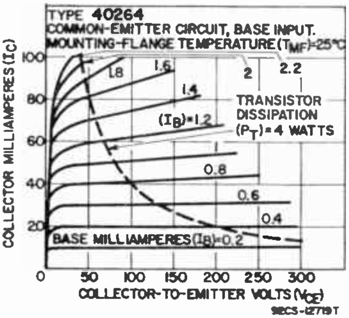
CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	300 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 1 mA, I_B = 0.005 mA)	$V_{(BR)CEX}$	300 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V

CHARACTERISTICS (cont'd)

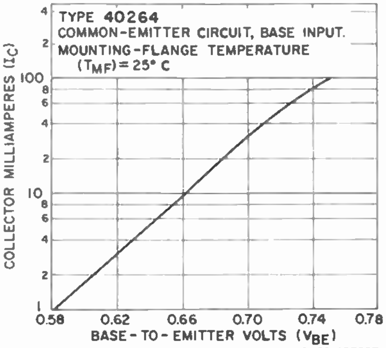
Collector-Cutoff Current:			
V_{CB} = 300 V, I_E = 0	I_{CBO}	100 max	µA
V_{CE} = 300 V, I_B = 0.005 mA	I_{CEX}	1 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA)	h_{FE}	30 to 150	
Intrinsic Base-Spreading Resistance (V_{CE} = 50 V, I_C = 20 mA, f = 100 Mc/s)	$r_{bb'}$	20	Ω
Gain-Bandwidth Product (V_{CE} = 50 V, I_C = 20 mA)	f_T	25	Mc/s
Output Capacitance (V_{CB} = 50 V, I_E = 0)	C_{obo}	5	pF
Thermal Resistance, Junction-to-Mounting Flange	θ_{J-MF}	20 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



92CS-12719T

TYPICAL TRANSFER CHARACTERISTIC



92CS-12723T

COMPUTER TRANSISTOR

40269

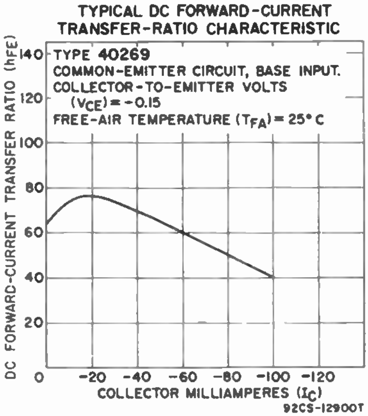
Ge p-n-p alloy-junction type used in medium-speed switching applications in industrial and military data-processing equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

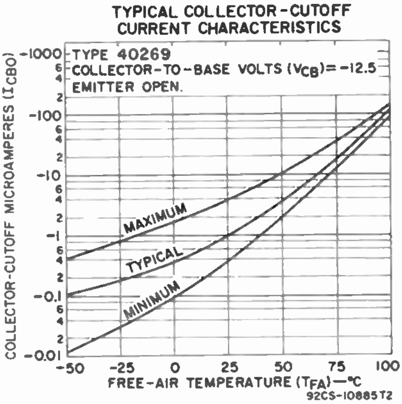
MAXIMUM RATINGS

Collector-to-Base Voltage (V_{BE} = 1 V)	V_{CBV}	−25	V
Emitter-to-Base Voltage	V_{EBO}	−12	V
Collector Current	I_C	−100	mA
Emitter Current	I_E	100	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	150	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 85	°C
Storage	T_{STG}	−65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −0.02 mA, V_{BE} = 1 V)	$V_{(BR)CBV}$	−25 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.02 mA, I_C = 0)	$V_{(BR)EBO}$	−12 min	V
Base-to-Emitter Saturation Voltage:			
I_C = −12 mA, I_B = −0.4 mA	V_{BE}(sat)	−0.35 max	V
I_C = −24 mA, I_B = −1 mA	V_{BE}(sat)	−0.4 max	V
Collector-to-Emitter Saturation Voltage (I_C = −24 mA, I_B = −1 mA)	V_{CE}(sat)	−0.2 max	V
Collector-Cutoff Current:			
V_{CB} = −12 V, I_E = 0, T_A = 25°C	I_{CBO}	−5 max	µA
V_{CB} = −12 V, I_E = 0, T_A = 80°C	I_{CBO}	−90 max	µA
Emitter-Cutoff Current (V_{EB} = −2.5 V, I_C = 0)	I_{EBO}	−2.5 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = −0.15 V, I_C = −12 mA)	h_{FE}	50 to 200	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −6 V, I_C = −1 mA)	f_{hfb}	4 min	Mc/s
Collector-to-Case Capacitance (V_{CB} = −6 V, I_C = 0)	C_c	20	pF
Stored Base Charge (I_C = −10 mA, I_B = −1 mA)	Q_s	1200 max	pC





40279 TRANSISTOR

Si n-p-n "overlay" epitaxial planar type used in ultra-high-reliability vhf-uhf applications in space, military, and industrial communications equipment. Used in class A, B, and C amplifiers, frequency multipliers, or oscillators. This device is subjected to special preconditioning tests for selection in high-reliability, large-signal, and high-power applications. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	65	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	65	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	1.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	11.6	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0 to 200 mA, pulsed through inductor L = 25 mA, df = 50%	$V_{(BR)CEO}$	40 min	V
V_{BE} = −1.5 V, I = 0 to 200 mA, pulsed through inductor L = 25 mA, df = 50%	$V_{(BR)CEV}$	65 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage (I_C = 0.5 A, I_B = 0.1 A)	V_{CE}(sat)	1 max	V
Collector-Cutoff Current (V_{CE} = 30 V, I_B = 0)	I_{CEO}	0.1 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 5 V, I_C = 150 mA)	h_{FE}	10 min	
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 Mc/s)	C_{obo}	10 max	pF
RF Power Output, Unneutralized Amplifier:			
V_{CE} = 28 V, P_{IE} = 1 W, R_G & R_L = 50 Ω, f = 100 Mc/s	P_{OE}	7.5* min	W
V_{CE} = 28 V, P_{IE} = 1 W, R_G & R_L = 50 Ω, f = 400 Mc/s	P_{OE}	3† min	W

* For conditions given, minimum efficiency = 65 per cent.
† For conditions given, minimum efficiency = 40 per cent.

TRANSISTOR 40280

Si n-p-n "overlay" epitaxial planar type used in vhf class C amplifier service requiring low supply voltages and high power output in industrial and military communications equipment. JEDEC TO-39, Outline No.12. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

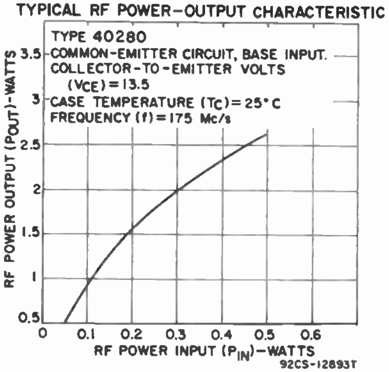
MAXIMUM RATINGS

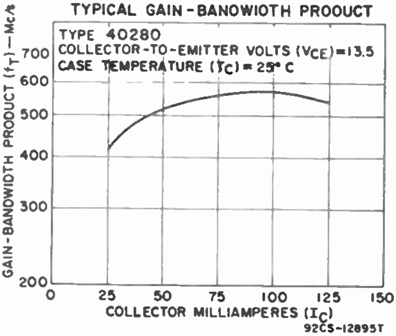
Collector-to-Base Voltage	V_{CBO}	36	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	36	V
Base open	V_{CEO}	18	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	0.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	7	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230*	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage ($I_C = 0.25$ mA, $I_E = 0$)	$V_{(BR)CBO}$	36 min	V
Collector-to-Emitter Breakdown Voltage ($I_C = 200$ mA, $I_B = 0$, pulsed through inductor L = 25 mH, df = 50%)	$V_{(BR)CEV}$	36 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.1$ mA, $I_C = 0$)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Sustaining Voltage ($I_C = 200$ mA, $I_B = 0$, pulsed through inductor L = 25 mH, df = 50%)	V_{CEO}(sus)	18 min	V
Collector-Cutoff Current ($V_{CE} = 15$ V, $I_B = 0$)	I_{CEO}	100 max	µA
Gain-Bandwidth Product ($V_{CE} = 13.5$ V, $I_C = 100$ mA)	f_T	550	Mc/s
Output Capacitance ($V_{CB} = 13.5$ V, $I_E = 0$, f = 1 Mc/s)	C_{obo}	15 max	pF
Input Resistance, Real Part ($V_{CE} = 13.5$ V, $I_C = 100$ mA, f = 175 Mc/s)	$R_e(h_{ie})$	10	Ω
Power Output, Class C Amplifier, Unneutralized ($V_{CE} = 13.5$ V, $P_{IE} = 0.125$ W, f = 175 Mc/s, R_G & $R_L = 50$ Ω)	P_{OE}	1† min	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	25 max	°C/W

* For types 40281 and 40282 this value is maximum Pin-Soldering Temperature.
† For conditions given, minimum efficiency = 60 per cent.





TRANSISTOR 40281

Si n-p-n "overlay" epitaxial planar type used in vhf class C amplifier service requiring low supply voltages and high power output in industrial and military communications equipment. JEDEC TO-60, Outline No.20. Terminals:

1 - emitter and case, 2 - base, 3 - collector. This type is identical with type 40280 except for the following items:

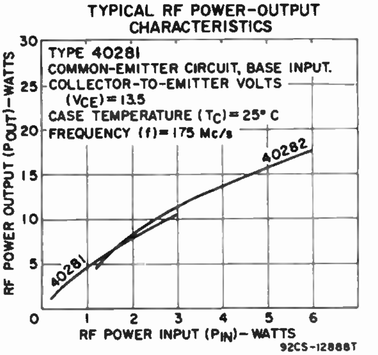
MAXIMUM RATINGS

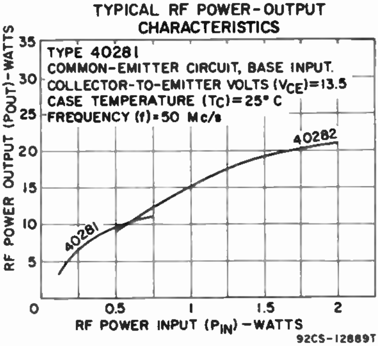
Collector Current	I_C	1	A
Transistor Dissipation: Tc up to 25°C	P_T	11.6	W

CHARACTERISTICS (At case temperature = 25°C)

Gain-Bandwidth Product (V_{CE} = 13.5 V, I_C = 400 mA)	f_T	400	Mc/s
Output Capacitance (V_{CB} = 13.5 V, I_E = 0, f = 1 Mc/s)	C_{obo}	22 max	pF
Collector-to-Case Capacitance	C_c	5 max	pF
Input Resistance, Real Part (V_{CE} = 13.5 V, I_C = 400 mA, f = 175 Mc/s)	$R_e(h_{ie})$	7	Ω
Power Output, Class C Amplifier, Unneutralized (V_{CE} = 13.5 V, P_{IE} = 1 W, f = 175 Mc/s, R_G & R_L = 50 Ω)	P_{OE}	4† min	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	15 max	°C/W

† For conditions given, minimum efficiency = 70 per cent.





40282 TRANSISTOR

Si **n-p-n** "overlay" epitaxial **planar** type used in vhf class C amplifier service requiring low supply voltages and high power output in industrial and military communications equipment. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter and case, 2 - base, 3 - collector. This type is identical with type 40280 except for the following items:

MAXIMUM RATINGS

Collector Current	I_C	2	A
Transistor Dissipation: Tc up to 25°C	P_T	23.2	W

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.5 mA, I_E = 0)	$V_{(BR)CBO}$	36 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.25 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-Cutoff Current (V_{CE} = 15 V, I_B = 0)	I_{CEO}	250 max	μA
Gain-Bandwidth Product (V_{CE} = 13.5 V, I_C = 800 mA)	f_T	350	Mc/s
Output Capacitance (V_{CB} = 13.5 V, I_E = 0, f = 1 Mc/s)	C_{obo}	45 max	pF
Collector-to-Case Capacitance	C_c	5 max	pF
Input Resistance, Real Part (V_{CE} = 13.5 V, I_C = 800 mA, f = 175 Mc/s)	$R_e(h_{ie})$	5	Ω
Power Output, Class C Amplifier, Unneutralized (V_{CE} = 13.5 V, P_{IE} = 4 W, f = 175 Mc/s, R_G & R_L = 50 Ω)	P_{OE}	12† min	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	7.5 max	°C/W

† For conditions given, minimum efficiency = 80 per cent.

COMPUTER TRANSISTOR

40283

Si **n-p-n double-diffused epitaxial planar** type used in core-driver and line-driver service in high-performance computers and in other critical applications requiring considerable output power. JEDEC TO-46, **Outline No.16. Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N3512 except for the following items:

MAXIMUM RATINGS

Collector-to-Emitter Voltage	V_{CEO}	30	V
Transistor Dissipation:			
T_A up to 25°C	P_T	0.4	W
T_C up to 25°C (with heat sink)	P_T	2	W
T_A and T_C (with heat sink) above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage ($I_C = 50$ mA, $I_B = 0$)	$V_{(BR)CEO}$	30 min	V

TRANSISTOR

40290

Si **n-p-n "overlay" epitaxial planar** type used in vhf class C amplifier service requiring low supply voltages and high power output in aircraft, military, and industrial communications equipment. JEDEC TO-39, **Outline No.12. Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	50	V
f = 100 Mc/s	V_{CES}(RF)	90	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	0.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	7	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230*	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
$I_C = 200$ mA, $V_{BE} = -1.5$ V, $R_{BE} = 39$ Ω, pulsed through inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	60 min	V
$I_C = 25$ mA, $V_{BE} = 0$, f ≧ 100 Mc/s	$V_{(BR)CES}$(RF)	90 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.1$ mA, $I_C = 0$)	$V_{(BR)EBO}$	4 min	V
Collector-Cutoff Current ($V_{CE} = 15$ V, $I_B = 0$)	I_{CEO}	100 max	μA
Gain-Bandwidth Product ($V_{CE} = 12.5$ V, $I_C = 100$ mA)	f_T	500	Mc/s
Output Capacitance ($V_{CB} = 12.5$ V, $I_E = 0$, f = 1 Mc/s)	C_{obo}	17 max	pF
Input Resistance, Real Part ($V_{CE} = 12.5$ V, $I_C = 100$ mA, f = 135 Mc/s)	$R_e(h_{ie})$	12	Ω
Power Output, Class C Amplifier, Unneutralized ($V_{CE} = 12.5$ V, $P_{IE} = 0.5$ W, f = 135 Mc/s, R_G & $R_L = 50$ Ω)	P_{OE}	2† min	W
Thermal Resistance, Junction-to-Case	Θ_{J-C}	25 max	°C/W

* For type 40291 this value is maximum Pin-Soldering Temperature.
† For conditions given, minimum efficiency = 70 per cent.

TRANSISTOR

40291

Si **n-p-n "overlay" epitaxial planar** type used in vhf class C amplifier service requiring low supply voltages and high power output in aircraft, military, and industrial communications equipment. JEDEC TO-60, **Outline No.20.**

Terminals: 1 - emitter, 2 - base, 3 - collector. This type is identical with type 40290 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation (T_C up to 25°C)	P_T	11.6	W

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Case Capacitance	C_c	6 max	pF
Thermal Resistance, Junction-to-Case	θ_{J-C}	15 max	°C/W

40292 TRANSISTOR

Si n-p-n "overlay" epitaxial planar type used in vhf class C amplifier service requiring low supply voltages and high power output in aircraft, military, and industrial communications equipment. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	50	V
f = 100 Mc/s	V_{CES}(RF)	90	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	1.25	A
Transistor Dissipation:			
T_C up to 25°C	P_T	23.2	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Voltage:			
$I_C = 200$ mA, $V_{BE} = -1.5$ V, $R_{BE} = 39\ \Omega$, pulsed through inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	60 min	V
$I_C = 50$ mA, $V_{BE} = 0$, f = 100 Mc/s	$V_{(BR)CES}$(RF)	90 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.25$ mA, $I_C = 0$)	$V_{(BR)EBO}$	4 min	V
Collector-Cutoff Current ($V_{CE} = 15$ V, $I_B = 0$)	I_{CEO}	250 max	µA
Gain-Bandwidth Product ($V_{CE} = 12.5$ V, $I_C = 400$ mA)	f_T	300	Mc/s
Collector-to-Case Capacitance	C_c	6 max	pF
Output Capacitance ($V_{CB} = 12.5$ V, $I_E = 0$, f = 1 Mc/s)	C_{obo}	30 max	pF
Input Resistance, Real Part ($V_{CE} = 12.5$ V, $I_C = 400$ mA, f = 135 Mc/s)	$R_e(h_{ie})$	6.5	Ω
Power Output, Class C Amplifier, Unneutralized ($V_{CE} = 12.5$ V, $P_{IE} = 2$ W, f = 135 Mc/s, R_G & $R_L = 50\ \Omega$)	P_{OE}	6† min	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	7.5 max	°C/W

† For conditions given, minimum efficiency = 70 per cent.

40294 TRANSISTOR

Si n-p-n double-diffused epitaxial planar type used in uhf amplifier, mixer, and oscillator applications. This type is electrically and mechanically identical with type 2N2857, but is specially controlled, processed, and tested for critical aerospace and military applications. JEDEC TO-72, Outline No.23. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - case.

40295 TRANSISTOR

Si n-p-n double-diffused epitaxial planar type used in uhf amplifier, mixer, and oscillator applications. This type is electrically and mechanically identical with type 2N2708, but is specially controlled, processed, and tested for critical aerospace and military applications. JEDEC TO-72, Outline No.23. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - case.

TRANSISTOR 40296

Si **n-p-n** double-diffused **epitaxial planar** type used in uhf amplifier, mixer, and oscillator applications. This type is electrically and mechanically identical with type 2N2857, but is specially controlled, processed, and tested for critical aerospace and military applications. JEDEC TO-72, Outline No.23. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - case.

TRANSISTOR 40305

Si **n-p-n** "overlay" **epitaxial planar** type subjected to special preconditioning tests for high-reliability, large-signal, high-power vhf-uhf applications in class A, B, and C amplifier, frequency-multiplier, and oscillator circuits in aerospace, industrial and military equipment. JEDEC TO-39, Outline No.12. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	65	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	65	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	1	A
Transistor Dissipation:			
T_C up to 25°C	P_T	7	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230*	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage ($I_C = 0.3$ mA, $I_E = 0$)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage:			
$I_C = 0$ to 200 mA, $I_B = 0$, pulsed through inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	40 min	V
$I_C = 0$ to 200 mA, $V_{BE} = -1.5$ V, pulsed through inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	65 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.1$ mA, $I_C = 0$)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 250$ mA, $I_B = 50$ mA)	V_{CE}(sat)	1 max	V
Collector-Cutoff Current ($V_{CE} = 30$ V, $I_B = 0$)	I_{CEO}	0.1 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = 5$ V, $I_C = 150$ mA)	h_{FE}	10 min	
Output Capacitance ($V_{CB} = 30$ V, $I_E = 0$, f = 1 Mc/s)	C_{obo}	10 max	pF
RF Power Output, Amplifier, Unneutralized: ($V_{CE} = 28$ V, $P_{IE} = 0.25$ W, f = 175 Mc/s, R_G & $R_L = 50\ \Omega$)	P_{OE}	2.5† min	W

* For type 40306 this value is maximum Pin-Soldering Temperature.
† For conditions given, minimum efficiency = 50 per cent.

TRANSISTOR 40306

Si **n-p-n** "overlay" **epitaxial planar** type subjected to special preconditioning tests for high-reliability, large-signal, high-power vhf-uhf applications in class A, B, and C amplifier, frequency-multiplier, and oscillator circuits in aerospace, industrial and military equipment. JEDEC TO-60, Outline No.20.

Terminals: 1 - emitter and case, 2 - base, 3 - collector. This type is identical with type 40305 except for the following items:

MAXIMUM RATINGS

Collector Current	I_C	1.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	11.6	W

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Saturation Voltage (I_C = 500 mA, I_B = 100 mA)	V_{CE}(sat)	1 max	V
RF Power Output, Amplifier, Unneutralized:			
V_{CE} = 28 V, P_{IE} = 1 W, f = 100 Mc/s, R_G & R_L = 50 Ω	P_{OE}	7.5* min	W
V_{CE} = 28 V, P_{IE} = 1 W, f = 400 Mc/s, R_G & R_L = 50 Ω	P_{OE}	3† min	W

* For conditions given, minimum efficiency = 65 per cent.

† For conditions given, minimum efficiency = 40 per cent.

40307 TRANSISTOR

Si **n-p-n "overlay" epitaxial planar** type subjected to special preconditioning tests for high-reliability, large-signal, high-power vhf-uhf applications in class A, B, and C amplifier, frequency-multiplier, and oscillator circuits in aerospace, industrial and military equipment. JEDEC TO-60, **Outline No.20. Terminals:** 1 - emitter and case, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	65	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	65	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	3	A
Transistor Dissipation:			
T_C up to 25°C	P_T	23	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	230	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.5 mA, I_E = 0)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0 to 200 mA, I_B = 0, pulsed through inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	40 min	V
I_C = 0 to 200 mA, V_{BE} = −1.5 V, pulsed through inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	65 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.25 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage (I_C = 500 mA, I_B = 100 mA)	V_{CE}(sat)	1 max	V
Collector-Cutoff Current (V_{CE} = 30 V, I_B = 0)	I_{CEO}	0.25 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 5 V, I_C = 200 mA)	h_{FE}	10 min	
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 Mc/s)	C_{obo}	20 max	pF
RF Power Output, Amplifier, Unneutralized: (V_{CE} = 28 V, P_{IE} = 0.35 W, f = 175 Mc/s, R_G & R_L = 50 Ω)	P_{OE}	13.5† min	W

† For conditions given, minimum efficiency = 70 per cent.

POWER TRANSISTOR 40309

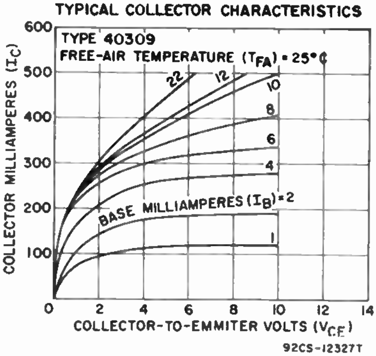
Si n-p-n type used in audio-amplifier driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

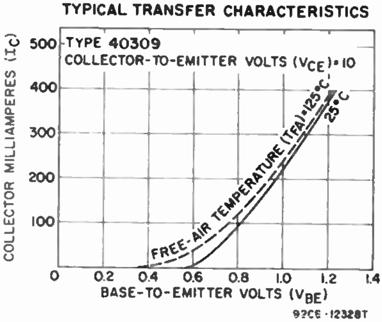
Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	18	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage ($I_C = 100$ mA, $I_B = 0$, $t_p = 300$ µs, df $\leqq 2\%$)	$V_{(BR)CEO}$	18 min	V
Base-to-Emitter Voltage ($V_{CE} = 4$ V, $I_C = 50$ mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
$V_{CB} = 15$ V, $I_E = 0$, $T_C = 25$°C	I_{CBO}	0.25 max	µA
$V_{CB} = 15$ V, $I_E = 0$, $T_C = 150$°C	I_{CBO}	1 max	mA
Emitter-Cutoff Current ($V_{EB} = 2.5$ V, $I_C = 0$)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = 4$ V, $I_C = 50$ mA)	h_{FE}	70 to 350	
Gain-Bandwidth Product ($V_{CE} = 10$ V, $I_C = 50$ mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Case	Θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	175 max	°C/W



92CS-12327T



92CS-12328T

POWER TRANSISTOR 40310

Si n-p-n type used in audio-amplifier driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

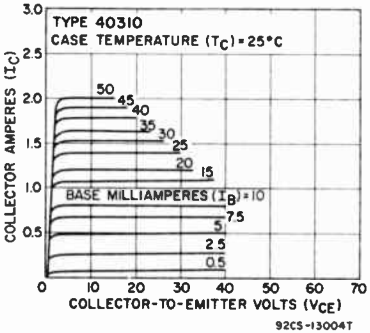
MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	35	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	4	A
Base Current	I_B	2	A
Transistor Dissipation:			
T_C up to 25°C	P_T	29	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C

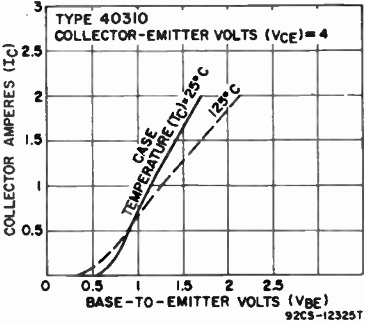
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage (I_C = 100 mA, I_B = 0)	$V_{(BR)CEO}$	35 min	V
Base-to-Emitter Voltage (V_{CE} = 2 V, I_C = 1 A)	V_{BE}	1.4 max	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_C = 25°C	I_{CBO}	10 max	µA
V_{CB} = 15 V, I_E = 0, T_C = 150°C	I_{CBO}	5 max	mA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 2 V, I_C = 1 A)	h_{FE}	20 to 120	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 500 mA)	f_T	750	kc/s
Thermal Resistance, Junction-to-Case	Θ_{J-C}	6 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



40311 POWER TRANSISTOR

Si **n-p-n** type used in audio-amplifier driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-5, **Outline** No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	30	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0, t_p = 300 µs, df ≦ 2%)	V_{CEO}(sus)	30 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 50 mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_C = 25°C	I_{CBO}	0.25 max	µA
V_{CB} = 15 V, I_E = 0, T_C = 150°C	I_{CBO}	1 max	mA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 50 mA)	h_{FE}	70 to 350	
Gain-Bandwidth Product (V_{CE} = 10 V, I_C = 50 mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Case	Θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	175 max	°C/W

40312 POWER TRANSISTOR

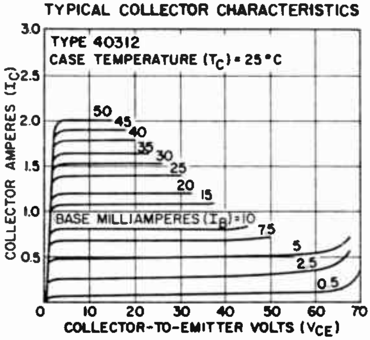
Si **n-p-n** type used in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

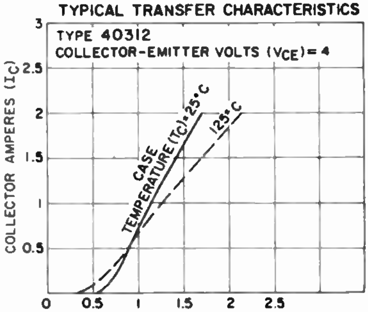
Collector-to-Emitter Sustaining Voltage (R_{BE} = 500 Ω)	V_{CER}(sus)	60	V
Emitter-to-Base Voltage	V_{CBO}	2.5	V
Collector Current	I_C	4	A
Base Current	I_B	2	A
Transistor Dissipation:			
T_C up to 25°C	P_T	29	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, R_{BE} = 500 Ω)	V_{CER}(sus)	60 min	V
Base-to-Emitter Voltage (V_{CE} = 2 V, I_C = 1 A)	V_{BE}	1.4 max	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_C = 25°C	I_{CBO}	10 max	μA
V_{CB} = 15 V, I_E = 0, T_C = 150°C	I_{CBO}	5 max	mA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 2 V, I_C = 1 A)	h_{FE}	20 to 120	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 500 mA)	f_T	750	kc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	6 max	°C/W



92CS-13091T



92CS-12325T

POWER TRANSISTOR

40313

Si n-p-n high-voltage type for direct 117-volt line operation in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

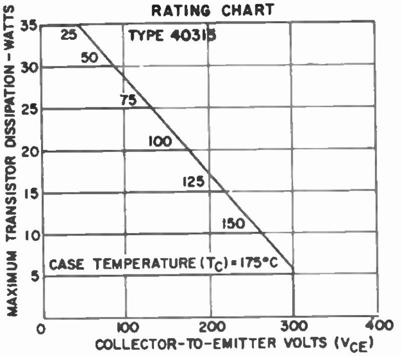
Collector-to-Emitter Sustaining Voltage (R_{BE} = 500 Ω)	V_{CER}(sus)	300	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	2	A
Base Current	I_B	1	A
Transistor Dissipation:			
T_C up to 25°C	P_T	35	W
T_C above 25°C	P_T	See Rating Chart	
T_C = 175°C	P_T	5	W
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

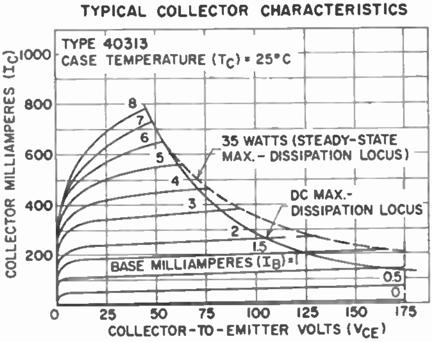
Collector-to-Emitter Sustaining Voltage (I_C = 200 mA, R_{BE} = 500 Ω)	V_{CER}(sus)	300 min	V
Base-to-Emitter Voltage (V_{CE} = 10 V, I_C = 0.1 A)	V_{BE}	1.5 max	V

CHARACTERISTICS (cont'd)

Collector-Cutoff Current:			
V_{CE} = 150 V, I_B = 0	I_{CEO}	5 max	mA
V_{CE} = 300 V, V_{BE} = −1.5 V, T_C = 25°C	I_{CEV}	10 max	mA
V_{CE} = 300 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	10 max	mA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 100 mA	h_{FE}	40 to 250	
V_{CE} = 10 V, I_C = 500 mA	h_{FE}	40 min	
Second-Breakdown Collector Current (V_{CE} = 150 V)	$I_{S/b}$	150 min	mA
Thermal Resistance, Junction-to-Case	θ_{J-C}	5 max	°C/W



TL 1744T



TL 1745T

40314

POWER TRANSISTOR

Si **n-p-n** type used in audio-amplifier driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0, t_p = 300 μs, df = 2%)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA)	V_{CE}(sat)	1.4 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 50 mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_C = 25°C	I_{CBO}	0.25 max	μA
V_{CB} = 15 V, I_E = 0, T_C = 150°C	I_{CBO}	1 max	mA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 50 mA)	h_{FE}	70 to 350	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 50 mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

40315

POWER TRANSISTOR

Si **n-p-n** type used in audio-amplifier inverter and driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	35	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage (I_C = 100 mA, I_B = 0, t_p = 300 µs, df = 2%)	$V_{(BR)CEO}$	35 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 50 mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_C = 25°C	I_{CBO}	0.25 max	µA
V_{CB} = 15 V, I_E = 0, T_C = 150°C	I_{CBO}	1 max	mA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 50 mA)	h_{FE}	70 to 350	
Gain-Bandwidth Product (V_{CE} = 10 V, I_C = 50 mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

POWER TRANSISTOR 40316

Si **n-p-n** type used in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 500 Ω)	V_{CER}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	4	A
Base Current	I_B	2	A
Transistor Dissipation:			
T_C up to 25°C	P_T	29	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, R_{BE} = 500 Ω)	V_{CER}(sus)	40 min	V
Base-to-Emitter Voltage (V_{CE} = 2 V, I_C = 1 A)	V_{BE}	1.4 max	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_C = 25°C	I_{CBO}	10 max	µA
V_{CB} = 15 V, I_E = 0, T_C = 150°C	I_{CBO}	5 max	mA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 2 V, I_C = 1 A)	h_{FE}	20 to 120	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 500 mA)	f_T	750	kc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	6 max	°C/W

POWER TRANSISTOR 40317

Si **n-p-n** type used in audio-amplifier inverter and driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-5, Outline No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

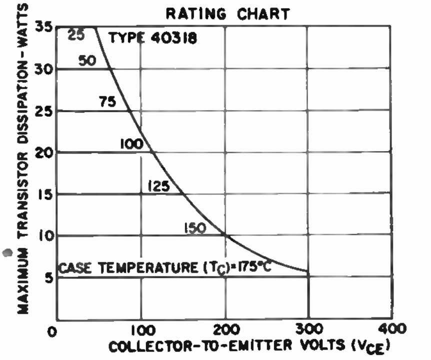
Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0, t_p = 300 μs, df ≤ 2%)	V_{CEO}(sus)	40 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 10 mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_C = 25°C	I_{CBO}	0.25 max	μA
V_{CB} = 15 V, I_E = 0, T_C = 150°C	I_{CBO}	1 max	mA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 10 mA)	h_{FE}	40 to 200	
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

40318 POWER TRANSISTOR

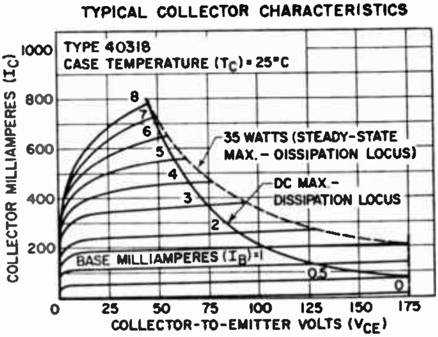
Si **n-p-n** high-voltage type for direct 117-volt line operation in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-66, **Outline** No.22. **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 500 Ω)	V_{CER}(sus)	300	V
Emitter-to-Base Voltage	V_{EBO}	6	V
Collector Current	I_C	2	A
Base Current	I_B	1	A
Transistor Dissipation:			
T_C up to 25°C	P_T	35	W
T_C above 25°C	P_T	See Rating Chart	
T_C = 175°C	P_T	5	W
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C



TL1561T



TL1562T

CHARACTERISTICS

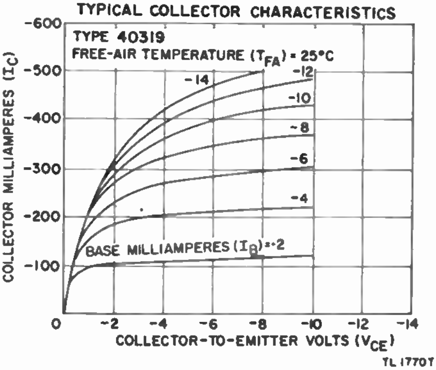
Collector-to-Emitter Sustaining Voltage ($I_C = 200$ mA, $R_{BE} = 500\ \Omega$)	V_{CER}(sus)	300 min	V
Base-to-Emitter Voltage ($V_{CE} = 10$ V, $I_C = 0.5$ A)	V_{BE}	1.5 max	V
Collector-Cutoff Current:			
$V_{CE} = 150$ V, $I_B = 0$	I_{CEO}	5 max	mA
$V_{CE} = 150$ V, $V_{BE} = -1.5$ V, $T_C = 25°C$	I_{CEV}	5 max	mA
$V_{CE} = 150$ V, $V_{BE} = -1.5$ V, $T_C = 150°C$	I_{CEV}	10 max	mA
Emitter-Cutoff Current ($V_{EB} = 6$ V, $I_C = 0$)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio:			
$V_{CE} = 10$ V, $I_C = 20$ mA	h_{FE}	40 min	
$V_{CE} = 10$ V, $I_C = 500$ mA	h_{FE}	50 min	
Second-Breakdown Collector Current ($V_{CE} = 150$ V)	$I_{S/b}$	100 min	mA
Second-Breakdown Energy ($V_{EB} = 4$ V, $R_{BE} = 20\ \Omega$, $L = 100\ \mu H$)	$E_{S/b}$	50 min	μJ
Thermal Resistance, Junction-to-Case	Θ_{J-C}	5 max	°C/W

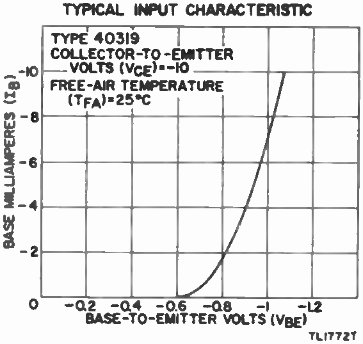
POWER TRANSISTOR 40319

Si p-n-p type used in audio-amplifier driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. P-N-P construction permits complementary driver operating with a matching n-p-n type, such as 40314. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	—40	V
Emitter-to-Base Voltage	V_{EBO}	—2.5	V
Collector Current	I_C	—0.7	A
Base Current	I_B	—0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C





CHARACTERISTICS

Collector-to-Emitter Sustaining Voltage ($I_C = -100$ mA, $I_B = 0$, $t_p = 300\ \mu s$, df $\leqq 2\%$)	V_{CEO}(sus)	—40 min	V
Collector-to-Emitter Saturation Voltage ($I_C = -150$ mA, $I_B = -15$ mA)	V_{CE}(sat)	—1.4 max	V
Base-to-Emitter Voltage ($V_{CE} = -4$ V, $I_C = -50$ mA)	V_{BE}	—1 max	V
Collector-Cutoff Current:			
$V_{CB} = -15$ V, $I_E = 0$, $T_C = 25°C$	I_{CBO}	—0.25 max	μA
$V_{CB} = -15$ V, $I_E = 0$, $T_C = 150°C$	I_{CBO}	—1 max	mA
Emitter-Cutoff Current ($V_{EB} = -2.5$ V, $I_C = 0$)	I_{EBO}	—1 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = -4$ V, $I_C = -50$ mA)	h_{FE}	35 to 200 max	
Gain-Bandwidth Product ($V_{CE} = -4$ V, $I_C = -50$ mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Case	Θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	175 max	°C/W

40320 POWER TRANSISTOR

Si n-p-n type used in audio-amplifier inverter and driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0, t_p = 300 μs, df $\leqq$ 2%)	V_{CEO}(sus)	40 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 10 mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_C = 25°C	I_{CBO}	0.25 max	μA
V_{CB} = 15 V, I_E = 0, T_C = 150°C	I_{CBO}	1 max	mA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 10 mA)	h_{FE}	40 to 200	
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W

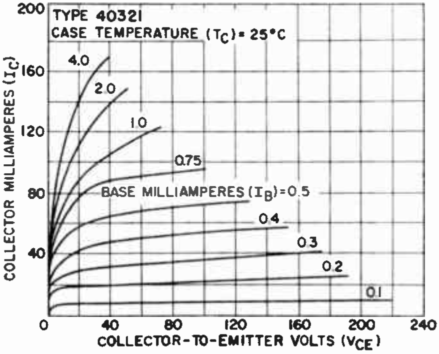
40321 POWER TRANSISTOR

Si n-p-n high-voltage type for direct 117-volt line operation in audio- amplifier driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

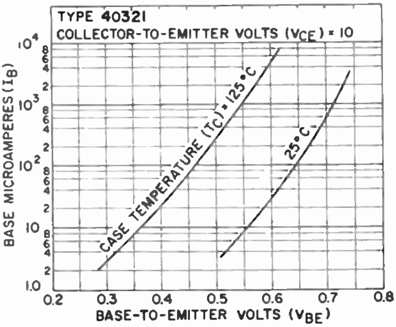
Collector-to-Emitter Sustaining Voltage (R_{BE} = 1000 Ω)	V_{CER}(sus)	300	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	1	A
Base Current	I_B	0.5	A
Transistor Dissipation:			
T_A up to 50°C	P_T	1	W
T_C up to 50°C	P_T	5	W
T_A and T_C above 50°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 300	°C

TYPICAL COLLECTOR CHARACTERISTICS



TL 1682T

TYPICAL INPUT CHARACTERISTICS



92CS-12618T

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage ($I_C = 50$ mA, $R_{BE} = 1000\ \Omega$)	V_{CER}(sus)	300 min	V
Base-to-Emitter Voltage ($V_{CE} = 10$ V, $I_C = 50$ mA)	V_{BE}	2 max	V
Collector-Cutoff Current:			
$V_{CB} = 150$ V, $I_E = 0$, $T_C = 150°C$	I_{CBO}	100 max	μA
$V_{CE} = 150$ V, $R_{BE} = 1000\ \Omega$	I_{CER}	5 max	μA
Emitter-Cutoff Current ($V_{EB} = 5$ V, $I_C = 0$)	I_{EBO}	100 max	μA
Static Forward-Current Transfer Ratio ($V_{CE} = 10$ V, $I_C = 20$ mA)	h_{FE}	25 to 200	
Thermal Resistance, Junction-to-Case	θ_{J-C}	30 max	°C/W

POWER TRANSISTOR 40322

Si **n-p-n** high-voltage type for direct 117-volt line operation in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-66, Outline No.22. Terminals: 1 - base, 2 - emitter, Mounting Flange - collector and case. For rating chart and collector-characteristics curves, refer to type 40318.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage ($R_{BE} = 500\ \Omega$)	V_{CER}(sus)	300	V
Emitter-to-Base Voltage	V_{EBO}	6	V
Collector Current	I_C	2	A
Base Current	I_B	1	A
Transistor Dissipation:			
T_C up to 25°C	P_T	35	W
T_C above 25°C	P_T	See Rating Chart	
$T_C = 175°C$	P_T	5	W
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage ($I_C = 200$ mA, $R_{BE} = 200\ \Omega$, $L = 5$ mH)	V_{CER}(sus)	300 min	V
Collector-Cutoff Current:			
$V_{CE} = 150$ V, $I_B = 0$, $T_C = 25°C$	I_{CEO}	5 max	mA
$V_{CE} = 150$ V, $V_{BE} = -1.5$ V, $T_C = 25°C$	I_{CEV}	10 max	mA
$V_{CE} = 150$ V, $V_{BE} = -1.5$ V, $T_C = 150°C$	I_{CEV}	10 max	mA
Emitter-Cutoff Current ($V_{EB} = 6$ V, $I_C = 0$)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio:			
$V_{CE} = 10$ V, $I_C = 20$ mA	h_{FE}	40 min	
$V_{CE} = 10$ V, $I_C = 500$ mA	h_{FE}	75 min	
Second-Breakdown Collector Current ($V_{CE} = 150$ V)	$I_{S/b}$	100 min	mA
Second-Breakdown Energy ($V_{EB} = 4$ V, $R_{BE} = 20\ \Omega$, $L = 100$ μH)	$E_{S/b}$	50 min	μJ
Thermal Resistance, Junction-to-Case	θ_{J-C}	5 max	°C/W

POWER TRANSISTOR 40323

Si **n-p-n** type used in audio-amplifier inverter and driver stages for economical high-quality performance. Designed to assure freedom from second 1 - emitter, 2 - base, 3 - collector. For collector-characteristics and transfer-characteristics curves, refer to type 40309.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	18	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage ($I_C = 100$ mA, $I_B = 0$, $t_p = 300$ μs, df ≦ 2%)	$V_{(BR)CEO}$	18 min	V
Base-to-Emitter Voltage ($V_{CE} = 4$ V, $I_C = 50$ mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
$V_{CB} = 15$ V, $I_E = 0$, $T_C = 25°C$	I_{CBO}	0.25 max	μA
$V_{CB} = 15$ V, $I_E = 0$, $T_C = 150°C$	I_{CBO}	1 max	mA
Emitter-Cutoff Current ($V_{EB} = 2.5$ V, $I_C = 0$)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = 4$ V, $I_C = 50$ mA)	h_{FE}	70 to 350	
Gain-Bandwidth Product ($V_{CE} = 10$ V, $I_C = 50$ mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

40324 POWER TRANSISTOR

Si **n-p-n** type used in audio-amplifier inverter and driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-66, Outline No.22. Terminals: 1 - base, 2 - emitter, Mounting Flange - collector and case. For collector-characteristics and transfer-characteristics curves, refer to type 40310.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	35	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	4	A
Base Current	I_B	2	A
Transistor Dissipation:			
T_C up to 25°C	P_T	29	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage ($I_C = 100$ mA, $R_{BE} = 500$ Ω)	$V_{(BR)CEO}$	35 min	V
Base-to-Emitter Voltage ($V_{CE} = 2$ V, $I_C = 1$ A)	V_{BE}	1.4 max	V
Collector-Cutoff Current:			
$V_{CB} = 15$ V, $I_E = 0$, $T_C = 25°C$	I_{CBO}	10 max	μA
$V_{CB} = 15$ V, $I_E = 0$, $T_C = 150°C$	I_{CBO}	5 max	mA
Emitter-Cutoff Current ($V_{EB} = 2.5$ V, $I_C = 0$)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = 2$ V, $I_C = 1$ A)	h_{FE}	20 to 120	
Gain-Bandwidth Product ($V_{CE} = 4$ V, $I_C = 500$ mA)	f_T	750	kc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	6 max	°C/W

40325 POWER TRANSISTOR

Si **n-p-n** type used in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

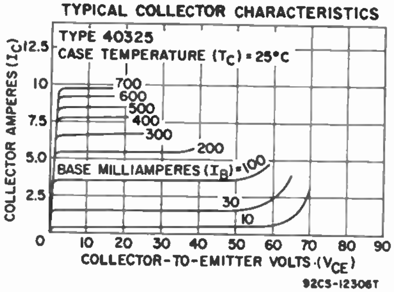
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	35	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	35	V
Base open (sustaining voltage)	V_{CEO}(sus)	35	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	15	A
Base Current	I_B	7	A
Transistor Dissipation:			
T_C up to 25°C	P_T	117	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C

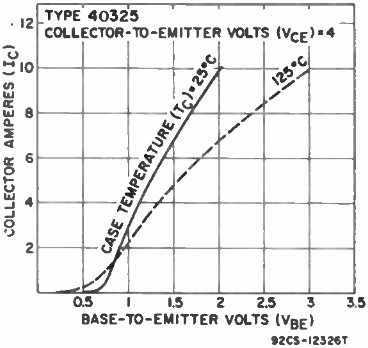
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage (I_C = 200 mA, I_B = 0)	$V_{(BR)CEO}$(sus)	35 min	V
Collector-to-Base Breakdown Voltage (I_C = 100 mA, I_E = 0)	$V_{(BR)CBO}$	35 min	V
Collector-to-Emitter Saturation Voltage (I_C = 8 A, I_B = 0.8 A)	V_{CE}(sat)	1.5 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 8 A)	V_{BE}	2 max	V
Collector-Cutoff Current:			
V_{CB} = 30 V, I_E = 0, T_C = 25°C	I_{CBO}	5 max	mA
V_{CB} = 30 V, I_E = 0, T_C = 150°C	I_{CBO}	10 max	mA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	10 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 8 A)	h_{FE}	12 to 60	
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC



POWER TRANSISTOR 40326

Si **n-p-n** type used in audio-amplifier inverter and driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-5, Outline No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector. For collector-characteristics curves, refer to type 40309.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0, t_p = 300 μs, df ≦ 2%)	V_{CEO}(sus)	40 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 10 mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_C = 25°C	I_{CBO}	0.25 max	μA
V_{CB} = 15 V, I_E = 0, T_C = 150°C	I_{CBO}	1 max	mA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 10 mA)	h_{FE}	40 to 200	
Thermal Resistance, Junction-to-Case	θ_{J-C}	30 max	°C/W

POWER TRANSISTOR 40327

Si **n-p-n high**-voltage type used for direct operation from a line source in audio-amplifier driver stages for economical high-quality performance.

Designed to assure freedom from second breakdown in the operating region. JEDEC TO-5, **Outline** No.3. **Terminals**: 1 - emitter, 2 - base, 3 - collector. For collector-characteristics and input-characteristics curves, refer to type 40321.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 1000 Ω)	V_{CER}(sus)	300	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	1	A
Base Current	I_B	0.5	A
Transistor Dissipation:			
T_A up to 50°C	P_T	1	W
T_C up to 50°C	P_T	5	W
T_A and T_C above 50°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 50 mA, R_{BE} = 1000 Ω)	V_{CER}(sus)	300 min	V
Base-to-Emitter Voltage (V_{CE} = 10 V, I_C = 50 mA)	V_{BE}	2 max	V
Collector-Cutoff Current:			
V_{CB} = 150 V, T_C = 150°C, I_E = 0	I_{CBO}	100 max	µA
V_{CE} = 150 V, R_{BE} = 1000 Ω	I_{CER}	5 max	µA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	100 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 20 mA)	h_{FE}	40 to 250	
Thermal Resistance, Junction-to-Case	θ_{J-C}	30 max	°C/W

40328 POWER TRANSISTOR

Si **n-p-n high-voltage** type used for direct operation from a line source in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-66, **Outline** No.22. **Terminals**: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. For rating chart and collector-characteristics curves, refer to type 40318.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 500 Ω)	V_{CER}(sus)	300	V
Emitter-to-Base Voltage	V_{EBO}	6	V
Collector Current	I_C	2	A
Base Current	I_B	1	A
Transistor Dissipation:			
T_C up to 25°C	P_T	35	W
T_C above 25°C	P_T	See Rating Chart	
T_C = 175°C	P_T	5	W
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 200 mA, R_{BE} = 500 Ω)	V_{CER}(sus)	300 min	V
Base-to-Emitter Voltage (V_{CE} = 10 V, I_C = 1 A)	V_{BE}	1.5 max	V
Collector-Cutoff Current:			
V_{CE} = 150 V, I_B = 0	I_{CEO}	5 max	mA
V_{CE} = 150 V, V_{BE} = −1.5 V, T_C = 25°C	I_{CEV}	10 max	mA
V_{CE} = 150 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	10 max	mA
Emitter-Cutoff Current (V_{EB} = 6 V, I_C = 0)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 1 A	h_{FE}	20 min	
V_{CE} = 10 V, I_C = 20 mA	h_{FE}	40 min	
Second-Breakdown Collector Current (V_{CE} = 150 V)	$I_{S/b}$	100 min	mA
Thermal Resistance, Junction-to-Case	θ_{J-C}	5 max	°C/W

40329 TRANSISTOR

Ge **p-n-p** alloy type for low-level, intermediate-level, and class A driver stages in consumer and industrial af-amplifier equipment such as preamplifiers, tone-control stages, and phonograph amplifiers using crystal pickups. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

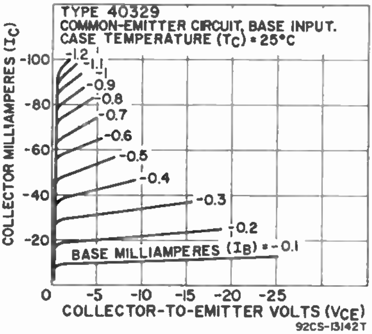
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	–25	V
Collector-to-Emitter Voltage ($R_{BE} \leq 4700\ \Omega$)	V_{CER}	–25	V
Emitter-to-Base Voltage	V_{EBO}	–2.5	V
Collector Current	I_C	–100	mA
Emitter Current	I_E	100	mA
Base Current	I_B	–20	mA
Transistor Dissipation:			
T_A up to 55°C (With practical heat sink, Θ = 50°C/W)	P_T	265	mW
T_A up to 55°C (Without heat sink)	P_T	125	mW
T_A with and without heat sink above 55°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	–65 to 100	°C
Storage	T_{STG}	–65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

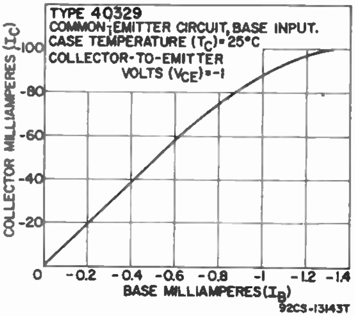
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = 0.05 mA, I_E = 0)	$V_{(BR)CBO}$	–25 min	V
Collector-to-Emitter Breakdown Voltage (R_{BE} = 4700 Ω, I_C = –1 mA)	$V_{(BR)CER}$	–25 min	V
Emitter-to-Base Breakdown Voltage (I_E = –0.05 mA)	$V_{(BR)EBO}$	–2.5 min	V
Collector-Cutoff Current (V_{CB} = –12 V, I_E = 0)	I_{CBO}	–14 max	µA
Emitter-Cutoff Current (V_{EB} = –2 V, I_C = 0)	I_{EBO}	–14 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = –1 V, I_C = –25 mA)	h_{FE}	50 to 200	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = –10 V, I_C = –10 mA, f = 1 kc/s	h_{fe}	75 to 300	
V_{CE} = –6 V, I_C = –1 mA, f = 1 kc/s	h_{fe}	50 to 200	
Small-Signal Forward-Current Transfer Ratio Cutoff Frequency (V_{CB} = –6 V, I_C = 1 mA)	f_{hfb}	1.5	Mc/s
Output Capacitance (V_{CB} = –6 V, f = 1 kc/s)	C_{obo}	35	pF
Small-Signal Input Impedance (V_{CE} = –10 V, I_C = –10 mA, f = 1 kc/s)	h_{ie}	400	Ω
Small-Signal Output Admittance (V_{CE} = –10 V, I_C = –10 mA, f = 1 kc/s)	h_{oe}	175	µmhos
Small-Signal Reverse Voltage-Transfer Ratio (V_{CE} = –10 V, I_C = –10 mA, f = 1 kc/s)	h_{re}	300×10^{-6}	
Equivalent RMS Noise Input Current (V_{CE} = –6 V, I_C = –0.5 mA, f = 20 c/s to 20 kc/s)		0.02 max	µA
Base-Spreading Resistance (V_{CE} = –6 V, I_C = –1 mA, f = 20 Mc/s)	$r_{bb'}$	100	Ω

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC



TRANSISTOR 40340

Si n-p-n "overlay" epitaxial planar type used in high-power class C amplifier applications at frequencies to 100 Mc/s. JEDEC TO-60, Outline No.20. Terminals: 1 - no connection, 2 - base, 3 - collector, Mounting Stud - emitter and case.

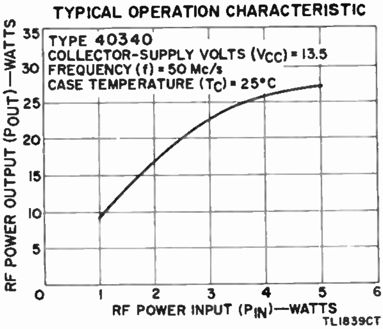
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	60	V
Base open	V_{CEO}	25	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Peak Collector Current	i_C(peak)	10	A
Continuous Collector Current	I_C	3.3	A
Transistor Dissipation (T_C = 25°C)	P_T	70	W
Temperature Range:			
Operating (Junction)	T_J(opr)	200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
I_C = 200 mA, V_{BE} = −1.5 V, pulsed through an inductor L = 25 mA, df = 50%	$V_{(BR)CEV}$	60 min	V
I_C = 200 mA, I_B = 0, pulsed through an inductor L = 25 mA, df = 50%	$V_{(BR)CEO}$	25 min	V
Emitter-to-Base Breakdown Voltage (I_E = 10 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-Cutoff Current:			
V_{CE} = 15 V, I_B = 0	I_{CEO}	1 max	mA
V_{CB} = 40 V, I_E = 0	I_{CBO}	10 max	mA
Output Capacitance (V_{CB} = 15 V, I_E = 0)	C_{obo}	120 max	pF
RF Power Output (V_{CE} = 13.5 V, P_{IE} = 5 W, f = 50 Mc/s, R_G & R_L = 50 Ω)	P_{OE}	25* min	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	2.5 max	°C/W

* For conditions given, minimum efficiency = 65 per cent.



40341 TRANSISTOR

Si **n-p-n** "overlay" epitaxial planar type used in high-power class C amplifier applications at frequencies to 100 Mc/s. JEDEC TO-60, Outline No.20. Terminals: 1 - no connection, 2 - base, 3 - collector, Mounting Stud - emitter and case. This type is identical with type 40340 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	80	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	80	V
Base open	V_{CEO}	35	V

CHARACTERISTICS (At case temperature = 25°C)

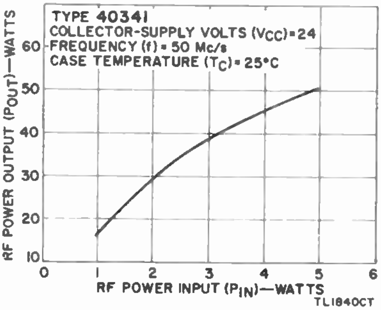
Collector-to-Emitter Breakdown Voltage:			
I_C = 200 mA, V_{BE} = −1.5 V, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	80 min	V
I_C = 200 mA, I_B = 0, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	35 min	V

CHARACTERISTICS (cont'd)

Collector-Cutoff Current:			
V_{CE} = 30 V, I_B = 0	I_{CEO}	1 max	mA
V_{CB} = 60 V, I_E = 0	I_{CBO}	10 max	mA
Output Capacitance (V_{CB} = 30 V, I_E = 0)	C_{obo}	85 max	pF
RF Power Output (V_{CE} = 24 V, P_{IE} = 3 W, f = 50 Mc/s, R_G & R_L = 50 Ω)	P_{OE}	30* min	W

* For conditions given, minimum efficiency = 60 per cent.

TYPICAL OPERATION CHARACTERISTIC



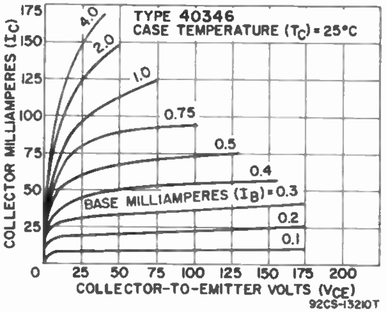
POWER TRANSISTOR 40346

Si n-p-n triple-diffused planar type used in low-power, high-voltage, general-purpose applications in military, industrial, and commercial equipment. This type is particularly useful in neon-indicator driver circuits and in high-voltage differential and high-voltage operational amplifiers. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

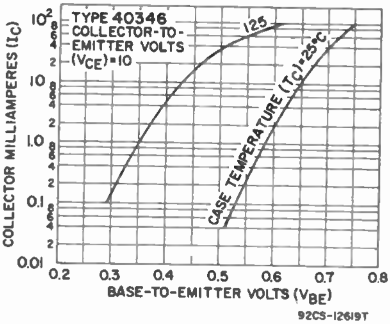
MAXIMUM RATINGS

Collector-to-Emitter Voltage (R_{BE} = 1000 Ω)	V_{CER}(sus)	175	V
Collector Current	I_C	1	A
Base Current	I_B	0.5	A
Transistor Dissipation:			
T_A up to 50°C	P_T	1	W
T_C up to 50°C	P_T	5	W
T_A and T_C above 50°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A-T_C)		−65 to 200	°C

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (R_{BE} = 1000 Ω, I_C = 50 mA)	V_{CER}(sus)	175 min	V
Collector-to-Emitter Saturation Voltage (I_B = 1 mA, I_C = 10 mA)	V_{CE}(sat)	0.5 max	V
Base-to-Emitter Voltage (V_{CE} = 10 V, I_C = 10 mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
V_{CE} = 100 V, I_B = 0	I_{CEO}	5 max	µA
V_{CE} = 200 V, V_{BE} = −1.5 V, T_C = 25°C	I_{CEV}	10 max	µA
V_{CE} = 200 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	1 max	mA
Emitter-Cutoff Current (V_{EB} = 4 V, I_C = 0)	I_{EBO}	5 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 10 mA)	h_{FE}	25 min	
Small-Signal, Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 10 mA, f = 5 Mc/s)	h_{fe}	2 min	
Thermal Resistance, Junction-to-Case	θ_{J-C}	30 max	°C/W

40347

POWER TRANSISTOR

Si **n-p-n single-diffused** type used in a wide variety of low- and medium-power applications where medium- and high-voltage power transistors are required, such as switching regulators, converters, inverters, relay controls, oscillators, and pulse and audio amplifiers. JEDEC TO-5, Outline No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

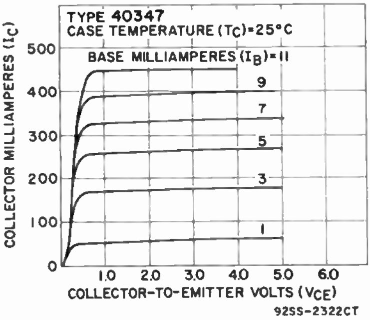
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	60	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Base Current	I_B	0.5	A
Transistor Dissipation:			
T_A up to 50°C	P_T	1	W
T_C up to 50°C	P_T	5	W
T_A and T_C above 50°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

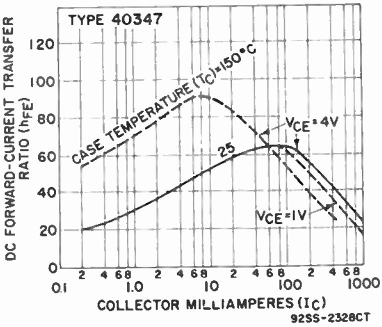
CHARACTERISTICS

Collector-to-Emitter Sustaining Voltage:			
V_{BE} = −1.5 V, I_C = 50 mA	V_{CEV}(sus)	60 min	V
I_C = 50 mA, I_B = 0	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Saturation Voltage (I_C = 450 mA, I_B = 45 mA)	V_{CE}(sat)	1 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 150 mA)	V_{BE}	1.5 max	V
Collector-Cutoff Current:			
V_{CE} = 30 V, I_B = 0, T_C = 25°C	I_{CEO}	1 max	µA
V_{CE} = 30 V, I_B = 0, T_C = 150°C	I_{CEO}	1 max	mA

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



CHARACTERISTICS (cont'd)

Emitter-Cutoff Current (V_{EB} = 7 V, I_C = 0)	I_{EBO}	10 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 450 mA)	h_{FE}	20 to 80	
Thermal Resistance, Junction-to-Case	θ_{J-C}	20 max	°C/W

POWER TRANSISTOR

40347V1

Si **n-p-n** single-diffused type with an attached heat radiator for printed-circuit-board use in a wide variety of low- and medium-power applications requiring medium- and high-voltage power transistors for switching regulators, converters, inverters, relay controls, oscillators, and pulse and audio amplifiers. JEDEC TO-5 (with heat radiator), **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with heat radiator). This type is identical with type 40347 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	4.3	W
T_C up to 25°C	P_T	8.75	W
T_A or T_C above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	40 max	°C/W

POWER TRANSISTOR

40347V2

Si **n-p-n** single-diffused type used in a wide variety of low- and medium-power applications requiring medium- and high-voltage power transistors for switching regulators, converters, inverters, relay controls, oscillators, and pulse and audio amplifiers. JEDEC TO-5 (with flange), **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with flange). This type is identical with type 40347 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_C up to 25°C	P_T	11.6	W
T_C above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Case	θ_{J-C}	15 max	°C/W

POWER TRANSISTOR

40348

Si **n-p-n** single-diffused type used in a wide variety of low- and medium-power applications where medium- and high-voltage power transistors are required, such as switching regulators, converters, inverters, relay controls, oscillators, and pulse and audio amplifiers. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

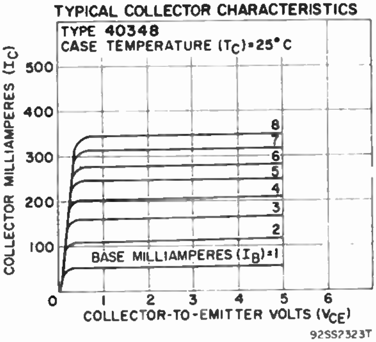
Collector-to-Base Voltage	V_{CBO}	90	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	90	V
Base open	V_{CEO}	65	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Base Current	I_B	0.5	A
Transistor Dissipation:			
T_A up to 50°C	P_T	1	W
T_C up to 50°C	P_T	5	W
T_A and T_C above 50°C	P_T	See curve page 112	

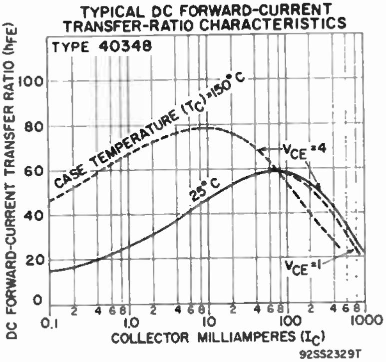
MAXIMUM RATINGS (cont'd)

Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

Collector-to-Emitter Sustaining Voltage:			
$V_{BE} = -1.5$ V, $I_C = 50$ mA	V_{CEV}(sus)	90 min	V
$I_C = 50$ mA, $I_B = 0$	V_{CEO}(sus)	65 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 300$ mA, $I_B = 30$ mA)	V_{CE}(sat)	0.75 max	V
Base-to-Emitter Voltage ($V_{CE} = 4$ V, $I_C = 300$ mA)	V_{BE}	1.3 max	V
Collector-Cutoff Current:			
$V_{CE} = 60$ V, $I_B = 0$, $T_C = 25°C$	I_{CEO}	1 max	μA
$V_{CE} = 60$ V, $I_B = 0$, $T_C = 150°C$	I_{CEO}	3 max	mA
Emitter-Cutoff Current ($V_{EB} = 7$ V, $I_C = 0$)	I_{EBO}	10 max	μA
Static Forward-Current Transfer Ratio:			
$V_{CE} = 4$ V, $I_C = 300$ mA	h_{FE}	30 to 100	
$V_{CE} = 4$ V, $I_C = 1$ A	h_{FE}	10 min	
Thermal Resistance, Junction-to-Case	Θ_{J-C}	20 max	°C/W





40348V1 POWER TRANSISTOR

Si n-p-n single-diffused type with an attached heat radiator for printed-circuit-board use in a wide variety of low- and medium-power applications requiring medium- and high-voltage power transistors for switching regulators, converters, inverters, relay controls, oscillators, and pulse and audio amplifiers. JEDEC TO-5 (with heat radiator), **Outline No.3. Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with heat radiator). This type is identical with type 40348 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	4.3	W
T_C up to 25°C	P_T	8.75	W
T_A or T_C above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	40 max	°C/W

40348V2 POWER TRANSISTOR

Si n-p-n single-diffused type used in a wide variety of low- and medium-power applications requiring medium- and high-voltage power transistors for switching regulators, converters, inverters, relay controls, oscillators, and pulse and audio amplifiers. JEDEC TO-5 (with flange), **Outline No.3.**

Terminals: 1 - emitter, 2 - base, 3 - collector and case (with flange). This type is identical with type 40348 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_C up to 25°C	P_T	11.6	W
T_C above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Case	θ_{J-C}	15 max	°C/W

POWER TRANSISTOR 40349

Si **n-p-n single-diffused** type used in a wide variety of low- and medium-power applications where medium- and high-voltage power transistors are required, such as switching regulators, converters, inverters, relay controls, oscillators, and pulse and audio amplifiers. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

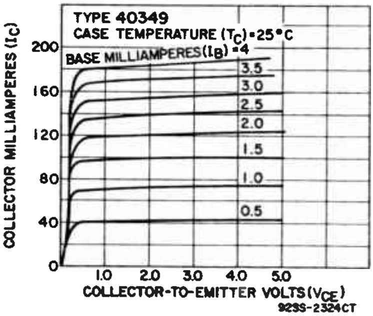
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	160	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	160	V
Base open	V_{CEO}	140	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Base Current	I_B	0.5	A
Transistor Dissipation:			
T_A up to 50°C	P_T	1	W
T_C up to 50°C	P_T	5	W
T_A and T_C above 50°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

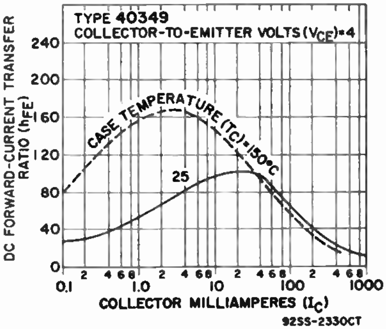
CHARACTERISTICS

Collector-to-Emitter Sustaining Voltage:			
$V_{BE} = -1.5$ V, $I_C = 50$ mA	V_{CEV}(sus)	160 min	V
$I_C = 50$ mA, $I_B = 0$	V_{CEO}(sus)	140 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 150$ mA, $I_B = 15$ mA)	V_{CE}(sat)	0.5 max	V
Base-to-Emitter Voltage ($V_{CE} = 4$ V, $I_C = 450$ mA)	V_{BE}	1.1 max	V
Collector-Cutoff Current:			
$V_{CE} = 100$ V, $I_B = 0$, $T_C = 25$°C	I_{CEO}	10 max	μA
$V_{CE} = 100$ V, $V_{BE} = -1.5$ V, $T_C = 150$°C	I_{CEV}	1 max	mA
Emitter-Cutoff Current ($V_{EB} = 7$ V, $I_C = 0$)	I_{EBO}	10 max	μA
Static Forward-Current Transfer Ratio:			
$V_{CE} = 4$ V, $I_C = 150$ mA	h_{FE}	25 to 100	
$V_{CE} = 4$ V, $I_C = 450$ mA	h_{FE}	10 min	
Thermal Resistance, Junction-to-Case	θ_{J-C}	20 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL DC FORWARD-CURRENT TRANSFER RATIO CHARACTERISTICS



40349V1 POWER TRANSISTOR

Si n-p-n single-diffused type with an attached heat radiator for printed-circuit-board use in a wide variety of low- and medium-power applications requiring medium- and high-voltage power transistors for switching regulators, converters, inverters, relay controls, oscillators, and pulse and audio amplifiers. JEDEC TO-5 (with heat radiator), Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case (with heat radiator). This type is identical with type 40349 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	4.3	W
T_C up to 25°C	P_T	8.75	W
T_A or T_C above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	40 max	°C/W

40349V2 POWER TRANSISTOR

Si n-p-n single-diffused type used in a wide variety of low- and medium-power applications requiring medium- and high-voltage power transistors for switching regulators, converters, inverters, relay controls, oscillators, and pulse and audio amplifiers. JEDEC TO-5 (with flange), Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case (with flange). This type is identical with type 40349 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_C up to 25°C	P_T	11.6	W
T_C above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Case	θ_{J-C}	15 max	°C/W

40350 TRANSISTOR

Si n-p-n type used as an rf amplifier in tuners covering television channels 2 through 13. Outline No.27. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	35	V
Collector Current	I_C	25	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	180	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 175	°C
Storage	T_{STG}	−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-Cutoff Current:			
$V_{CB} = 1$ V, $I_E = 0$	I_{CBO}	0.02 max	µA
$V_{CB} = 35$ V, $I_E = 0$	I_{CBO}	1 max	µA
Emitter-Cutoff Current ($V_{EB} = 3$ V, $I_C = 0$)	I_{EBO}	1 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = 6$ V, $I_E = -1$ mA)	h_{FE}	40 to 170	
Gain-Bandwidth Product ($V_{CE} = 6$ V, $I_E = -1$ mA)	f_T	800	Mc/s

CHARACTERISTICS (cont'd)

Input Resistance (V_{CE} = 10 V, I_E = −3 mA, f = 216 Mc/s)	R_{ie}	110	Ω
Output Resistance (V_{CE} = 10 V, I_E = −3 mA, f = 216 Mc/s)	R_{oe}	6	kΩ
Extrinsic Transconductance (V_{CE} = 10 V, I_E = −3 mA, f = 216 Mc/s)	g_m	48.2	mmhos
Noise Figure (V_{CE} = 10 V, I_E = −3 mA, R_S = 100 Ω, R_G = 100 Ω, f = 216 Mc/s)	NF	3.3	dB
Collector-to-Base Feedback Capacitance (V_{CE} = 10 V, I_E = −3 mA, f = 216 Mc/s)	C_{cb}	0.5	pF
Maximum Available Amplifier Gain (V_{CE} = 10 V, I_E = −3 mA, f = 216 Mc/s)	MAG	25.8	dB
Maximum Usable Amplifier Gain, Unneutralized (V_{CE} = 10 V, I_E = −3 mA, f = 216 Mc/s)	MUG	13.4	dB
Maximum Usable Amplifier Gain, Neutralized (V_{CE} = 10 V, I_E = −3 mA, f = 216 Mc/s)	MUG	18.5	dB

TRANSISTOR 40351

Si **n-p-n** type used in 45-Mc/s television if amplifiers. **Outline No.27. Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	35	V
Collector Current	I_C	25	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	180	mW
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 175	°C
Storage	T_{STG}	−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-Cutoff Current:			
V_{CB} = 1 V, I_E = 0	I_{CBO}	0.02 max	µA
V_{CB} = 35 V, I_E = 0	I_{CBO}	1 max	µA
Emitter-Cutoff Current (V_{EB} = 3 V, I_C = 0)	I_{EBO}	1 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	40 to 170	
Gain-Bandwidth Product (V_{CE} = 6 V, I_E = −1 mA)	f_T	700	Mc/s
Input Resistance (V_{CE} = 12 V, I_E = −4 mA, f = 45 Mc/s)	R_{ie}	410	Ω
Output Resistance (V_{CE} = 12 V, I_E = −4 mA, f = 45 Mc/s)	R_{oe}	36	kΩ
Extrinsic Transconductance (V_{CE} = 12 V, I_E = −4 mA, f = 45 Mc/s)	g_m	97	mmhos
Collector-to-Base Feedback Capacitance (V_{CE} = 12 V, I_E = −4 mA, f = 45 Mc/s)	C_{cb}	0.5	pF
Maximum Available Amplifier Gain (V_{CE} = 12 V, I_E = −4 mA, f = 45 Mc/s)	MAG	45.4	dB
Maximum Usable Amplifier Gain, Unneutralized: V_{CE} = 12 V, I_E = −4 mA, f = 45 Mc/s			
For 1 stage	MUG	23.3	dB
For 2 stages	MUG	21.1	dB
For 3 stages	MUG	19.3	dB
Maximum Usable Amplifier Gain, Neutralized: V_{CE} = 12 V, I_E = −4 mA, f = 45 Mc/s			
For 1 stage	MUG	28.4	dB
For 2 stages	MUG	26.2	dB
For 3 stages	MUG	24.4	dB

TRANSISTOR 40352

Si **n-p-n** type used in 45-Mc/s television if amplifiers. **Outline No.27. Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case. This type is identical with type 40351 except for the following item:

CHARACTERISTICS

Static Forward-Current Transfer Ratio (V_{CB} = 6 V, I_E = −1 mA)	h_{FE}	27 to 100	

40354 TRANSISTOR

Si **n-p-n** type used in video-output amplifier stages of black-and-white television receivers. **Outline** No.27. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Emitter Voltage	V_{CEO}	150	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	50	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 175	°C
Storage	T_{STG}	−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage ($I_C = 1$ mA, $I_B = 0$)	$V_{(BR)CEO}$	150 min	V
Emitter-to-Base Breakdown Voltage ($I_E = -10$ μA, $I_C = 0$)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 30$ mA, $I_B = 1$ mA)	V_{CE}(sat)	5 max	V
Collector-Cutoff Current ($V_{CB} = 120$ V, $I_E = 0$)	I_{CBO}	100 max	V
Static Forward-Current Transfer Ratio ($V_{CE} = 10$ V, $I_C = 10$ mA)	h_{FE}	55	
Collector-to-Base Feedback Capacitance ($V_{CE} = 10$ V, $I_C = 30$ mA)	C_{cb}	3.5 max	pF
Gain-Bandwidth Product:			
$V_{CE} = 10$ V, $I_C = 30$ mA	f_T	50 min	Mc/s
$V_{CE} = 140$ V, $I_C = 2$ mA	f_T	50 min	Mc/s
Thermal Resistance, Junction-to-Case	Θ_{J-C}	60 max	°C/W

40355 TRANSISTOR

Si **n-p-n** type used in video-output amplifier stages of black-and-white television receivers. **Outline** No.27 with heat sink. Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 40354 except for the outline and the following item:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W

40360 POWER TRANSISTOR

Si **n-p-n** type used in audio-amplifier inverter and driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-5, **Outline** No.3. Terminals: 1 - emitter, 2 - base, 3 - collector. For collector-characteristics and transfer-characteristics curves, refer to type 40309.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	70	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	70 min	V
Collector-to-Emitter Saturation Voltage (I_B = 15 mA, I_C = 150 mA)	V_{CE}(sat)	1.4 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 10 mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
V_{CE} = 60 V, I_B = 0, T_C = 25°C	I_{CEO}	1 max	µA
V_{CE} = 60 V, I_B = 0, T_C = 150°C	I_{CEO}	250 max	µA
Emitter-Cutoff Current (V_{EB} = 4 V, I_C = 0)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 10 mA)	h_{FE}	40 to 200	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 50 mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

POWER TRANSISTOR 40361

Si **n-p-n** type used in audio-amplifier inverter and driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-5, **Outline No.3. Terminals:** 1 - emitter, 2 - base, 3 - collector. For collector-characteristics and transfer-characteristics curves, refer to type 40309.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 200 Ω)	V_{CER}(sus)	70	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (R_{BE} = 200 Ω, I_C = 100 mA)	V_{CER}(sus)	70 min	V
Collector-to-Emitter Saturation Voltage (I_B = 15 mA, I_C = 150 mA)	V_{CE}(sat)	1.4 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 50 mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
V_{CE} = 60 V, R_{BE} = 200 Ω, T_C = 25°C	I_{CER}	1 max	µA
V_{CE} = 60 V, R_{BE} = 200 Ω, T_C = 150°C	I_{CER}	100 max	µA
Emitter-Cutoff Current (V_{EB} = 4 V, I_C = 0)	I_{EBO}	1 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 50 mA)	h_{FE}	70 to 350	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 50 mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

POWER TRANSISTOR 40362

Si **p-n-p** used in audio-amplifier driver stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. P-N-P structure permits complementary driver operation with a matching n-p-n type such as 40361. JEDEC TO-5, **Outline No.3. Terminals:** 1 - emitter, 2 - base, 3 - collector. For collector-characteristics and input-characteristics curves, refer to type 40319.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 200 Ω)	V_{CER}(sus)	—70	V
Emitter-to-Base Voltage	V_{EBO}	—4	V
Collector Current	I_C	—0.7	A
Base Current	I_B	—0.2	A

MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (R_{BE} = 200 Ω, I_C = 100 mA)	V_{CER}(sus)	−70 min	V
Collector-to-Emitter Saturation Voltage (I_B = 15 mA, I_C = −150 mA)	V_{CE}(sat)	−1.4 max	V
Base-to-Emitter Voltage (V_{CE} = −4 V, I_C = −50 mA)	V_{BE}	−1 max	V
Collector-Cutoff Current:			
V_{CE} = −60 V, R_{BE} = 200 Ω, T_C = 25°C	I_{CER}	−1 max	µA
V_{CE} = −60 V, R_{BE} = 200 Ω, T_C = 150°C	I_{CER}	−100 max	µA
Emitter-Cutoff Current (V_{EB} = −4 V, I_C = 0)	I_{EBO}	−4 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = −4 V, I_C = −50 mA)	h_{FE}	35 to 200	
Gain-Bandwidth Product (V_{CE} = −4 V, I_C = −50 mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

40363 POWER TRANSISTOR

Si **n-p-n** type used in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. For collector-characteristics and transfer-characteristics curves, refer to type 40325.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 200 Ω)	V_{CER}(sus)	70	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	15	A
Base Current	I_B	7	A
Transistor Dissipation:			
T_C up to 25°C	P_T	115	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (R_{BE} = 200 Ω, I_C = 200 mA)	V_{CER}(sus)	70 min	V
Collector-to-Emitter Saturation Voltage (I_C = 4 A, I_B = 0.4 A)	V_{CE}(sat)	1.1 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 4 A)	V_{BE}	1.8 max	V
Collector-Cutoff Current:			
V_{CE} = 60 V, R_{BE} = 200 Ω, T_C = 25°C	I_{CER}	0.5 max	mA
V_{CE} = 60 V, R_{BE} = 200 Ω, T_C = 150°C	I_{CER}	2 max	mA
Emitter-Cutoff Current (V_{EB} = 4 V, I_C = 0)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 4 A)	h_{FE}	20 to 70	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 3 A)	f_T	700	kc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

40364 POWER TRANSISTOR

Si **n-p-n** type used in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 150 Ω)	V_{CER}(sus)	60	V
Emitter-to-Base Voltage	V_{EBO}	4	V

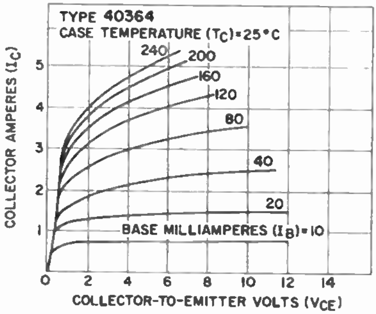
MAXIMUM RATINGS (cont'd)

Collector Current	I_C	7	A
Base Current	I_B	5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	35	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

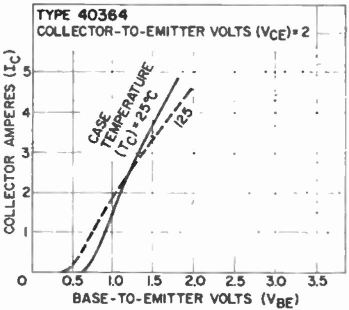
Collector-to-Emitter Sustaining Voltage (R_{BE} = 150 Ω, I_C = 200 mA)	V_{CER}(sus)	60 min	V
Collector-to-Emitter Saturation Voltage (I_C = 2.5 A, I_B = 0.25 A)	V_{CE}(sat)	2 max	V
Base-to-Emitter Voltage (V_{CE} = 5 V, I_C = 2.5 A)	V_{BE}	1.8 max	V
Collector-Cutoff Current:			
V_{CE} = 50 V, R_{BE} = 150 Ω, T_C = 25°C	I_{CER}	0.5 max	mA
V_{CE} = 50 V, R_{BE} = 150 Ω, T_C = 150°C	I_{CER}	2 max	mA
Emitter-Cutoff Current (V_{EB} = 4 V, I_C = 0)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 0.5 A	h_{FE}	35 to 175	
V_{CE} = 5 V, I_C = 2.5 A	h_{FE}	20 min	
Gain-Bandwidth Product (V_{CE} = 10 V, I_C = 2.5 A)	f_T	15	Mc/s
Second-Breakdown Collector Current (V_{CE} = 40 V)	$I_{S/b}$	750 min	mA
Thermal Resistance, Junction-to-Case	θ_{J-C}	5 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



92SS-2227CT

TYPICAL TRANSFER CHARACTERISTICS



92SS-2202CT

POWER TRANSISTOR 40366

Si n-p-n single-diffused type featuring a base composed of a homogeneous-resistivity silicon material. This type is subjected to special preconditioning tests for high-reliability operation in medium- and high-power switching and amplifier applications in military and industrial equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N2102 except for the following items:

MAXIMUM RATINGS

Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage (V_{BE} = −1.5 V, I_C = 0.1 mA)	$V_{(BR)CBV}$	120 min	V

POWER TRANSISTOR 40367

Si n-p-n single-diffused type featuring a base composed of a homogeneous-resistivity silicon material. This type is subjected to special preconditioning tests for high-reliability operation in medium- and high-power switching and amplifier applications in military and industrial equipment. JEDEC TO-5, **Outline No.3. Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is a high-reliability version of type 2N1482.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	100	V
Base open	V_{CEO}	55	V
Emitter-to-Base Voltage	V_{EBO}	12	V
Collector Current	I_C	1.5	A
Base Current	I_B	1	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	5	W
T_A or T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	255	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage (V_{BE} = −1.5 V, I_C = 0.25 mA)	$V_{(BR)CEV}$	100 min	V
Collector-to-Emitter Sustaining Voltage (I_C = 50 mA, I_B = 0)	V_{CEO}(sus)	55 min	V
Collector-to-Emitter Saturation Voltage (I_C = 200 mA, I_B = 10 mA)	V_{CE}(sat)	1.4 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 200 mA)	V_{BE}	3 max	V
Collector-Cutoff Current (V_{CB} = 30 V, I_E = 0)	I_{CBO}	4 max	μA
Emitter-Cutoff Current (V_{EB} = 12 V, I_C = 0)	I_{EBO}	2 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 200 mA)	h_{FE}	35 to 100	

40368 POWER TRANSISTOR

Si **n-p-n single-diffused** type featuring a base comprised of a homogeneous-resistivity silicon material. This type is subjected to special preconditioning tests for high-reliability operation in medium- and high-power switching and amplifier applications in military and industrial equipment. JEDEC TO-8, **Outline No.5. Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is a high-reliability version of type 2N1486.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	100	V
Base open	V_{CEO}	55	V
Emitter-to-Base Voltage	V_{EBO}	12	V
Collector Current	I_C	3	A
Base Current	I_B	1.5	A
Transistor Dissipation:	P_T	See curve page 112	
T_C up to 25°C			
T_C above 25°C	P_T	25	W
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature	T_P	235	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage (V_{BE} = −1.5 V, I_C = 0.25 mA)	$V_{(BR)CEV}$	100 min	V
Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	55 min	V
Collector-to-Emitter Saturation Voltage (I_C = 750 mA, I_B = 10 mA)	V_{CE}(sat)	0.75 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 750 mA)	V_{BE}	2.5 max	V
Collector-Cutoff Current (V_{CB} = 30 V, I_E = 0)	I_{CBO}	9 max	μA
Emitter-Cutoff Current (V_{EB} = 12 V, I_C = 0)	I_{EBO}	5 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 750 mA)	h_{FE}	35 to 100	

POWER TRANSISTOR 40369

Si n-p-n single-diffused type featuring a base comprised of a homogeneous-resistivity silicon material. This type is subjected to special preconditioning tests for high-reliability operation in medium- and high-power switching and amplifier applications in military and industrial equipment JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is a high-reliability version of type 2N1490.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	100	V
Base open	V_{CEO}	55	V
Emitter-to-Base Voltage	V_{EBO}	10	V
Collector Current	I_C	6	A
Base Current	I_B	3	A
Transistor Dissipation:			
T_C up to 25°C	P_T	75	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J (opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	235	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage (V_{BE} = −1.5 V, I_C = 0.25 mA)	$V_{(BR)CEV}$	100 min	V
Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	55 min	V
Collector-to-Emitter Saturation Voltage (I_C = 1300 mA, I_B = 100 mA)	V_{CE}(sat)	1 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 1500 mA)	V_{BE}	2.5 max	V
Collector-Cutoff Current (V_{CB} = 30 V, I_E = 0)	I_{CBO}	10 max	µA
Emitter-Cutoff Current (V_{EB} = 10 V, I_C = 0)	I_{EBO}	6 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 1500 mA)	h_{FE}	25 to 75	

POWER TRANSISTOR 40372

Si n-p-n diffused-junction type with an attached heat radiator for printed-circuit-board use in power-switching circuits, series- and shunt-regulator driver and output stages, and high-fidelity amplifiers in commercial and industrial equipment. JEDEC TO-66 (with heat radiator), Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case (with heat radiator). This type is identical with type 2N3054 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	5.8	W
T_C up to 25°C	P_T	29	W
T_A or T_C above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	30 max	°C/W
Thermal Resistance, Junction-to-Case	θ_{J-C}	6 max	°C/W

POWER TRANSISTOR 40373

Si n-p-n diffused type with an attached radiator for printed-circuit-board used in high-voltage applications in power-switching circuits, series- and shunt-regulator driver and output stages, and dc-to-dc converters in military, commercial, and industrial equipment. JEDEC TO-66 (with heat radiator), Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case (with heat radiator). This type is identical with type 2N3441 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	5.8	W
T_C up to 25°C	P_T	29	W
T_A or T_C above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	30 max	°C/W
Thermal Resistance, Junction-to-Case	θ_{J-C}	6 max	°C/W

40374 TRANSISTOR

Si **n-p-n triple-diffused** type with an attached radiator for printed-circuit-board use in high-speed switching and linear amplifier applications such as high-voltage operational amplifiers, high-voltage switches, switching regulators, converters, inverters, deflection and high-fidelity amplifiers in military, industrial, and commercial equipment. JEDEC TO-66 (with heat radiator), Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case (with heat radiator). This type is identical with type 2N3583 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	5.8	W
T_C up to 25°C	P_T	35	W
T_A or T_C above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	35 max	°C/W
Thermal Resistance, Junction-to-Case	θ_{J-C}	5 max	°C/W

40375 POWER TRANSISTOR

Si **n-p-n epitaxial** type with an attached heat radiator for printed-circuit-board use in audio, ultrasonic, and rf circuits and in low-distortion power amplifiers, oscillators, switching regulators, series regulators, converters, and inverters. JEDEC TO-66 (with heat radiator), Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case (with heat radiator). This type is identical with type 2N3878 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	5.8	W
T_A above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	30 max	°C/W

40389 POWER TRANSISTOR

Si **n-p-n triple-diffused planar** type with an attached heat radiator for printed-circuit-board use in a wide variety of small-signal, medium-power applications (up to 20 Mc/s) in commercial and industrial equipment. JEDEC TO-5 (with heat radiator), Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case (with heat radiator). This type is identical with type 2N3053 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	3.5	W
T_A above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	50 max	°C/W

TRANSISTOR 40390

Si **n-p-n triple-diffused** type with an attached heat radiator for printed-circuit-board use in high-speed switching and linear amplifier applications such as high-voltage differential and operational amplifiers, high-voltage inverters, and series regulators for industrial and military applications. JEDEC TO-5 (with heat radiator), **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with heat radiator). This type is identical with type 2N3440 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	3.9	W
T_A above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	45 max	°C/W

POWER TRANSISTOR 40391

Si **p-n-p double-diffused epitaxial planar** type with an attached heat radiator for printed-circuit-board use in a wide variety of small-signal, medium-power applications in military, industrial, and commercial equipment. JEDEC TO-5 (with heat radiator), **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with heat radiator). This type is identical with type 2N4037 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	2.5	W
T_A above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	50 max	°C/W

POWER TRANSISTOR 40392

Si **n-p-n triple-diffused planar** type used in a wide variety of small-signal, medium-power applications at frequencies up to 20 Mc/s. JEDEC TO-5 (with flange), **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with flange). This type is identical with type 2N3053 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_C up to 25°C	P_T	7	W
T_C above 25°C	P_T	See curve page 112	

CHARACTERISTICS

Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W

40394 POWER TRANSISTOR

Si **p-n-p double-diffused epitaxial planar** type used in a wide variety of small-signal, medium-power applications in military, industrial, and commercial equipment. JEDEC TO-5 (with flange), **Outline No.3. Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with flange). This type is electrically identical with type 2N4037.

40395 TRANSISTOR

Ge **p-n-p alloy-junction** type used in high-gain low-level audio stages. JEDEC TO-1, **Outline No.1. Terminals:** 1 - emitter, 2 - base, 3 - collector.

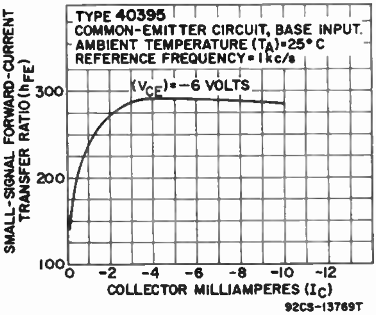
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−20	V
Collector-to-Emitter Voltage ($R_{BE} \leqq 4.7$ kΩ)	V_{CER}	−18	V
Emitter-to-Base Voltage	V_{EBO}	−20	V
Collector Current	I_C	−50	mA
Transistor Dissipation:			
T_A up to 55°C	P_T	120	mW
T_A above 55°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 100	°C
Storage	T_{STG}	−65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage (I_C = −1 mA, I_B = 0, R_{BE} = 10 kΩ)	$V_{(BR)CER}$	−18 min	V
Collector-Cutoff Current (V_{CB} = −20 V, I_E = 0)	I_{CBO}	−12 max	μA
Emitter-Cutoff Current (V_{EB} = 20 V, I_C = 0)	I_{EBO}	−12 max	μA
Noise Current (V_{CE} = −6 V, I_C = −1 mA, f = 0.05 to 15 kc/s)		10 max	nA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_C = −1 mA)	h_{fe}	170 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = −6 V, I_C = −1 mA)	f_{hfb}	10	Mc/s

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC

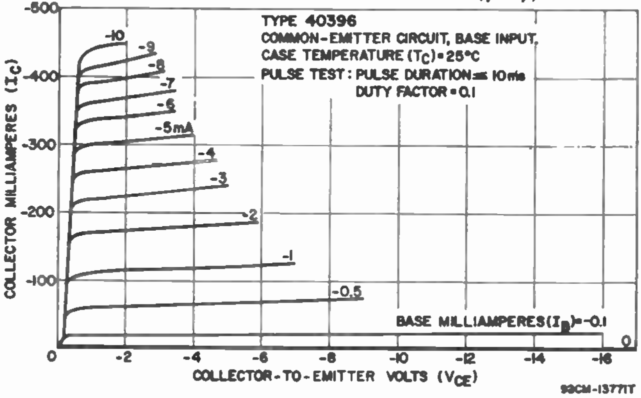


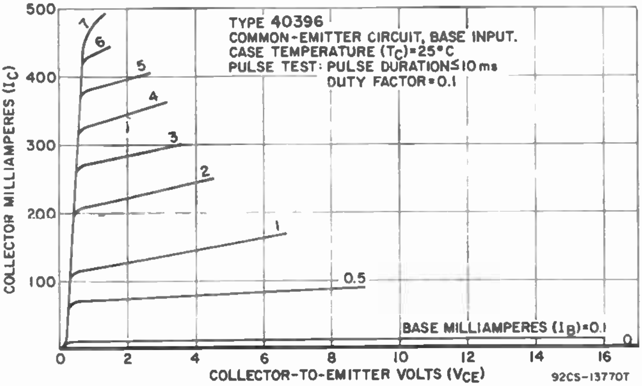
40396 POWER TRANSISTORS (Matched Pair)

Ge **p-n-p** and Ge **n-p-n** types, in separate packages, with matched characteristics for use in complementary symmetry af output-amplifier stages. JEDEC TO-1, **Outline No.1. Terminals:** 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

		p-n-p	*n-p-n*	
Collector-to-Base Voltage	V_{CBO}	—18	18	V
Collector-to-Emitter Voltage ($R_{BE} \leq 4.7$ kΩ)	V_{CER}	—18	18	V
Emitter-to-Base Voltage	V_{EBO}	—2.5	2.5	V
Collector Current	I_C	—500	500	mA
Transistor Dissipation:				
T_C up to 55°C	P_T	300	300	mW
T_C above 55°C	P_T	See curve page 112		
Temperature Range:				
Operating (Junction)	T_J(opr)	—65 to 85		°C
Storage	T_{STG}	—65 to 85		°C
Lead-Soldering Temperature	T_L	255	255	°C


TYPICAL COLLECTOR CHARACTERISTICS (p-n-p)


TYPICAL COLLECTOR CHARACTERISTICS (n-p-n)

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage:				
I_C = —1 mA, R_{BE} = 4.7 kΩ	$V_{(BR)CER}$	—18 min		V
I_C = 1 mA, R_{BE} = 4.7 kΩ	$V_{(BR)CER}$		18 min	V
Collector-to-Emitter Saturation Voltage:				
I_C = —250 mA, I_B = —25 mA	V_{CE}(sat)	—0.25		V
I_C = 250 mA, I_B = 25 mA	V_{CE}(sat)		—0.25	V
Collector-Cutoff Current:				
V_{CB} = —12 V, I_E = 0	I_{CBO}	—14 max		μA
V_{CB} = 12 V, I_E = 0	I_{CBO}		14 max	μA

CHARACTERISTICS (cont'd)

		p-n-p	*n-p-n*	
Emitter-Cutoff Current:				
V_{EB} = –2.5 V, I_C = 0	I_{EBO}	–14 max		µA
V_{EB} = 2.5 V, I_C = 0	I_{EBO}		14 max	µA
Static Forward-Current Transfer Ratio:				
V_{CE} = –1 V, I_C = –250 mA	h_{FE}	30 min		
V_{CE} = 1 V, I_C = 250 mA	h_{FE}		30 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency:				
V_{CB} = –6 V, I_C = –1 mA	f_{hfb}	1.5		Mc/s
V_{CB} = 6 V, I_C = 1 mA	f_{hfb}		2	Mc/s

40404

TRANSISTOR

Si n-p-n epitaxial planar type used in vhf low-level class C rf amplifiers and frequency multipliers at frequencies to 170 Mc/s in communications equipment. JEDEC TO-52, Outline No.18. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

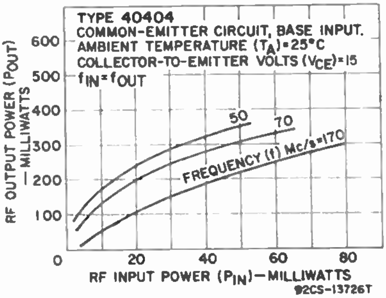
Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage	V_{CEO}	16	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	0.5	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.3	W
T_C up to 25°C	P_T	1	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A-T_C)		–65 to 175	°C
Storage	T_{STG}	–65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C

CHARACTERISTICS

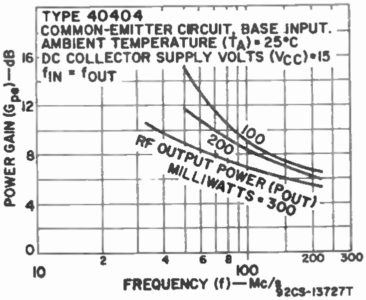
Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	40 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 10 mA, I_B = 0, $t_p \leqq$ 100 ns, df = 2%)	$V_{(BR)CEO}$	16 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.01 mA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-Cutoff Current (V_{CB} = 20 V, I_E = 0)	I_{CBO}	25 max	nA
Static Forward-Current Transfer Ratio (V_{CE} = 2 V, I_C = 50 mA)	h_{FE}	25 to 65	
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 0.1 to 1 Mc/s)	C_{obo}	4 max	pF
RF Power Output, Frequency-Doubler (V_{CC} = 12 V, P_{ie} = 5 mW, f(in) = 43 Mc/s, f(out) = 86 Mc/s)	P_{oe}	50* min	mW

* For conditions given, minimum efficiency = 35 per cent.

TYPICAL OPERATION CHARACTERISTICS



TYPICAL POWER-GAIN CHARACTERISTICS



TRANSISTOR 40405

Si **n-p-n epitaxial planar** type used in class C rf power amplifiers, drivers, and frequency multipliers at frequencies to 400 Mc/s in battery-operated communications equipment. JEDEC TO-52, **Outline** No.18. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

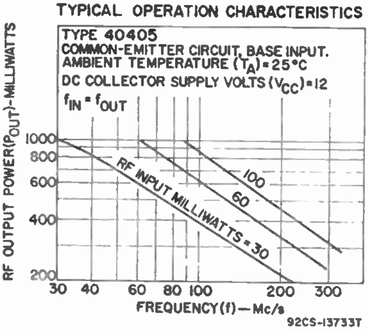
MAXIMUM RATINGS

Collector-to-Emitter Voltage:			
Base open	V_{CEO}	16	V
$V_{BE} = 0$	V_{CES}	40	V
Emitter-to-Base Voltage	V_{EBO}	6	V
Collector Current	I_C	0.5	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.3	W
T_C up to 25°C	P_T	1	W
T_A and T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (T_A-T_C)		−65 to 175	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	300	°C

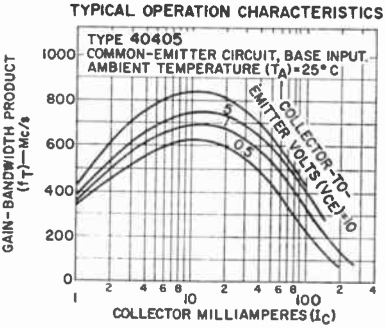
CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage:			V
$I_C = 10$ mA, $I_B = 0$, $t_p = 100$ µs, df = 2%	$V_{(BR)CEO}$	16 min	
$I_C = 5$ mA, $R_{BE} = 0$	$V_{(BR)CES}$	40 min	V
Emitter-to-Base Breakdown Voltage ($I_E = 0.01$ mA, $I_C = 0$)	$V_{(BR)EBO}$	6 min	V
Collector-Cutoff Current ($V_{CE} = 15$ V, $R_{BE} = 0$)	I_{CES}	0.4 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = 1$ V, $I_C = 100$ mA)	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio ($V_{CE} = 1$ V, $I_C = 100$ mA, f = 100 Mc/s)	h_{fe}	3 min	
Gain Bandwidth Product ($I_C = 100$ mA, $V_{CE} = 1$ V)	f_T	300 min	Mc/s
Output Capacitance ($V_{CB} = 5$ V, $I_E = 0$, f = 0.1 to 1 Mc/s)	C_{obo}	3.5 max	pF
RF Power Output, Frequency-Doubler ($V_{CC} = 15$ V, $P_{ie} = 30$ mW, f(in) = 86 Mc/s, f(out) = 172 Mc/s)	P_{oe}	200* min	mW

* For conditions given, minimum efficiency = 35 per cent.



92CS-13733T



92CS-13734T

TRANSISTOR 40406

Si **p-n-p** type used in the input stages in af-amplifier applications in industrial and commercial equipment. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. For collector-characteristics and input-characteristics curves, refer to type 40319.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	−50	V
Emitter-to-Base Voltage	V_{EBO}	−4	V
Collector Current	I_C	−0.7	A
Base Current	I_B	−0.2	A
Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage ($I_C = -100$ mA, $I_B = 0$)	V_{CEO}(sus)	−50 min	V
Base-to-Emitter Voltage ($I_C = -0.1$ mA)	V_{BE}	−0.8 max	V
Collector-Cutoff Current:			
$V_{CE} = -40$ V, $I_B = 0$, $T_C = 25$°C	I_{CEO}	−1 max	µA
$V_{CE} = -40$ V, $I_B = 0$, $T_C = 150$°C	I_{CEO}	−10 max	µA
Emitter-Cutoff Current ($V_{EB} = -4$ V, $I_C = 0$)	I_{EBO}	−1 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = -10$ V, $I_C = -0.1$ mA)	h_{FE}	20 to 200	
Gain-Bandwidth Product ($V_{CE} = -4$ V, $I_C = -50$ mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

40407 TRANSISTOR

Si **n-p-n** type used in predriver stages in af-amplifier applications in industrial and commercial equipment. This type is recommended for use in a Darlington circuit with a type such as the 40408. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is electrically identical with type 40406 except for reversal of all polarity signs. For collector-characteristics and transfer-characteristics curves, refer to type 40309.

40408 TRANSISTOR

Si **n-p-n** type used in predriver stages in af-amplifier applications in industrial and commercial equipment. This type is recommended for use in a Darlington circuit with a type such as the 40407. JEDEC TO-5, **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case. For collector-characteristics and transfer-characteristics curves, refer to type 40309.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	90	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Tranistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage ($I_C = 100$ mA, $I_B = 0$)	V_{CEO}(sus)	90 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 150$ mA, $I_B = 15$ mA)	V_{CE}(sat)	1.4 max	V
Base-to-Emitter Voltage ($V_{CE} = 4$ V, $I_C = 10$ mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
$V_{CE} = 80$ V, $I_B = 0$, $T_C = 25$°C	I_{CEO}	1 max	µA
$V_{CE} = 80$ V, $I_B = 0$, $T_C = 150$°C	I_{CEO}	250 max	µA
Emitter-Cutoff Current ($V_{EB} = 4$ V, $I_C = 0$)	I_{EBO}	1 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = 4$ V, $I_C = 10$ mA)	h_{FE}	40 to 200	
Gain-Bandwidth Product ($V_{CE} = 4$ V, $I_C = 50$ mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

POWER TRANSISTOR 40409

Si n-p-n type used in driver stages in af-amplifier applications in industrial and commercial equipment. This type and type 40410 together form a complementary pair of drivers. In a typical class AB circuit a complementary pair can drive two series-connected 40411 transistors to provide an audio output of 70 watts with a total harmonic distortion of less than 0.25 per cent at 1000 cycles per second. JEDEC TO-5 (with heat radiator), **Outline No.3. Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with heat radiator). For collector-characteristics and transfer-characteristics curves, refer to type 40309.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage ($R_{BE} \leqq 10\ \Omega$)	V_{CER}(sus)	90	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	0.7	A
Base Current	I_B	0.2	A
Transistor Dissipation:			
T_A up to 50°C	P_T	3	W
T_A above 50°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS

Collector-to-Emitter Sustaining Voltage ($R_{BE} = 100\ \Omega$, $I_C = 100$ mA)	V_{CER}(sus)	90 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 150$ mA, $I_B = 15$ mA)	V_{CE}(sat)	1.4 max	V
Base-to-Emitter Voltage ($V_{CE} = 4$ V, $I_C = 150$ mA)	V_{BE}	1.1 max	V
Collector-Cutoff Current:			
$V_{CE} = 80$ V, $R_{BE} = 100\ \Omega$, $T_C = 25$°C	I_{CER}	1 max	µA
$V_{CE} = 80$ V, $R_{BE} = 100\ \Omega$, $T_C = 150$°C	I_{CER}	100 max	µA
Emitter-Cutoff Current ($V_{EB} = 4$ V, $I_C = 0$)	I_{EBO}	1 max	µA
Static Forward-Current Transfer Ratio ($V_{CE} = 4$ V, $I_C = 150$ mA)	h_{FE}	50 to 250	
Gain-Bandwidth Product ($V_{CE} = 4$ V, $I_C = 50$ mA)	f_T	100	Mc/s
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	50 max	°C/W

POWER TRANSISTOR 40410

Si p-n-p type used in driver stages in af-amplifier applications in industrial and commercial equipment. This type and type 40409 form a complementary pair of drivers. In a typical class AB circuit a complementary pair can drive two series-connected 40411 transistors to provide an audio output of 70 watts with a total harmonic distortion of less than 0.25 per cent at 1000 cycles per second. JEDEC TO-5 (with heat radiator), **Outline No.3. Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with heat radiator). This type is electrically identical with type 40409 except for the reversal of all polarity signs. For collector-characteristics and input-characteristics curves, refer to type 40319.

POWER TRANSISTOR 40411

Si n-p-n type used in output stages in af-amplifier applications in industrial and commercial equipment. In a typical class AB circuit, two series-connected 40411 transistors driven by a complementary pair of transistors (40409 and 40410) can provide an audio output of 70 watts with a total harmonic distortion of less than 0.25 per cent at 1000 cycles per second. JEDEC TO-3, **Outline No.2. Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

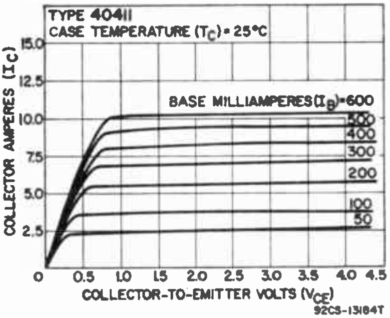
MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage ($R_{BE} \leqq 100\ \Omega$)	V_{CER}(sus)	90	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	30	A
Base Current	I_B	15	A
Transistor Dissipation:			
T_C up to 25°C	P_T	150	W
T_C above 25°C	P_T	See curve page 112	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

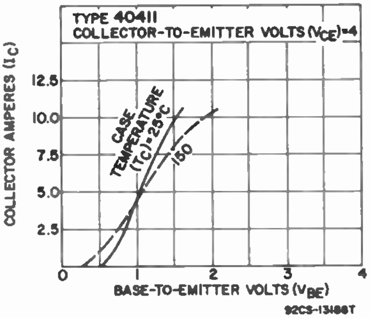
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage ($R_{BE} = 100\ \Omega$, $I_C = 200$ mA)	V_{CER}(sus)	90 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 4$ A, $I_B = 400$ mA)	V_{CE}(sat)	1 max	V
Base-to-Emitter Voltage ($V_{CE} = 4$ V, $I_C = 4$ A)	V_{BE}	1.8 max	V
Collector-Cutoff Current:			
$V_{CE} = 80$ V, $R_{BE} = 100\ \Omega$, $T_C = 25$°C	I_{CER}	0.5 max	mA
$V_{CE} = 80$ V, $R_{BE} = 100\ \Omega$, $T_C = 150$°C	I_{CER}	2 max	mA
Emitter-Cutoff Current ($V_{EB} = 4$ V, $I_C = 0$)	I_{EBO}	5 max	mA
Static Forward-Current Transfer Ratio ($V_{CE} = 4$ V, $I_C = 4$ A)	h_{FE}	35 to 100	
Gain-Bandwidth Product ($V_{CE} = 4$ V, $I_C = 4$ A)	f_T	800	kc/s
Power-Rating Test (40 V at 5 A for 1 s max)		200	W
Thermal Resistance, Junction-to-Case	Θ_{J-C}	1.17 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



LIST OF DISCONTINUED TRANSISTORS

(Shown for reference only; see page 113 for symbol identification.)

RCA Type	Material	Out-line	MAXIMUM RATINGS				CHARACTER-ISTICS		Maximum Operating Tempera-ture (°C)	Can be replaced by RCA type
			V_{CB} (volts)	V_{EB} (volts)	I_C (amperes)	P_T (watts)	Min. h_{FE}	I_{CB} (µA)		
2N105	Ge	*	−25	—	−0.015	0.035	55	−5	55	2N408
2N206	Ge	1	−30	—	−0.050	0.075	33	−10	85	2N408
2N247	Ge	4	−35	—	−0.010	0.080	60	−10	71	2N1180
2N269	Ge	1	−25	−12	−0.100	0.120	24	−5	85	2N404
2N301	Ge	2	−40	−10	−3	11	70	−100	91	2N2869/2N301
2N301A	Ge	2	−60	−10	−3	11	70	−100	91	2N2870/2N301A
2N307	Ge	2	−35	—	−1	10	20	−1500	75	2N2869
2N331	Ge	6	−30	−12	−0.200	0.200	50	−16	71	2N1638
2N356	Ge	*	20	20	0.5	0.100	30	5	85	2N647
2N357	Ge	*	20	20	0.5	0.100	30	5	85	2N647
2N358	Ge	*	20	20	0.5	0.100	30	5	85	2N647
2N373	Ge	4	−25	−0.5	−0.010	0.080	60	−8	71	2N1638
2N374	Ge	4	−25	−0.5	−0.010	0.080	60	−8	71	2N1631
2N456	Ge	22	−40	−20	−5	50	52	—	95	2N2869
2N457	Ge	22	−60	−20	−5	50	52	—	95	2N2869
2N497	Si	3	60	8	—	4	12	10	200	—
2N544	Ge	4	−18	−1	−0.010	0.080	60	−4	71	2N217
2N561	Ge	22	−80	−60	−10	50	75	—	100	2N2869
2N578	Ge	6	−20	−12	−0.400	0.120	10	−5	71	2N412
2N579	Ge	6	−20	−12	−0.400	0.120	20	−5	71	2N412
2N580	Ge	6	−20	−12	−0.400	0.120	30	−5	71	2N412
2N583	Ge	1	−18	−10	−0.100	0.120	20	−10	85	2N412
2N584	Ge	1	−25	−12	−0.100	0.120	40	−5	85	2N408
2N640	Ge	4	−34	−1	−0.010	0.080	50	−5	71	2N1637
2N641	Ge	4	−34	−1	−0.010	0.080	50	−7	71	2N1638
2N642	Ge	4	−34	−1	−0.010	0.080	50	−7	71	2N1639
2N643	Ge	6	−30	−2	−0.100	0.120	20	−10	71	
2N644	Ge	6	−30	−2	−0.100	0.100	20	−10	71	
2N645	Ge	6	−30	−2	−0.100	0.120	20	−10	71	
2N656	Si	3	60	8	—	4	30	10	200	—
2N696	Si	3	60	5	−0.500	2	20	1	175	—
2N705	Ge	9	−15	−3.5	−0.05	0.15	25	−3	100	—
2N710	Ge	9	−15	−2	−0.05	0.15	25	−3	100	—
2N711	Ge	9	−12	−1	−0.1	0.15	20	−3	100	—
2N794	Ge	9	−13	−1	−0.100	0.150	30	−3	85	2N1300
2N795	Ge	9	−13	−4	−0.100	0.150	30	−3	85	2N1301
2N796	Ge	9	−13	−4	−0.100	0.150	50	−3	85	2N1683
2N828	Ge	9	−15	−2.5	−0.2	0.3	25	−3	100	—
2N955	Ge	9	12	2	0.1	0.15	30	5	100	—
2N955A	Ge	9	12	2	0.15	0.15	30	5	100	—
2N960	Ge	9	−15	−2.5	−0.1	0.3	20	−3	100	—
2N961	Ge	9	−12	−2	−0.1	0.3	20	−3	100	—

* 1 - emitter, 2 - base, 3 - collector.

LIST OF DISCONTINUED TRANSISTORS (cont'd)

			MAXIMUM RATINGS				CHARACTERISTICS			
RCA Type	Material	Outline	V_{CB} (volts)	V_{EB} (volts)	I_C (amperes)	P_T (watts)	Min. h_{FE}	I_{CB} (μA)	Maximum Operating Temperature (°C)	Can be replaced by RCA type
2N962	Ge	9	—12	—1.25	—0.1	0.3	20	—3	100	—
2N963	Ge	9	—12	—1.25	—0.1	0.3	20	—5	100	—
2N964	Ge	9	—15	—2.5	—0.1	0.3	40	—3	100	—
2N965	Ge	9	—12	—2	—0.1	0.3	40	—3	100	—
2N966	Ge	9	—12	—1.25	—0.1	0.3	40	—3	100	—
2N967	Ge	9	—12	—1.25	—0.1	0.3	40	—5	100	—
2N1014	Ge	22	—100	—60	—10	50	75	—	100	2N2869
2N1067	Si	5	60	12	0.5	5	35	15	175	2N3053
2N1068	Si	5	60	12	1.5	10	38	15	175	2N3262
2N1069	Si	2	60	1.7	4	50	20	25	175	2N1489
2N1070	Si	2	60	9	4	50	20	25	175	2N1702
2N1092	Si	3	60	12	0.5	2	35	15	175	—
2N1169	Ge	3	25	25	0.4	0.12	20	10	71	—
2N1170	Ge	3	40	40	0.4	0.12	20	8	71	—
2N1213	Ge	3	—25	—1	—0.100	0.075	—	—3	85	—
2N1214	Ge	3	—25	—1	—0.100	0.075	—	—3	85	—
2N1215	Ge	3	—25	—1	—0.100	0.075	—	—3	85	—
2N1216	Ge	3	—25	—1	—0.100	0.075	—	—3	85	—
2N1319	Ge	3	—20	—20	—0.4	0.12	15	—6	71	—
2N1425	Ge	4	—24	—0.5	—0.010	0.080	50	—12	71	2N1638
2N1426	Ge	4	—24	—0.5	—0.010	0.080	130	—12	71	2N1638
2N1450	Ge	6	—30	—1	—0.100	0.120	20	—10	85	2N217
2N1511	Si	11	60	60	6	75	15	25	200	2N1487
2N1512	Si	11	100	100	6	75	15	25	200	2N1488
2N1513	Si	11	60	60	6	75	15	25	200	2N1489
2N1514	Si	11	100	100	6	75	15	25	200	2N1490
2N1633	Ge	13	—34	—0.5	—0.010	0.080	75	—16	85	2N1638
2N1634	Ge	1	—34	—0.5	—0.010	0.080	75	—16	85	2N1638
2N1635	Ge	13	—34	—0.5	—0.010	0.080	75	—16	85	2N1638
2N1636	Ge	1	—34	—0.5	—0.010	0.080	75	—16	85	2N1638
2N1768	Si	19	60	12	3	40	35	15	200	2N1485
2N1769	Si	19	100	12	3	40	35	15	200	2N1486
2N2206	Si	16	25	3	0.2	1	40	0.025	175	—
2N2273	Ge	9	—25	—1	—0.1	0.1	20	—10	100	2N1179
2N2339	Si	19	60	40	2.5	40	20	3000	200	2N1701
2N2482	Ge	9	20	3	0.1	0.15	25	5	100	—
2N2873	Ge	1	—35	—0.1	—0.010	0.115	40	12	100	—
2N2898	Si	16	120	7	1	1.8	40	0.002	200	—
2N2899	Si	16	140	7	1	1.8	60	0.01	200	—
2N2900	Si	16	60	7	1	1.8	50	0.05	200	—
3746	Ge	14	—34	—0.5	—0.20	0.080	—	—16	85	—
3907/2N404	Ge	3	—25	—12	—0.2	0.15	30	—5	85	—

Silicon Rectifiers

SILICON rectifiers are essentially cells containing a simple p-n junction. As a result, they have low resistance to current flow in one (forward) direction, but high resistance to current flow in the opposite (reverse) direction. They can be operated at ambient temperatures up to 200 degrees centigrade and at current levels as high as hundreds of amperes, with voltage levels as high as 1000 volts. In addition, they can be used in parallel or series arrangements to provide higher current or voltage capabilities.

Because of their high forward-to-reverse current ratios, silicon rectifiers can achieve rectification efficiencies close to 99 per cent. When properly used, they have excellent life characteristics which are not affected by aging, moisture, or temperature. They are very small and light-weight, and can be made impervious to shock and other severe environmental conditions.

THERMAL CONSIDERATIONS

Although rectifiers can operate at high temperatures, the thermal capacity of a silicon rectifier is quite low, and the junction temperature rises rapidly during high-current operation. Sudden rises in junction temperature caused by either high currents or excessive ambient-temperature conditions can cause failure. (A silicon rectifier is considered to have failed when either the forward voltage drop or the reverse current has increased to a point where the crystal structure or surrounding material breaks down.) Consequently, temperature effects are very important in the consideration of silicon rectifier characteristics.

REVERSE CHARACTERISTICS

When a reverse-bias voltage is applied to a silicon rectifier, a limited amount of reverse current (usually measured in microamperes, as compared to milliamperes or amperes of forward current) begins to flow. As shown in Fig. 158, this reverse current flow increases slightly as the bias voltage increases, but then tends to remain constant even though the voltage continues to increase significantly. However, an increase in operating temperature increases the reverse current considerably for a given reverse bias.

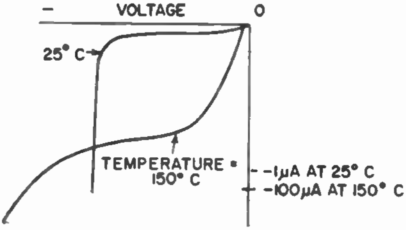


Figure 158. Typical reverse characteristics.

At a specific reverse voltage (which varies for different types of diodes), a very sharp increase in reverse current occurs. This voltage is called the breakdown or avalanche (or zener) voltage. In many applications, rectifiers can operate safely at the avalanche point. If the reverse voltage is increased beyond this point, however, or if the ambient temperature is raised sufficiently (for example, a rise from 25 to 150 degrees centigrade increases the current by a factor of several hundred), "thermal runaway" results and the diode may be destroyed.

FORWARD CHARACTERISTICS

A silicon rectifier usually requires a forward voltage of 0.4 to 0.8 volt (depending upon the temperature and the impurity concentration in the p-type and n-type materials) before significant current flow occurs. As shown in Fig. 159, a slight rise in voltage beyond this point increases the forward current sharply. Because of the small mass of the silicon rectifier, the forward voltage drop must be carefully controlled so that the specified maximum value of dissipation for the device is not exceeded. Otherwise, the diode may be seriously damaged or destroyed.

Fig. 159 shows the effects of an increase in temperature on the forward-current characteristic of a silicon rectifier. In certain applications, close control of ambient temperature is required for satisfactory operation. Close control is not usually required, however, in power circuits.

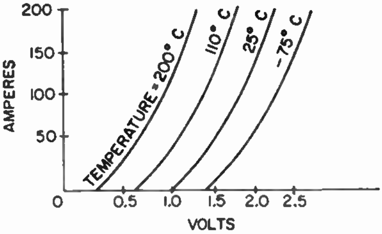


Figure 159. Typical forward characteristics.

RATINGS

Ratings for silicon rectifiers are determined by the manufacturer on the basis of extensive reliability testing. One of the most important ratings is the maximum peak reverse voltage (PRV), i.e., the highest amount of reverse voltage which can be applied to a specific rectifier before the avalanche breakdown point is reached. PRV ratings range from about 50 volts to as high as 1000 volts for some single-junction diodes. As will be discussed later, several junction diodes can be connected in series to obtain the PRV values required for very-high-voltage power-supply applications.

Because the current through a rectifier is normally not dc, current ratings are usually given in terms of average, rms, and peak values. The waveshapes shown in Figs. 160 and 161 help to illustrate the relationships among these ratings. For example, Fig. 160 shows the current variation with time of a sine wave that has a peak current I_{peak} of 10 amperes. The area under the curve can be translated mathematically into an equivalent rectangle that indicates the average value I_{av} of the sine wave. The relationship between the average and peak values of the total sine-wave current is then given by

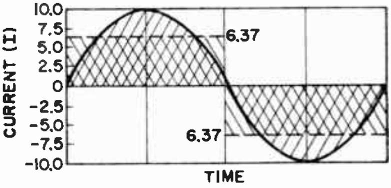


Figure 160. Variation of current of a sine wave with time.

$$I_{av} = 0.637\ I_{peak}$$

or

$$I_{peak} = 1.57\ I_{av}$$

However, the power P consumed by a device (and thus the heat generated within it) is equal to the square of the current through it times its finite electrical resistance R (i.e., $P = I^2R$). Therefore, the power is proportional to the square of the current rather than to the peak or average value. Fig. 161 shows the square of the current for the sine wave of Fig. 160. A horizontal line drawn through a point halfway up the I^2 curve indicates the average (or mean) of the squares, and the square root of the I^2 value

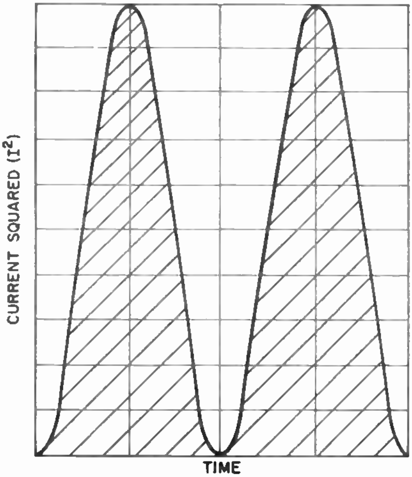


Figure 161. Variation of the square of sine-wave current with time.

at this point is the root-mean-square (rms) value of the current. The relationship between rms and peak current is given by

$$I_{rms} = 0.707\ I_{peak}$$

or

$$I_{peak} = 1.414\ I_{rms}$$

Because a single rectifier cell passes current in one direction only, it conducts for only half of each cycle of an ac sine wave. Therefore, the second half of the curves in Figs. 160 and 161 is eliminated. The average current I_{av} then becomes half of the value determined for full-cycle conduction, and the rms current I_{rms} is equal to the square root of half the mean-square value for full-cycle conduction. In terms of half-cycle sine-wave conduction (as in a single-phase half-wave circuit), the relationships of the rectifier currents can be shown as follows:

$$\begin{aligned} I_{peak} &= \pi \times I_{av} = 3.14\ I_{av} \\ I_{av} &= (1/\pi)\ I_{peak} = 0.32\ I_{peak} \\ I_{rms} &= (\pi/2)\ I_{av} = 1.57\ I_{av} \\ I_{av} &= (2/\pi)\ I_{rms} = 0.64\ I_{rms} \\ I_{peak} &= 2\ I_{rms} \\ I_{rms} &= 0.5\ I_{peak} \end{aligned}$$

For different combinations of rectifier cells and different circuit configurations, these relationships are, of course, changed again. Current (and voltage) relationships have been derived for various types of rectifier applications and are given in Table I later in this section.

Published data for silicon rectifiers usually include maximum ratings for both average and peak forward current. As shown in Fig. 162, the **maximum average forward current** is the maximum average value of current which is allowed to flow in the forward direction during a full ac cycle at a specified ambient or case temperature. Typical average current outputs range from 0.5 ampere to as high as 100 amperes for single silicon diodes. The **peak recurrent forward current** is the maximum repetitive instantaneous forward current permitted under stated conditions.

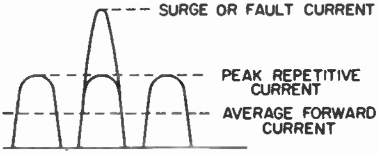


Figure 162. Representation of rectifier currents.

In addition, ratings are usually given for non-repetitive **surge,** or **fault,** current. In rectifier applications, conditions may develop which cause momentary currents that are considerably higher than normal operating current. These increases (current surges) may occur from time to time during normal circuit operation as a result of normal load variations, or they may be caused by abnormal conditions or faults in the circuit. Although a rectifier can usually absorb a limited amount of additional heat without any effects other than a momentary rise in junction temperature, a sufficiently high surge can drive the junction temperature high enough to destroy the rectifier. Surge ratings indicate the amount of current overload or surge that the rectifier can withstand without detrimental effects.

Fig. 163 shows universal surge

rating charts for families of rectifiers having average current ratings up to 40 amperes. The rms currents shown in these charts are incremental values which add to the normal rms forward current during surge periods. The charts indicate maximum current increments that can be safely handled by the rectifiers for given lengths of time. These charts can be used by designers to determine whether circuit modifications are necessary to protect the rectifiers. If the value and duration of expected current surges are greater than the ratings for the rectifier, impedance should be added to capacitive-load circuits or fuses or circuit breakers to variable-load circuits for surge protection.

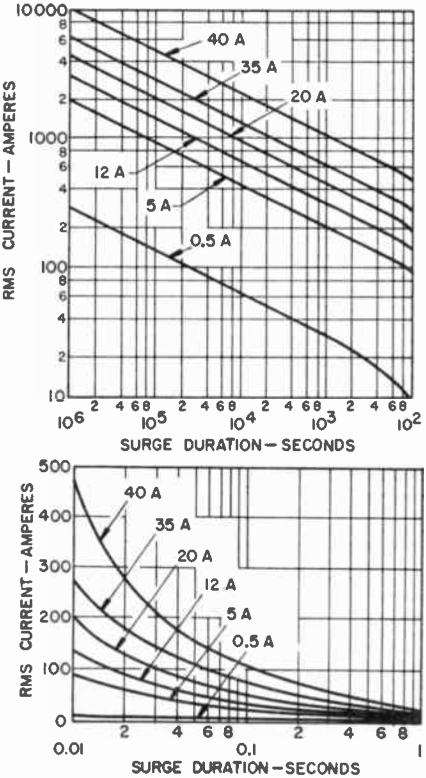


Figure 163. Universal surge rating charts for RCA rectifiers.

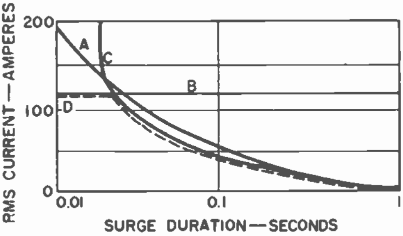


Figure 164. Typical coordination chart for determining fusing requirements (A - surge-rating chart for 20-ampere rectifier, B - expected surge current in half-wave circuit, C - opening characteristics of protective device, D - resulting surge current in modified circuit).

The fusing requirements for a given circuit can be determined by use of a coordination chart such as that shown in Fig. 164. Two characteristics are plotted on the coordination chart initially: (A) the surge rating curve for the rectifier, and (B) the maximum surge (fault current) expected in the circuit. In Fig. 164, curve A is the surge rating curve for a 20-ampere rectifier, and curve B is the maximum surge expected to occur in a single-phase half-wave rectifier circuit that has an input voltage of 600 volts and is subject to overload conditions in which the load resistance can decrease to 2 ohms. The maximum rms current which can flow under these conditions is given by

$$I_{rms} = E_{in}/2R_L = 600/4$$
$$= 150 \text{ amperes}$$

The incremental portion of this current is determined by subtracting the normal rms current of the 20-ampere rectifier ($I_{rms} = 1.57\ I_{av} = 1.57 \times 20 = 31.4$ amperes; $I_{surge} = 150 - 31.4 = 118.6$ amperes). The straight line of curve B is then drawn at an rms value of 118.6 amperes in Fig. 164.

The intersection of curves A and B indicates that the 20-ampere rectifier can safely support an incremental rms surge current of 118.6 amperes for a maximum duration of about 40 milliseconds. Therefore, the circuit must be modified to include a protective element that has an "opening" characteristic that falls below the rectifier surge rating curve for all times greater than 40 milliseconds. The opening characteristic of such a protective element is shown in Fig. 164 as curve C. Surge current in the modified circuit is then limited by the circuit resistance for periods up to 40 milliseconds and by the protective element for surges of longer duration, as shown by curve D.

Surge currents generally occur when the equipment is first turned on, or when unusual voltage transients are introduced in the ac supply line. Protection against excessive currents of this type can be provided in various ways, as will be discussed later.

Because these maximum current ratings are all affected by thermal variations, ambient-temperature conditions must be considered in the application of silicon rectifiers. Temperature-rating charts are usually provided to show the percentage by which maximum currents must be decreased for operation at temperatures higher than normal room temperature (25 degrees centigrade).

OVERLOAD PROTECTION

In the application of silicon rectifiers, it is necessary to guard against both over-voltage and over-current (surge) conditions. A voltage surge in a rectifier arrangement can be caused by dc switching, reverse recovery transients, transformer switching, inductive-load switching, and various other causes. The effects of such surges can be reduced by the use of a capacitor connected across the input or the output of the rectifier. In addition, the magnitude of the voltage surge can be reduced by changes in the switching elements or the sequence of switching, or by a reduction in the speed of current interruption by the switching elements.

In all applications, a rectifier having a more-than-adequate peak reverse voltage rating should be used. The safety margin for reverse voltage usually depends on the application. For a single-phase half-wave application using switching of the transformer primary and having no transient suppression, a rectifier having a peak reverse voltage three or four times the expected working voltage should be used. For a full-wave bridge using load switching and having adequate suppression of transients, a margin of 1.5 to 1 is generally acceptable.

Because of the small size of the silicon rectifier, excessive surge currents are particularly harmful to rectifier operation. Current surges may be caused by short circuits, capacitor inrush, dc overload, or failure of a single cell in a multiple arrangement. In the case of low-power cells, fuses or circuit breakers are often placed in the ac input circuit to the rectifier to interrupt the fault current before it damages the rectifier. When circuit requirements are such that service must be continued in case of failure of an individual diode, a number of cells can be used in parallel, each with its own fuse. Additional fuses should be used in the ac line and in series with the load for protection against dc load faults. In high-power cells, an arrangement of circuit breakers, fuses, and series resistances is often used to reduce the amplitude of the surge current. Fusing requirements can be determined by use of coordination charts for the particular circuits and rectifiers used.

SERIES AND PARALLEL ARRANGEMENTS

Silicon rectifiers can be arranged in series or in parallel to provide higher voltage or current capabilities, respectively, as required for specific applications.

A parallel arrangement of rectifiers can be used when the maximum average forward current required is larger than the maximum current rating of an individual rectifier cell. In such arrangements, however, some means must be provided to assure proper division of current through the parallel rectifier cells. Parallel rectifier arrangements are not in general use. Designers normally use a polyphase arrangement to provide higher currents, or simply substitute the readily available higher-current rectifier types.

Series arrangements of silicon rectifiers are used when the applied reverse voltage is expected to be greater than the maximum peak reverse voltage rating of a single silicon rectifier (or cell). For example, four rectifiers having a maximum reverse voltage rating of 200 volts each could be connected in series to handle an applied reverse voltage of 800 volts.

In a series arrangement, the most important consideration is that the applied voltage be divided equally across the individual rectifiers. If the instantaneous voltage is not uniformly divided, one of the rectifiers may be subjected to a voltage greater than its specified maximum reverse voltage, and, as a result, may be destroyed. Uniform voltage division can usually be assured by connection of either resistors or capacitors in parallel with individual cells. Shunt resistors are used in steady-state applications, and shunt capacitors in applications in which transient voltages are expected. Both resistors and capacitors should be used if the circuit is to be exposed to both dc and ac components. When only a few diodes are in series, multiple transformer windings may be used, each winding supplying its own assembly consisting of one series diode. The outputs of the diodes are then connected in series for the desired voltage.

RCA rectifier stacks (CR101, CR201, and CR301 series) are designed to provide equal reverse voltage across the individual rectifier cells in the assembly under both steady-state and transient conditions. The CR101 and CR301 series stacks include an integral resistance-capacitance network to equalize the reverse voltage across the series-connected rectifier cells. The CR201 series stacks use precisely matched rectifier cells for internal voltage equalization. Extended life tests have shown that these rectifier stacks are capable of operating for many thousands of hours without noticeable degradation of performance.

CIRCUIT FACTORS

The current and voltage relationships for silicon rectifiers vary for different types of circuit configurations. The particular circuit in which a rectifier is used is chosen on the basis of the requirements for a specific application.

Silicon rectifiers are used in a continually broadening range of applications. Originally developed for use in such equipment as dc-to-dc converters, battery chargers, mobile power supplies, transmitters, and electroplating devices, silicon rectifiers are also used in power supplies for radio and television receivers and phonograph amplifiers, as well as in such applications as in-line-type modulators, hold-off and charging diodes, pulse-forming networks, and brushless alternators. They are also being used in many aircraft applications because of their small size, light weight, and high efficiency.

The most suitable type of rectifier circuit for a particular application depends on the dc voltage and current requirements, the amount of rectifier "ripple" (undesired fluctuation in the dc output caused by an ac component) that can be tolerated in the circuit, and the type of ac power available. Figs. 165 through 171 show seven basic rectifier configurations. (Filters used to smooth the rectifier output are not shown for each circuit, but are discussed later.) Figs. 165 through 171 also include the output-voltage waveforms for the various circuits and the current waveforms for each individual rectifier cell in the circuits. Ideally, the voltage waveform should be as flat as possible (i.e., approaching almost pure dc). A flat curve indicates a peak-to-average voltage ratio of one. In the case of the current waveform, the smaller the current flowing through the individual rectifier, the less chance there is for malfunction or burnout of the cell.

The **half-wave single-phase** circuit shown in Fig. 165 delivers only one pulse of current for each cycle of ac input voltage. As shown by the current waveform, the single rectifier cell is exposed to the entire current flow. This type of circuit, which contains a very high percentage of output ripple, is used principally in low-voltage high-current applications and in low-current high-voltage applications.

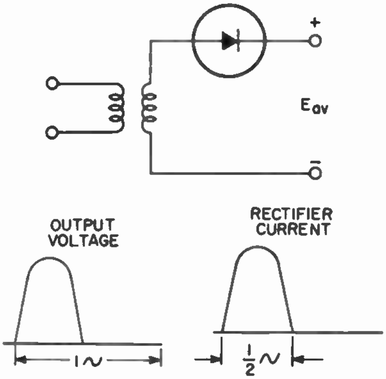


Figure 165. Single-phrase half-wave circuit.

Fig. 166 shows a **single-phase full-wave** circuit with a center-tapped high-voltage winding. This circuit has a lower peak-to-average voltage ratio than the circuit of Fig. 165, and about 50 per cent less ripple. This type of circuit is widely used in television receivers and large audio amplifiers.

The **single-phase full-wave bridge** circuit shown in Fig. 167 uses four rectifiers, and does not require the use of a transformer center-tap. It can be used to supply twice as much output voltage as the circuit of Fig. 166 for the same transformer voltage, or to expose the individual rectifier cell to only half as much peak reverse voltage and allow only 50 per cent of the total current to flow through each cell. This type of circuit is popular in amateur transmitter use.

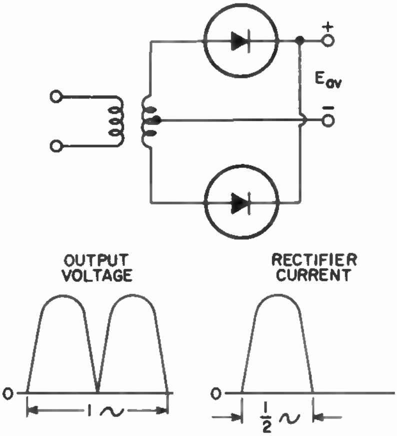


Figure 166. Single-phase full-wave circuit with center-tap.

The three-phase circuits shown in Figs. 168 through 171 are usually found in heavy industrial equipment such as high-power transmitters. The **three-phase (Y) half-wave** circuit

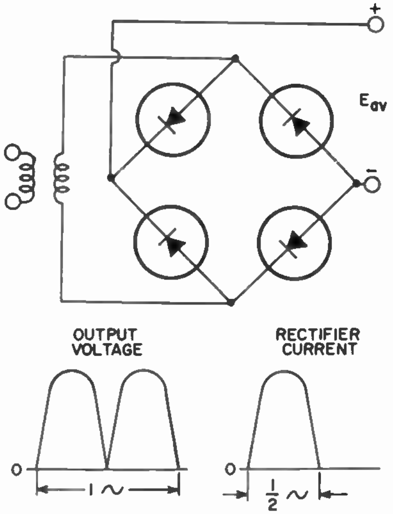


Figure 167. Single-phase full-wave circuit without center-tap.

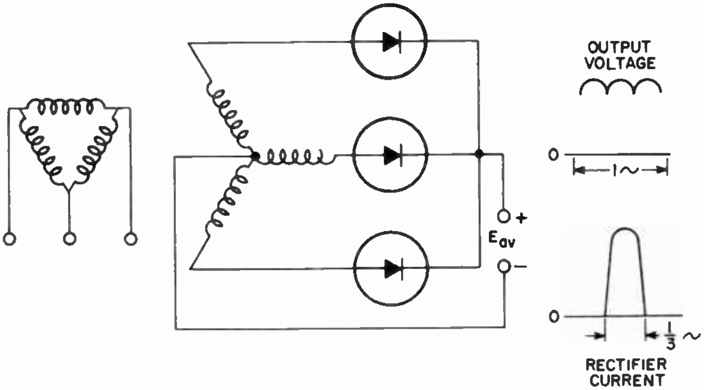


Figure 168. Three-phase (Y) half-wave circuit.

shown in Fig. 168 uses three rectifier cells. This circuit has considerably less ripple than the circuits discussed above. In addition, it allows only one-third of the total current to flow through each rectifier cell. This type of circuit is used in alternator rectifiers in automobiles.

Fig. 169 shows a three-phase (Y) **full-wave bridge** circuit which uses a total of six rectifier cells. In this arrangement, two half-wave rectifiers are connected in series across each leg of a high-voltage transformer. This circuit delivers twice as much voltage output as the circuit of Fig. 168 for the same transformer conditions. In addition, this circuit, as well as those shown in Figs. 170 and 171, has an extremely small percentage of ripple.

The six-phase "star" circuit shown in Fig. 170, which also uses six rectifier cells, allows the least amount of the total current (one-sixth) to flow through each cell. The three-phase **double-Y and interphase transformer** circuit shown in Fig. 171 uses six half-wave rectifiers in parallel. This arrangement delivers six current pulses per cycle and twice as much output current as the circuit shown in Fig. 168.

Table I lists voltage and current ratios for the circuits shown in Figs. 165 through 171 for resistive or inductive loads. These ratios apply for sinusoidal ac input voltages. It is

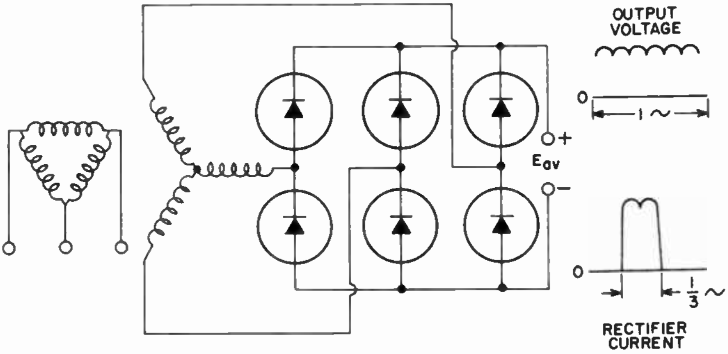


Figure 169. Three-phase (Y) full-wave bridge circuit.

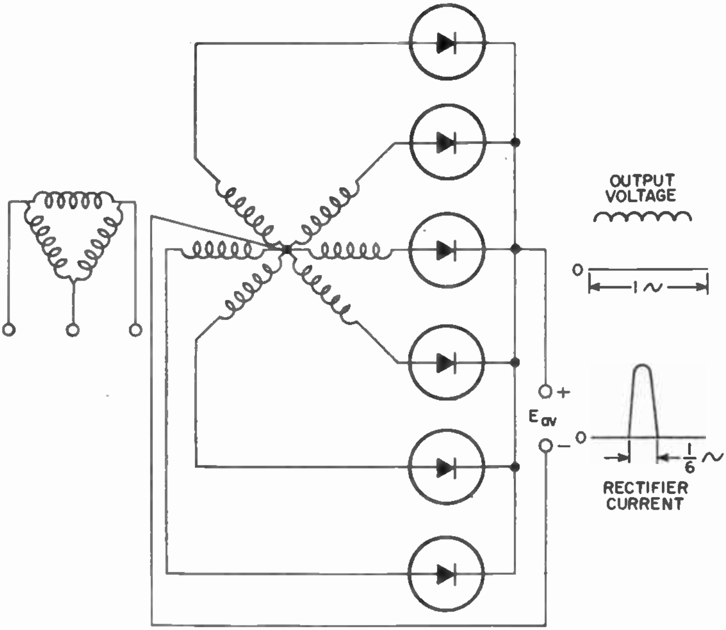


Figure 170. Six-phase "star" circuit.

generally recommended that inductive loads rather than resistive loads be used for filtering of rectifier current, except for the circuit of Fig. 165. Current ratios given for inductive loads apply only when a filter

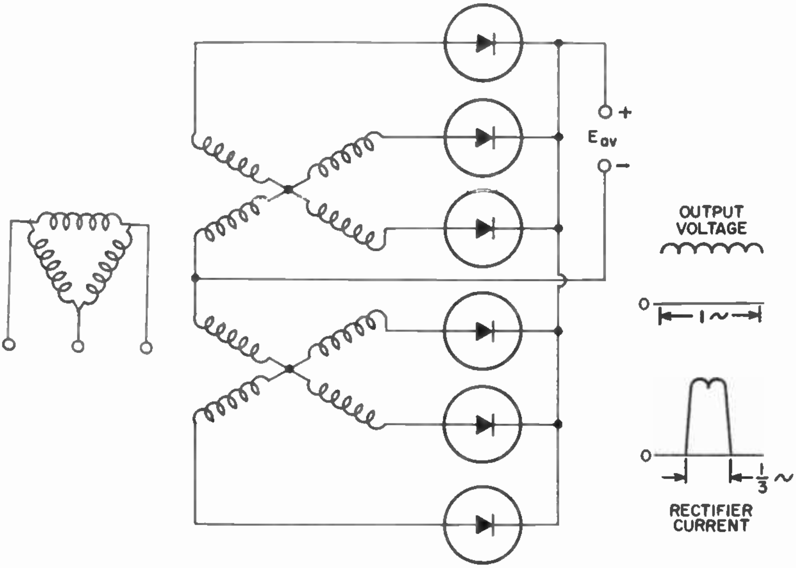


Figure 171. Three-phase double-Y and interphase transformer circuit.

CIRCUIT RATIOS	Fig. 165	Fig. 166	Fig. 167	Fig. 168	Fig. 169	Fig. 170	Fig. 171
Output Voltage:							
Average	E_{av}	E_{av}	E_{av}	E_{av}	E_{av}	E_{av}	E_{av}
Peak (x E_{av})	3.14	1.57	1.57	1.21	1.05	1.05	1.05
RMS (x E_{av})	1.57	1.11	1.11	1.02	1.00	1.00	1.00
Ripple (%)	121	48	48	18.3	4.3	4.3	4.3
Input Voltage (RMS):							
Phase (x E_{av})	2.22	1.11*	1.11	0.855•	0.428•	0.74•	0.855•
Line-to-Line (x E_{av})	2.22	2.22	1.11	1.48	0.74	1.48†	1.71‡
Average Output (Load) Current	I_{av}	I_{av}	I_{av}	I_{av}	I_{av}	I_{av}	I_{av}
RECTIFIER CELL RATIOS							
Forward Current:							
Average (x I_{av})	1.00	0.5	0.5	0.333	0.333	0.167	0.167
RMS (x I_{av}):							
resistive load	1.57	0.785	0.785	0.587	0.579	0.409	0.293
inductive load	—	0.707	0.707	0.578	0.578	0.408	0.289
Peak (x I_{av}):							
resistive load	3.14	1.57	1.57	1.21	1.05	1.05	0.525
inductive load	—	1.00	1.00	1.00	1.00	1.00	0.500
Ratio peak to average:							
resistive load	3.14	3.14	3.14	3.63	3.15	6.30	3.15
inductive load	—	2.00	2.00	3.00	3.00	6.00	3.00
Peak Reverse Voltage:							
x E_{av}	3.14	3.14	1.57	2.09	1.05	2.42	2.09
x E_{rms}	1.41	2.82	1.41	2.45	2.45	2.83	2.45

* to center tap • to neutral † maximum value ‡ maximum value, no load

Table 1—Voltage and current ratios for rectifier circuits shown in Figs. 165 through 171. Fig. 165 uses a resistive load, and Figs. 166 through 171 an inductive load.

choke is used between the output of the rectifier and any capacitor in the filter circuit. Values shown do not take into consideration voltage drops which occur in the power transformer, the silicon rectifiers, or the filter components under load conditions. When a particular rectifier type has been selected for use in a specific circuit, Table I can be used to determine the parameters and characteristics of the circuit.

In Table I, all ratios are shown as functions of either the average output voltage E_{av} or the average dc output current I_{av}, both of which are expressed as unity for each circuit. In practical applications, the magnitudes of these average values will, of course, vary for the different circuit configurations.

Filter circuits are generally used to smooth out the ac ripple in the output of a rectifier circuit. A smoothing filter usually consists of capacitors and iron-core chokes. In any filter-design problem, the load impedance must be considered as an integral part of the filter because the load is an important factor in filter performance. Smoothing effect is obtained from the chokes because they are in series with the load and offer a high impedance to the ripple voltage. Smoothing effect is obtained from the capacitors because they are in parallel with the load and store energy on the voltage peaks; this energy is released on the voltage dips and serves to maintain the voltage at the load substantially constant. Smoothing filters are classified as **choke-input** or **capacitor-input** according to whether a choke or capacitor is placed next to the rectifier. Typical filter circuits are shown in Fig. 172.

If an input capacitor is used, con-

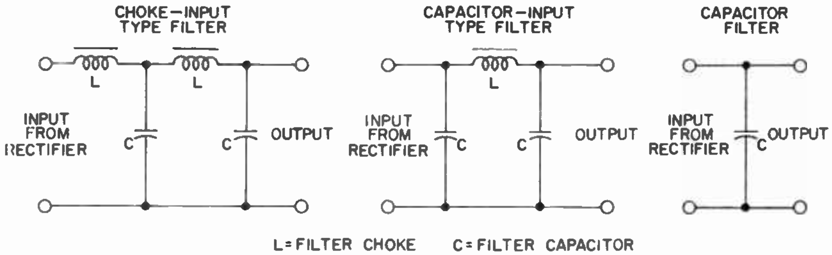


Figure 172. Typical filter circuits.

sideration must be given to the instantaneous peak value of the ac input voltage. This peak value is about 1.4 times the rms value as measured by an ac voltmeter. Filter capacitors, therefore, especially the input capacitor, should have a rating high enough to withstand the instantaneous peak value if breakdown is to be avoided. When the input-choke method is used, the available dc output voltage will be somewhat lower than with the input-capacitor method for a given ac voltage. However, improved regulation together with lower peak current will be obtained.

CAPACITIVE-LOAD CIRCUITS

When rectifiers are used in circuits with capacitive loads, the rectifier current waveforms may deviate considerably from their true sinusoidal shape. This deviation is most evident for the peak-to-average-current ratio, which is somewhat higher than that for a resistive load. For this reason, capacitive-rating calculations are generally more complicated and time-consuming than those for resistive-load rectifier circuits. However, the simplified rating system described below allows the designer to calculate the characteristics of capacitive-load rectifier circuits quickly and accurately.

Fig. 173 shows typical half-wave and voltage-doubling rectifier circuits that use capacitive loads. In such circuits, the low forward voltage drop of the silicon rectifiers may result in a very high surge of current when the capacitive load is first energized. Although the generator or source impedance may be high enough to protect the rectifier, additional resistance must be added in some cases. The sum of this resistance plus the source resistance is referred to as the total limiting resistance R_s. The magnitude of R_s required for protection of the rectifier may be calculated from surge rating charts such as those shown in Figs. 163 and 164. Each point of these curves defines a surge rating by indicating the maximum time for which the device can safely carry a specific value of rms current.

With a capacitive load, maximum surge current occurs if the circuit is switched on when the input voltage is near its peak value. When the time

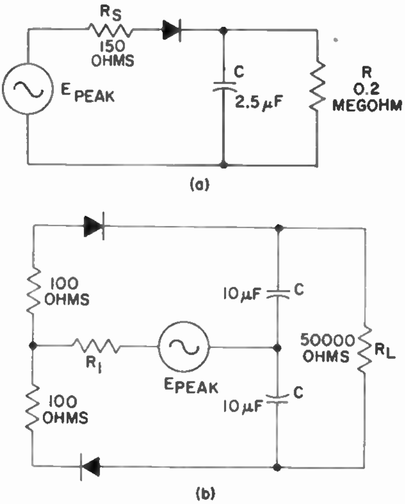


Figure 173. Typical circuits using capacitive loads; (a) half-wave rectifier circuit, (b) voltage-doubling rectifier circuit.

constant R_sC of the surge loop is much smaller than the period of the input voltage, the peak current I_{peak} is equal to the peak voltage E_{peak} divided by the limiting resistance R_s, and the resulting surge approximates an exponentially decaying current with the time constant R_sC.

Surge-current ratings for rectifiers are often given in terms of the rms value of the surge current and the time duration t of the surge. For rating purposes, the surge duration t is defined by the time constant R_sC. The rms surge current I_{rms} is then approximated by the following equations:

$$I_{rms} = 0.7\ (E_{peak}C/R_sC)$$
$$= 0.7\ (E_{peak}C/t)$$

and

$$I_{rms}\ t = 0.7\ E_{peak}\ C$$

where E_{peak} and C are the values specified by the circuit design. This equation may then be plotted on the surge-rating chart, which has axes labeled I_{rms} and t. Because R_sC is equal to t, any given value of R_s defines a specific time t, and hence a specific point on the plot of the equation for I_{rms} t. However, R_s must be large enough to make this point fall below the rating curve for the rectifier used.

The following example illustrates the use of this simplified procedure for the half-wave rectifier circuit shown in Fig. 173a, which has a frequency f of 60 cycles per second and a peak input voltage E_{peak} of 4950 volts. The values shown for E_{peak} and C are substituted in the equation for I_{rms} t as follows:

$$I_{rms}\ t = 0.7\ (4950)\ (2.5 \times 10^{-6})$$
$$= 0.0086$$

When this value is plotted on the surge-rating chart of Fig. 174, the resulting line intersects the rectifier rating curve at 3.3×10^{-4} second. The minimum limiting resistance which affords adequate surge protection is then calculated as follows:

$$R_sC \geq 3.3 \times 10^{-4}$$

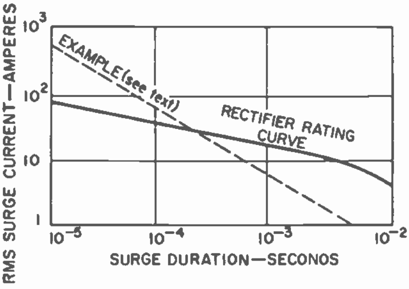


Figure 174. Surge rating chart for stack rectifier CR210.

$$R_s \geq \frac{3.3 \times 10^{-4}}{2.5 \times 10^{-6}} = 132 \text{ ohms}$$

Therefore the value of 150 ohms shown for R_s in Fig. 173a provides adequate surge-current protection for the rectifier.

The design of rectifier circuits having capacitive loads often requires the determination of rectifier current waveforms in terms of average, rms, and peak currents. These waveforms are needed for calculation of circuit parameters, selection of components, and matching of circuit parameters with rectifier ratings. Although actual calculation of rectifier current is a rather lengthy process, the current-relationship charts shown in Figs. 175 and 176 can be used to determine peak or rms current if the average current is known, or vice versa.

The ratios of peak-to-average current (I_{peak}/I_{av}) and rms-to-average current (I_{rms}/I_{av}) are shown in Fig. 175 as functions of the circuit constants $n\omega CR_L$ and R_s/nR_L. The quantity ωCR_L is the ratio of resistive-to-capacitive reactance in the load, and the quantity R_s/R_L is the ratio of the limiting resistance to the load resistance. The factor n, referred to as the "charge factor", is simply a multiplier which allows the chart to be used for various circuit configurations. The value of n is equal to unity for half-wave circuits, to 0.5 for doubler circuits, and to 2 for full-wave circuits. (These values actually represent the relative quantity of charge delivered to the capacitor

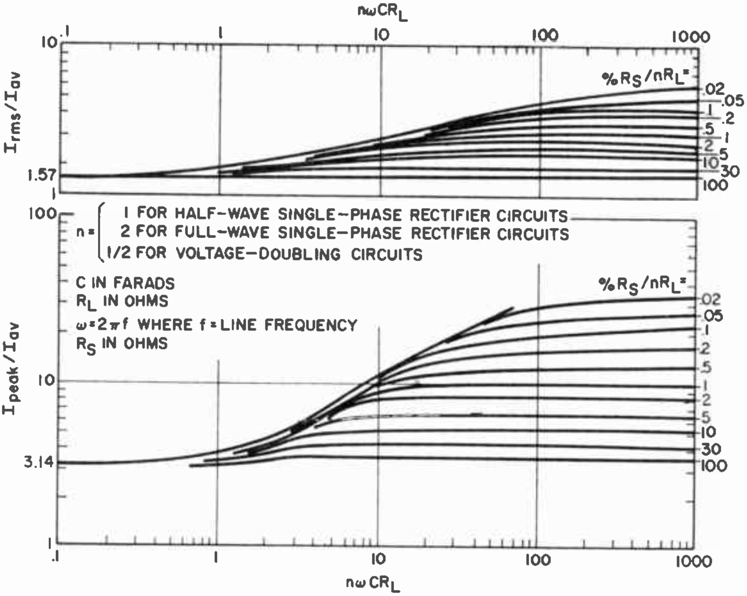


Figure 175. Relationship of peak, average, and rms rectifier currents in capacitor-input circuits.

on each cycle.)

In many silicon rectifier circuits, R_s may be neglected when compared with the magnitude of R_L. In such circuits, the calculation of rectifier currents is simplified by use of Fig. 176, which gives current ratios under the limitation that R_s/R_L approaches zero. Even if this condition is not fully satisfied, the use of Fig. 176 merely indicates a higher peak and higher rms current than will actually flow in the circuit, i.e., the rectifiers will operate more conservatively than calculated. As a result, this simplified solution can be used whenever a rough approximation or a quick check is needed

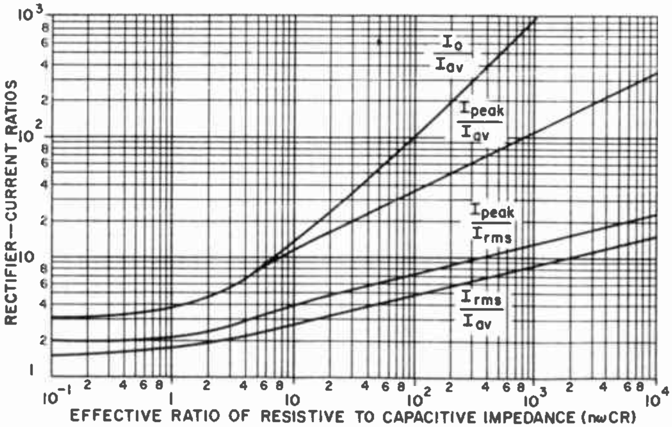


Figure 176. Forward-current ratics for rectifiers in capacitor-input circuits in which R_s is much less than 1/ C.

on whether a particular rectifier will fit a specific application. When more exact information is needed, the chart of Fig. 175 should be used.

Average output voltage E_{av} is another important quantity in capacitor-input rectifier circuits because it can be used to determine average output current I_{av}. The relationships between input and output voltages for half-wave, voltage-doubler, and full-wave circuits are shown in Figs. 177, 178, and 179, respectively. Fig. 180 shows curves of output ripple voltage (as a percentage of E_{av}) for all three types of circuits.

The following example illustrates the use of these curves in rectifier-current calculations. Both exact and approximate solutions are given. For the half-wave circuit of Fig. 173a, the resistive-to-capacitive reactance ωCR_L is given by

$$\omega CR_L = 2\pi \times 60 \times 2.5 \times 10^{-6} \times 200{,}000 = 189$$

For an exact solution using Fig. 175, the ratio of R_s to R_L is first calculated as follows:

$$\frac{R_s}{R_L} = \frac{150}{200{,}000} = 0.075$$

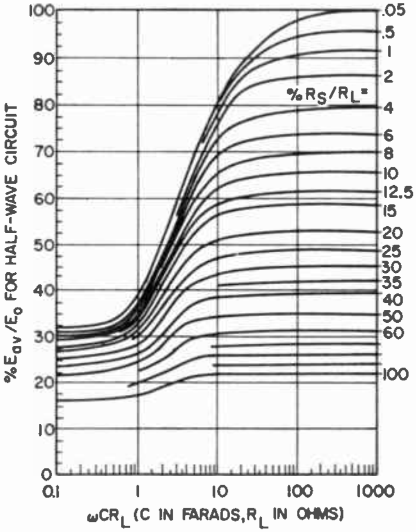


Figure 177. Relationship of applied ac peak voltage to dc output voltage in half-wave capacitor-input circuit.

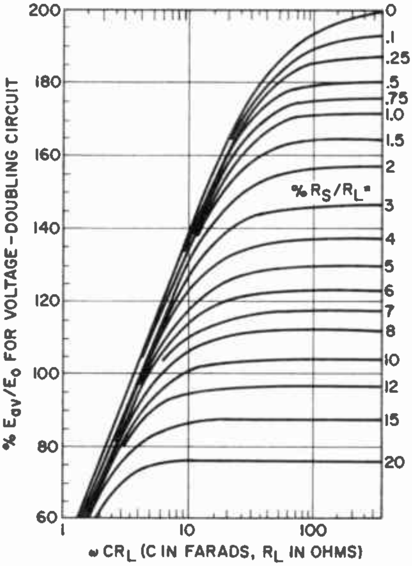


Figure 178. Relationship of applied ac peak voltage to dc output voltage in capacitor-input voltage-doubler circuit.

The values for ωCR_L and R_s/R_L are then plotted in Fig. 177 to determine the average output voltage E_{av} and the average output current I_{av} as follows:

$E_{av}/E_{peak} = 98$ per cent
$E_{av} = 0.98 \times 4950 = 4850$ volts
$I_{av} = E_{av}/R_L$
$I_{av} = 4850$ volts/200,000 ohms $= 24.2$ milliamperes

This value of I_{av} is then substituted in the ratio of I_{rms}/I_{av} obtained from Fig. 175, and the exact value of rms current I_{rms} in the rectifier is determined as follows:

$I_{rms}/I_{av} = 4.4$
$I_{rms} = 4.4 \times 24.2 = 107$ milliamperes.

For a simplified solution using Fig. 176, it is assumed that the average output current I_{av} is approximately equal to the peak input voltage E_{peak} divided by the load resistance R_L, as follows:

$I_{av} = E_{peak}/R_L$
$I_{av} = 4950/200{,}000$
$= 24.7$ milliamperes

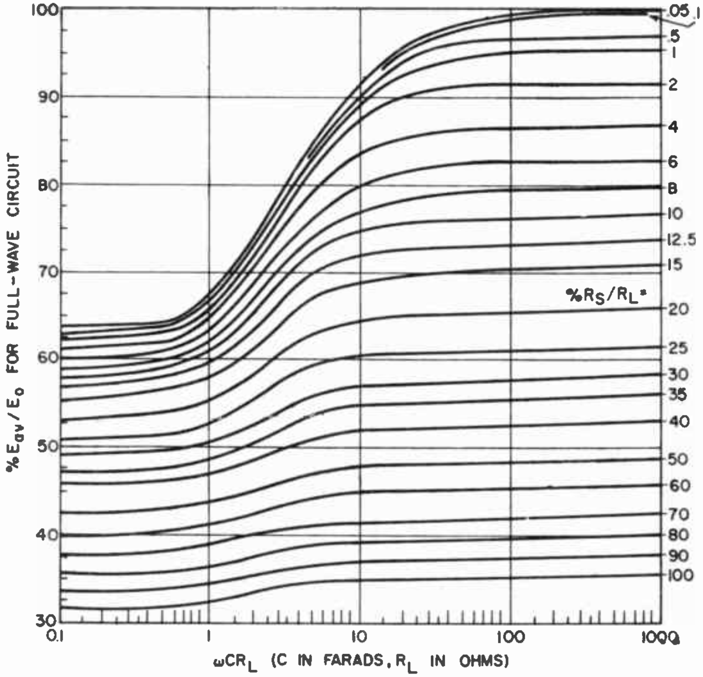


Figure 179. Relationship of applied ac peak voltage to dc output voltage in full-wave capacitor-input circuit.

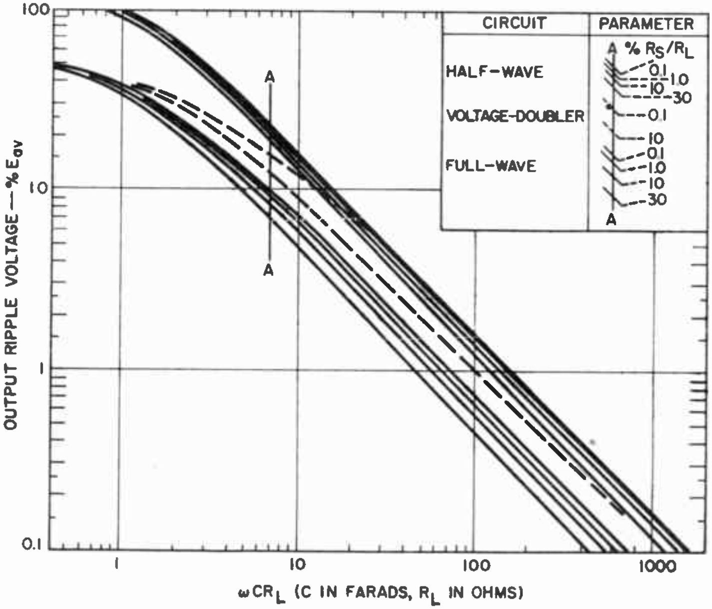


Figure 180. RMS ripple voltage in capacitor-input circuit.

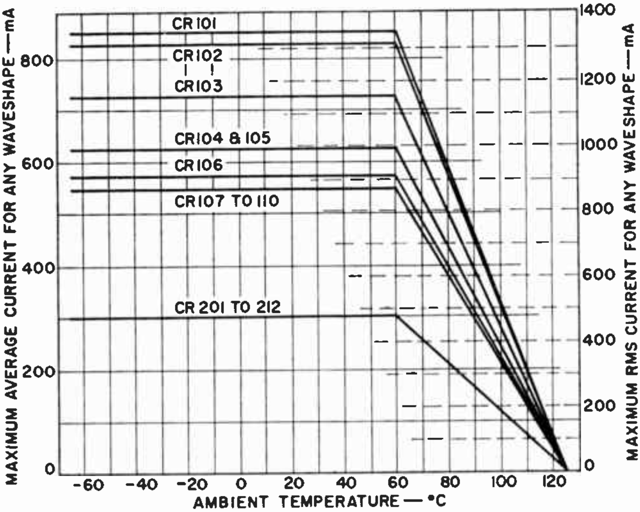


Figure 181. Current-temperature ratings for silicon stack rectifiers.

This value of I_{av} is then substituted in the ratio of I_{rms}/I_{av} obtained from Fig. 176, and the approximate rms current is determined, as follows:

$$I_{rms}/I_{av} = 5.7$$
$$I_{rms} = 5.7 \times 24.7$$
$$= 141 \text{ milliamperes}$$

Current-versus-temperature ratings for rectifiers are usually given in terms of average current for a resistive load with 60-cycle sinusoidal input voltage. When the ratio of peak-to-average current becomes higher (as with capacitive loads), however, junction heating effects become more and more dependent on rms current rather than average current. Therefore, capacitive-load ratings should be obtained from a curve of rms current as a function of temperature. Because the ratio of rms-to-average current for the rated service is 1.57 (as shown by I_{rms}/I_{av} at low ωCR on Figs. 175 and 176), the current axis of the average-current rating curves for a sinusoidal source and resistive load can be multiplied by 1.57 to convert the curves to rms rating curves. Fig. 181 shows an example of this conversion for RCA stack rectifier rating curves.

HEAT SINKS

Silicon rectifiers are often mounted on devices called "heat sinks". A heat sink generally consists of a relatively large metal plate attached to the heat-conducting side of the rectifier. Because of its large surface, a heat sink can readily dissipate heat and thereby safeguard the rectifier against damage.

The size of a heat sink for a given rectifier application depends upon the ambient temperature and the maximum average forward current of the rectifier. As a result, the actual size must be calculated for each application which involves an ambient temperature or forward current other than that recommended by the manufacturer. For this calculation, two charts are used: the current-multiplying-factor chart shown in Fig. 182, and the heat-sink cooling chart shown in Fig. 183. Fig. 182 applies to all rectifier types for both polyphase and dc operation; Fig. 183 differs for different rectifier types.

The calculation requires four steps:

1. From Fig. 182, the current-multiplying factor is determined for the applicable conduction angle (i.e., the

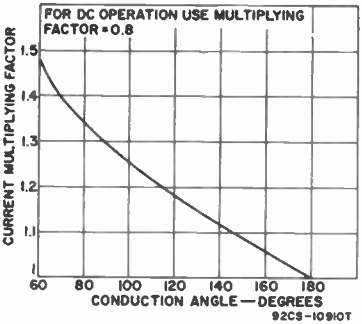


Figure 182. Current-multiplying-factor chart.

fraction of the ac input cycle during which forward current is expected to flow in the particular application). For dc operation of a silicon rectifier, a multiplying factor of 0.8 is generally specified.

2. The desired output current (expressed in amperes) is divided by the number of current paths. The actual number of paths depends on the type of operation intended, and can be determined from the table below.

Type of Operation	Number of Current Paths
Single-Phase, Full-Wave:	
Center-Tapped	2
Bridge	2
Three-Phase:	
Y	3
Double Y	6
Bridge	3
Six-Phase Star	6

The resulting figure is the average forward current of the rectifier.

3. The average current is then multiplied by the current-multiplying factor obtained in Step 1. The resulting figure represents the adjusted average forward current of the rectifier.

4. This adjusted current is applied to Fig. 183 to determine either the maximum allowable ambient temperature for a given heat-sink size or the minimum heat-sink size for a given ambient temperature. (Published data may also include a chart similar to Fig. 183 for forced-air-cooling applications.)

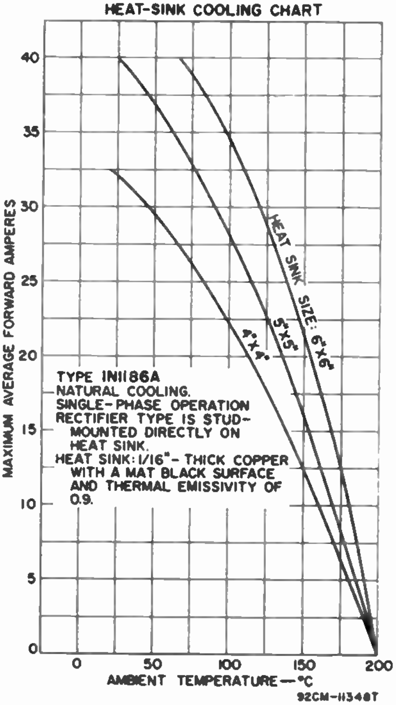


Figure 183. Typical heat-sink cooling chart.

The following example illustrates the calculation of minimum heat-sink size for a three-phase, half-wave (Y) circuit. The conduction angle is 120 degrees, the desired output current is 90 amperes, and the ambient temperature is 90 degrees centigrade.

1. From Fig. 182, the current-multiplying factor for a conduction angle of 120 degrees is 1.18.

2. For three-phase half-wave operation, the number of current paths is 3. The average forward current through the rectifier, therefore, is 90 divided by 3, or 30 amperes.

3. This average forward current is then multiplied by the current-multiplying factor (1.18) obtained in Step 1 to provide an adjusted forward current of 35.4 amperes.

4. From Fig. 183, the minimum heat-sink size for the above conditions is found to be 6 by 6 inches.

Silicon Controlled Rectifiers

THE silicon controlled rectifier (SCR) is basically a four-layer n-p-n-p semiconductor device having three electrodes: a cathode, an anode, and a control electrode called the **gate**. Like all rectifiers, it conducts current primarily in one direction. However, it differs from conventional rectifiers in that it will not conduct a substantial amount of current in the forward direction until the anode voltage exceeds a certain minimum value called the **forward breakover voltage**. The value of this voltage can be varied, or controlled, by the introduction of an external signal at the third electrode, or gate, of the silicon controlled rectifier. This unique control characteristic makes the SCR a particularly useful switching or power-control-device, especially in high-power circuits.

(The name **thyristor** has been adopted as a generic term for semiconductor devices having control characteristics similar to those of thyratron tubes. The silicon controlled rectifier belongs in this generic class, and is, more specifically, a **reverse-blocking triode** type of thyristor.)

CONSTRUCTION

Fig. 184 shows a cutaway view of a silicon controlled rectifier. Construction details for the semiconductor pellet are shown in Fig. 185. The alternate layers of diffused silicon material serve as the cathode, the gate, the base (or substrate), and the anode. These layers are enclosed in a special metal container which is hermetically sealed to maintain an ultra-dry atmosphere. This container is then mounted in a rugged case which provides protection against severe thermal environmental stresses. The pedestal below the semiconductor layers acts as a heat sink to help dissipate the heat developed internally during operation.

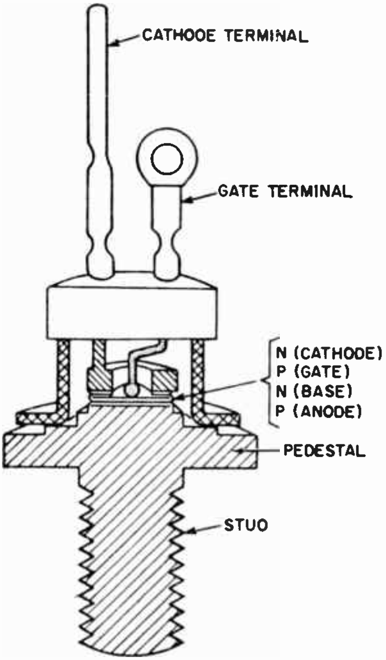


Figure 184. Construction details of typical silicon controlled rectifier.

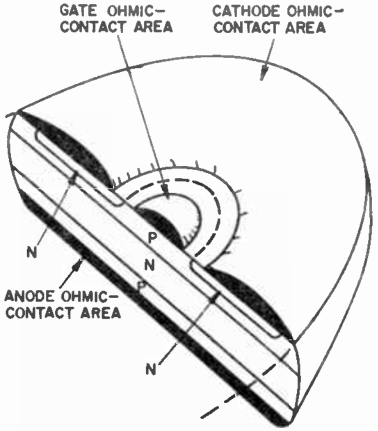


Figure 185. Construction of SCR pellet.

CURRENT-VOLTAGE CHARACTERISTICS

The voltage-current characteristic and the circuit symbol of the silicon controlled rectifier are shown in Fig. 186. Under reverse-bias conditions, the device operates in a manner similar to that of conventional rectifiers, and exhibits a slight reverse leakage current which is called the **reverse blocking current** (I_{RBOM}). This current has a small value until the **peak reverse voltage** v_{RM} is exceeded, at which point the reverse current increases by several orders of magnitude. The value of the peak reverse voltage differs for individual SCR's.

Under forward-bias conditions, there is a similar small leakage current called the **forward blocking current** (I_{FBOM}). Also, as the forward bias is increased, a voltage point is reached at which a forward breakover condition occurs and forward current increases rapidly. This point is called the **forward voltage breakover point** (V_{BOO}).

However, when the forward current exceeds a critical value at V_{BOO}, the voltage across the device suddenly reverts back to a very low value (V_F). (It is assumed that the rectifier is connected to a load resistance of sufficient value to permit this "cut-back" in voltage.) When this phenomenon occurs, the rectifier is considered to be triggered, or in the "on" condition. The forward current then continues to increase rapidly with slight increases in forward bias, and the device enters a state of high forward conduction.

It can be seen that when the forward breakover voltage of a silicon controlled rectifier is exceeded, the high internal resistance of the device changes to a very low value. The lower resistance then permits a high current to flow through the device at very low voltage values (V_F).

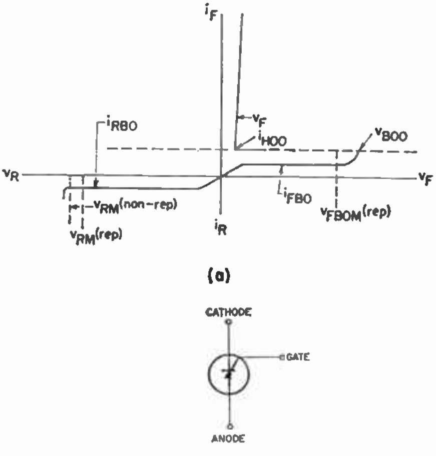


Figure 186. (a) Typical voltage and current characteristic and (b) circuit symbol for silicon controlled rectifier.

This change in internal resistance makes the SCR an ideal device for switching applications. When the operating voltage is below the breakover point, rectifier current is extremely small and the switch is effectively open. When the voltage increases to a value exceeding the breakover point, the rectifier switches to its high-conduction state and the switch is closed. The silicon controlled rectifier remains in the high-conduction state until the current drops below a value which can maintain the breakover condition. This value is called the holding current (i_{HOO}). When the anode-to-cathode voltage drops to a value too low to support a current equal to i_{HOO}, the device reverts back to the forward blocking region, and the rectifier switches to the "off" mode.

The voltage breakover point of a silicon controlled rectifier can be varied, or controlled, by injection of a signal at the gate, as indicated by the family of curves shown in Fig. 187. When the gate current is zero, the forward voltage must reach the V_{BOO} value of the device before breakover occurs. As the gate current is increased, however, the value of breakover voltage becomes less until the curve closely resembles that of a conventional rectifier. In normal operation, silicon controlled rectifiers are operated well below the forward voltage breakover point, and a gate signal of sufficient amplitude is used to assure triggering of the rectifier to the "on" mode.

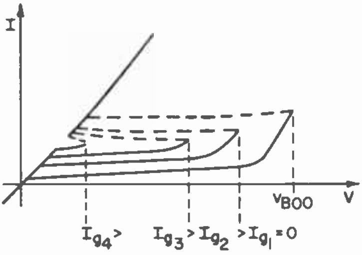


Figure 187. Family of curves with gate current at different values.

After the silicon controlled rectifier is triggered by the gate signal, the current flow through the device is independent of gate voltage or gate current. It remains in the high-conduction state until the primary or anode current is reduced to a level below that required to sustain conduction. Turnoff of the device can be achieved in minimum time by application of a reverse bias.

MAXIMUM RATINGS

Like other semiconductor devices, silicon controlled rectifiers must be operated within the maximum ratings specified by the manufacturer for best results in terms of performance, life, and reliability. Several voltage ratings are generally given for SCR's to prevent operation beyond the breakover points of the characteristic curve and possible permanent damage to the semiconductor pellet. Other ratings are given to define the values of current and power that the device can safely handle. The following definitions are used for the various ratings and characteristics given in the data charts for SCR's in this Manual:

Maximum peak reverse voltage v_{RM}(rep) is the maximum instantaneous value of negative (reverse-blocking) voltage which may be applied repetitively between anode and cathode when the gate is open (gate voltage zero or negative with respect to cathode).

Maximum transient peak reverse voltage v_{RM}(non-rep) is the maximum instantaneous value of negative (reverse-blocking) voltage which may be applied between anode and cathode for not more than 5 milliseconds when the gate is open.

Maximum peak forward blocking voltage v_{FBOM}(rep) is the maximum instantaneous value of positive (forward-blocking) voltage which may be applied repetitively between anode and cathode when the gate is open.

Maximum average forward current I_{FAV} and **maximum rms forward current** I_{FRMS} are the maximum average (dc) and rms values of current allowed to flow from anode to cathode for a conduction angle of 180 degrees at a specified case temperature.

Maximum peak surge current i_{FM}(surge) is the maximum total instantaneous value of forward current which may be imposed during one forward half-cycle with the device operating within its specified maximum voltage, average-forward-current, gate-power, and temperature ratings in a single-phase circuit with 60-cycle-per-second supply and resistive load. The peak surge current may be repeated after sufficient time has elapsed for the device to return to pre-surge thermal equilibrium conditions.

Maximum peak forward or reverse blocking current i_{FBOM} or i_{RBOM} is the maximum value of the forward or reverse blocking current when the gate is open.

Forward breakover voltage v_{BOO} is the value of positive anode voltage at which an SCR switches into the conducting state when the gate is open.

Holding current i_{HOO} is the instantaneous value of forward current i_F below which an SCR with its gate open returns to its forward blocking state.

Forward voltage drop v_F is the instantaneous voltage drop across an SCR at a given instantaneous forward current i_F.

Gate-trigger current I_{GT} is the gate current required to trigger an SCR operating at a specified temperature when the anode is at a potential of +6 volts with respect to the cathode.

Gate-trigger voltage V_{GT} is the gate-to-cathode voltage required to trigger an SCR operating at a specified temperature when the anode is at a potential of +6 volts with respect to the cathode.

Maximum peak gate power P_{GM} is the maximum instantaneous value of power dissipated between gate and cathode.

If the value and duration of expected surge currents in an SCR circuit are greater than the ratings for the particular device, it is necessary to add a fuse or other type of protective element to the circuit to protect the SCR. As in the case of silicon rectifiers, the fusing requirements can be determined by use of a coordination chart based on the surge rating chart included in the published data for the type of SCR used. In the case of silicon controlled rectifiers, however, the surge rating charts are usually given for maximum rated average forward current during 180-degree conduction at a specified case temperature; for other conduction angles and case temperatures, the curves must be derated as prescribed in the data.

TRIGGERING CHARACTERISTICS

As stated previously, SCR's are normally operated well below the forward voltage breakover point and are triggered into conduction by a gate signal of sufficient amplitude. The trigger signal applied to the gate of the SCR must not exceed the maximum ratings of the gate, but must be sufficiently large to assure reliable triggering under all conditions. However, the gate voltage during "off" periods must be sufficiently low to prevent random triggering. Because the maximum gate voltage for "off" periods varies with temperature, a sufficiently low voltage must be used to prevent undesired triggering at all temperature values encountered in a particular application. Fig. 188 shows typical gate-voltage requirements for triggering the 2N681 silicon controlled rectifier.

The SCR gate is usually overdriven with gate trigger pulses many times the dc triggering current of the device to provide positive triggering, reduce turn-on variations, minimize temperature effects, and decrease switching time. Restrictions on peak gate power, maximum

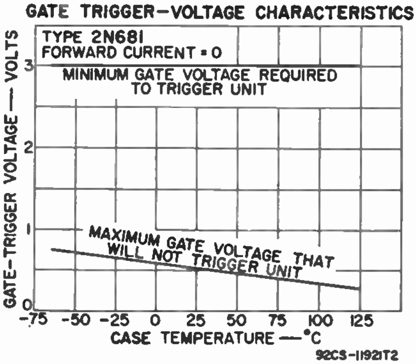


Figure 188. Triggering characteristics for 2N681.

gate voltage, and maximum gate current often result in a narrow area between the minimum requirements to trigger the SCR and the maximum gate limitations. RCA silicon controlled rectifiers utilize a coaxial construction and a "shorted emitter" technique to extend the range of maximum gate ratings and reduce the spread in gate turn-on characteristics for more reliable and precise triggering performance.

The "shorted emitter" technique makes use of the resistance path between the gate layer and the cathode contact shown in Fig. 185. When gate current is first initiated in the SCR, most of the current bypasses the gate-cathode junction and flows from the gate layer through the resistance element directly to the cathode contact. When the threshold voltage of the gate-cathode junction is exceeded, the SCR is turned on. Because the resistance element also shunts some reverse current from the cathode-gate junction, it allows greater flexibility in the reverse direction. Thus, the "shorted emitter" technique allows greater peak gate power dissipations in both the forward and reverse directions, provides more uniform gate characteristics, and also improves forward blocking capability.

When a negative voltage is applied to the anode of an SCR, the positive voltage at the gate significantly increases the reverse leakage current and, as a result, the power which must be dissipated by the device. This dissipation may be reduced by means of a "clamping" circuit in which a diode and a resistor are connected between the gate and the anode. This arrangement attenuates positive gate signals when the anode is negative. An alternative arrangement is to place a conventional rectifier having a low reverse leakage current in series with the SCR. A large percentage of the negative voltage is then assumed by the diode, and reverse dissipation in the controlled rectifier is greatly reduced.

SWITCHING CHARACTERISTICS

When an SCR is triggered by a gate signal, the turn-on time of the device occurs in two steps, a delay time and a rise time, as shown in Fig. 189. The **turn-on time** t_{on} is defined as the time interval between the initiation of the gate signal and the time when the resulting forward current reaches 90 per cent of its maximum value. The **delay time** t_d is defined as the time between the 50-per-cent point of the leading edge of the gate-trigger voltage and the 10-per-cent point of the resulting forward anode current. The **rise time** t_r is the time interval required for the anode current to rise from 10 per cent to 90 per cent of its maximum value. Turn-on time ($t_{on} = t_d + t_r$) is affected to some extent by the forward blocking voltage and the peak forward current level of the SCR, but is influenced primarily by the magnitude of the gate trigger pulse. When larger currents are available from the gate trigger pulses, the delay-time portion of the turn-on period is reduced, and the over-all turn-on time is decreased. The use of higher gate driving signals also helps to reduce variation of turn-on times between units and for a variety of conditions. The value of t_{on} is an indication of the response time of the SCR.

During and immediately following the rise time, the current flowing from anode to cathode is concentrated in a portion of the cathode nearest the gate. The finite time required for the spread of the current to the remainder of the cathode is called the **equalization time** t_e. Until the current density is equalized, the dynamic forward voltage drop is high, power loss is high, and the unequal "power density" can produce hot spots in the cathode. The initial magnitude and time constant of reduction of the dynamic forward voltage drop during the time t_e is an indication of the current-switching capability of the SCR. The turn-on

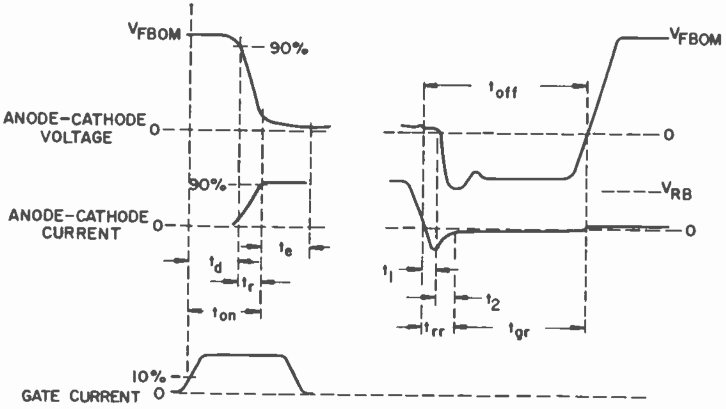


Figure 189. Switching waveshapes for SCR.

losses resulting from this equalization period are proportional to the current and the repetition rate of the gate signal and, in many applications, determine the output available from the SCR.

The **turn-off** time of an SCR also occurs in two steps, a reverse recovery time and a gate recovery time, as shown in Fig. 189. When the forward current is reduced to zero at the end of a conduction period, application of reverse anode voltage causes reverse current to flow in the SCR until the reverse blocking junction (between the p-type anode layer and the n-type base or substrate) establishes a depletion region. The time interval between the application of reverse voltage and the time that the reverse current reaches its peak value is called the reverse recovery time t_{rr}. A second recovery period called the gate recovery time t_{gr} must then elapse until the forward blocking junction (between the n-type base or substrate and the p-type gate layer) can establish a forward depletion region so that forward blocking voltage can be reapplied and successfully blocked by the SCR.

The gate recovery time t_{gr} is generally much larger than the reverse recovery time t_{rr}. The total time measured from the beginning of reverse recovery current flow to the beginning of the reapplied forward blocking voltage is called the turn-off time t_{off}. Factors affecting turn-off time include the forward current prior to turn-off, the rate of change of current during the transition from forward to reverse, the reverse current available, the reverse blocking voltage, the rate of change of the reapplied forward voltage, the gate trigger level, the gate bias, and the junction temperature. Of these effects, temperature and forward current are the most significant.

The gate trigger pulse for an SCR must be maintained only until the magnitude of the forward current has reached the "latching-current" value (i.e., the value at which the forward voltage drops to a relatively low value and the high internal resistance of the device changes to a very low resistance). In most conservative designs, however, the gate trigger pulse width is at least equal to or somewhat greater than the complete turn-on time of the device. In all cases, the total average gate dissipation in both the forward and the reverse direction must not exceed the rated value for the SCR being used.

OVERLOAD PROTECTION

In any silicon-controlled-rectifier circuit, precautions should be taken to protect the device from over-current and over-voltage surge conditions. Protection against over-current surges can be achieved by either preventing or interrupting the current surge, or by limiting the magnitude of the current flow by means of the circuit impedance. For the first approach, circuit fuses or breakers can be used effectively to disconnect the entire circuit from the power supply or to isolate the faulted silicon controlled rectifiers. In addition, dc fuses can be used to protect the devices from dc feedback originating in the load or parallel conduction circuits. The magnitude of the over-current flow can be limited by proper selection of source and transformer impedances, as well as the inductance and reactance, of the dc circuit.

The effects of voltage transients in silicon-controlled-rectifier circuits can be minimized by reducing the rate at which the energy is dissipated in the devices. This "slowdown" of energy release can be achieved by relocation of the switching elements in the circuit or by a change in the sequence of switching. Other preventive methods include the change of speed of current interruption by the switching elements, or the use of an additional energy source or dissipation means in the circuit.

POWER CONTROL

As mentioned previously, silicon controlled rectifiers are used in a large number of commercial and industrial power-control applications. Fig. 190a shows a simple power-control circuit using a controlled rectifier; Fig. 190b shows the waveforms for applied voltage and load current. In this circuit, the rectifier is connected in series with the load, and the gate circuit receives its triggering signal from the pulse generator. The rectifier selected has a voltage breakover point which is higher than the value of applied peak ac anode voltage. As a result, if no gate signal is applied by the pulse generator, the rectifier remains in the "off" condition, and no current flows through the load except a slight leakage current.

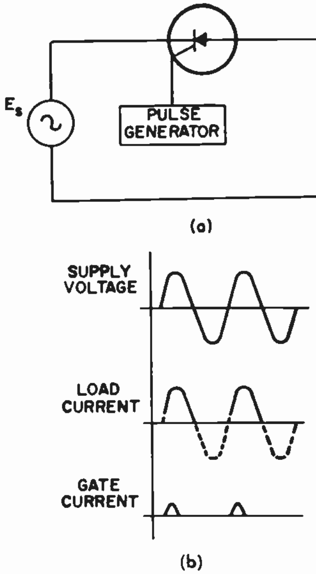


Figure 190. (a) Basic power-control circuit and (b) waveforms for supply voltage, load current, and gate current.

When a gate signal of sufficient amplitude is applied at the beginning of the positive anode voltage, the rectifier is triggered and current flows through the circuit for the remainder of the positive cycle, even when the triggering signal is removed. The load current ceases only when the applied ac signal becomes negative and the rectifier current falls below the value required to maintain conduction.

A silicon controlled rectifier can be used to conduct during any desired portion of the positive cycle of anode voltage by applying the gate signal at the proper value of the anode voltage. For example, if the triggering signal is applied at the positive peak of the anode voltage waveform, the rectifier conducts only a quarter of the cycle. This flexibility of control distinguishes the silicon controlled rectifier from all other types of semiconductor devices.

CURRENT RATIOS

In the design of circuits using

silicon controlled rectifiers, it is often necessary to determine the specific values of peak, average, and rms current flowing through the device. In the case of conventional rectifiers, these values are readily determined by the use of the current ratios shown in Table I of the section on Silicon Rectifiers. For silicon controlled rectifiers, however, the calculations are more difficult because the current ratios become functions of both the conduction angle and the firing angle of the device.

The charts in Figs. 191, 192, and 193 show several current ratios as functions of conduction and firing angles for three basic silicon-controlled-rectifier circuits. These charts can be used in a number of ways to calculate desired current values. For example, they can be used to determine the peak or rms current in a silicon controlled rectifier when a certain average current is to be delivered to a load during a specific part of the conduction period. It is also possible to work backwards and determine the necessary period of conduction if, for example, a specified peak-to-average current ratio must be maintained in a particular application. Another use is the calculation of the rms current at various conduction angles when it is necessary to determine the power delivered to a load, or power losses in transformers, motors, leads, or bus bars. Although the charts are presented in terms of device current, they are equally useful for the calculation of load current and voltage ratios.

The charts provide ratios relating average current I_{avg}, rms current I_{rms}, peak current I_{pk}, and a parameter I_o called the reference current.

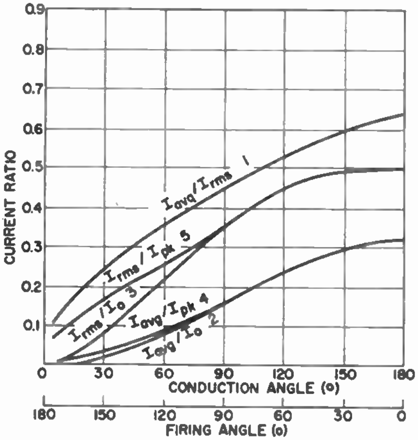


Figure 191. Ratio of device current as a function of conduction and firing angles for single-phase half-wave conduction into a resistive load.

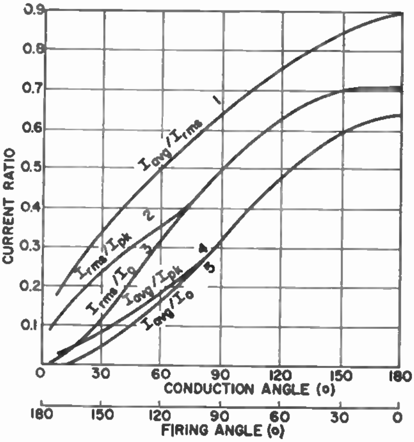


Figure 192. Ratio of device current as a function of conduction and firing angles for single-phase full-wave conduction into a resistive load.

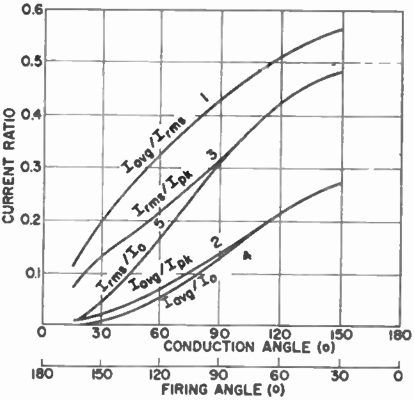


Figure 193. Ratio of device current as a function of conduction and firing angles for three-phase half-wave circuit having a resistive load.

This last value represents a constant of the circuit, and is equal to the peak source voltage V_{pk} divided by the load resistance R_L. The term I_{pk} refers to the peak current which appears at the controlled rectifier during its period of forward conduction. I_o is the maximum value that the current can obtain and corresponds to the peak of the sine wave. For conduction angles greater than 90 degrees, I_{pk} is equal to I_o; for conduction angles smaller than 90 degrees, I_{pk} is smaller than I_o.

The general procedure for the use of the charts is as follows:

1. Identify the unknown or desired parameter.
2. Determine the values of the parameters fixed by the circuit specifications.
3. Use the appropriate curve to find the unknown quantity as a function of two of the fixed parameters.

Example No. 1: In the single-phase half-wave circuit shown in Fig. 194, a 2N685 silicon controlled rectifier is used to control power from a sinusoidal ac source of 120 volts rms (170 volts peak) into a 2.8-ohm load. This application requires a load current which can be varied from 2 to 25 amperes rms. It is necessary to determine the range of conduction angles required to obtain this range of load current.

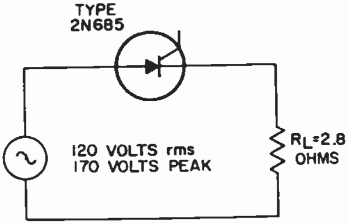
First, the reference current I_o is calculated, as follows:

$$I_o = \frac{V_{pk}}{R_L} = \frac{170}{2.8} = 61 \text{ amperes}$$

The ratios of I_{rms}/I_o for the maximum and minimum load-current values are then calculated, as follows:

$$\left[\frac{I_{rms}}{I_o}\right] \text{min} = \frac{2}{61} = 0.033$$

$$\left[\frac{I_{rms}}{I_o}\right] \text{max} = \frac{25}{61} = 0.41$$



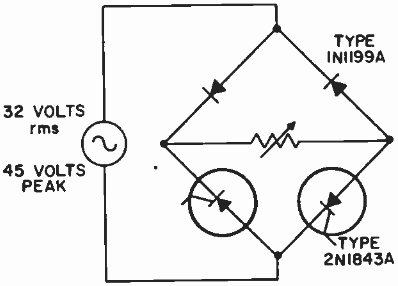
$$I = 0 (0° \leq \theta \leq \theta_f)$$
$$I = I_0 \sin \theta \ (\theta_f \leq \theta \leq 180°)$$
$$I_{avg} = 1/2\pi \int_{\theta_f}^{180°} I d\theta$$
$$I_{rms} = \left[1/2\pi \int_{\theta_f}^{180°} I^2 d\theta\right]^{1/2}$$
$$I_{pk} = I_0 \ (0 \geq \theta_f \geq 90°)$$
$$I_{pk} = I_0 \sin \theta_f \ (90° \leq \theta_f \leq 180°)$$

Figure 194. Single-phase half-wave circuit using resistive load, and respective equations for device current.

These current-ratio values are then applied to curve 3 of Fig. 191, and the corresponding conduction angles are determined to be

$$(\Theta_c) \text{ min} = 15 \text{ degrees}$$
$$(\Theta_c) \text{ max} = 106 \text{ degrees}$$

Example No. 2: In the single-phase full-wave bridge circuit (two legs controlled) shown in Fig. 195, a constant average load current of seven amperes is to be maintained while the load resistance varies from 0.2 to 4 ohms. In this case, it is



$$I = 0 (0° \leq \theta \leq \theta_f)$$
$$I = I_0 \sin \theta \ (\theta_f \leq \theta \leq 180°)$$
$$I_{avg} = 1/\pi \int_{\theta_f}^{180°} I d\theta$$
$$I_{rms} = \left[1/\pi \int_{\theta_f}^{180°} I^2 d\theta\right]^{1/2}$$
$$I_{pk} = I_0 \ (0° \leq \theta_f \leq 90°)$$
$$I_{pk} = I_0 \sin \theta_f \ (90° \leq \theta_f \leq 180°)$$

Figure 195. Single-phase full-wave bridge circuit using resistive load, and respective equations for device current.

necessary to determine the variation required in the conduction angle. The average silicon controlled rectifier current is half the load current, or 3.5 amperes. The applicable current ratios for this circuit are shown in Fig. 191 (the individual device currents are half-wave although the load current is full-wave).

Again, the first quantity to be calculated is the reference current. Because the reference current varies with the load resistance, the maximum and minimum values are determined as follows:

$$(I_o)\ \max = \frac{V_{pk}}{(R_L)\ \min} = \frac{45}{0.2}$$
$$= 225 \text{ amperes}$$
$$(I_o)\ \min = \frac{V_{pk}}{(R_L)\ \max} = \frac{45}{4}$$
$$= 11.2 \text{ amperes}$$

The corresponding ratios of I_{avg}/I_o are then calculated, as follows:

$$\left[\frac{I_{avg}}{I_o}\right]_{\min} = \frac{3.5}{225} = 0.015$$
$$\left[\frac{I_{avg}}{I_o}\right]_{\max} = \frac{3.5}{11.2} = 0.312$$

Finally, these ratios are applied to curve 2 of Fig. 191 to determine the desired conduction values, as follows:

$$(\theta_c)\ \min = 25 \text{ degrees}$$
$$(\theta_c)\ \max = 165 \text{ degrees}$$

Example No. 3: In the three-phase half-wave circuit shown in Fig. 196, the firing angle is varied continuously from 30 to 155 degrees. In this case, it is necessary to determine the resultant variation in the attainable load power. Reference current for this circuit is determined as follows:

$$I_o = \frac{V_{pk}}{R_L} = \frac{85}{3.0} = 28 \text{ amperes}$$

Rectifier current ratios are determined from Fig. 193 for the extremes of the firing range, as follows:

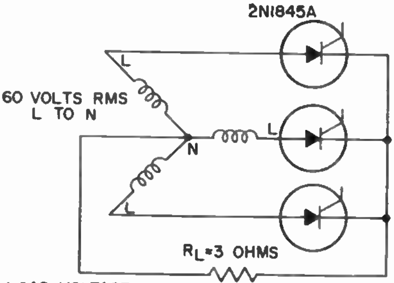
$$\theta_F = 30°;\ \frac{I_{rms}}{I_o} = 0.49$$
$$\theta_F = 155°;\ \frac{I_{rms}}{I_o} = 0.06$$

These ratios, together with the reference current, are then used to determine the range of rms current in the rectifiers, as follows:

$$(I_{rms})\ \max = 0.49 \times 28$$
$$= 13.7 \text{ amperes}$$
$$(I_{rms})\ \min = 0.06 \times 28$$
$$= 1.7 \text{ amperes}$$

In this circuit, the rms current in the load is equal to the rms rectifier current multiplied by the square root of three; as a result, the desired power range of the load is as follows:

$$P = (I_{rms}\sqrt{3})^2\ R$$
$$P_{max} = 1700 \text{ watts}$$
$$P_{min} = 26 \text{ watts}$$



LOAD VOLTAGE=85 VOLTS PEAK
DEVICE VOLTAGE=85 VOLTS PEAK FORWARD
DEVICE VOLTAGE=149 VOLTS PEAK REVERSE

$$I = I_0 \sin\theta\ (30° \le \theta \le 180°)$$
$$I_{avg} = 1/2\pi \int_{\theta_f}^{\theta_f+120} I\,d\theta\ \ (30° \le \theta_f \le 60°)$$
$$I_{avg} = 1/2\pi \int_{\theta_f}^{180°} I\,d\theta\ \ (60° \le \theta_f \le 180°)$$
$$I_{rms} = \left[1/2\pi \int_{\theta_f}^{\theta_f+120°} I^2\,d\theta\right]^{1/2}\ (30° \le \theta_f \le 60°)$$
$$I_{rms} = \left[1/2\pi \int_{\theta_f}^{180°} I^2\,d\theta\right]^{1/2}\ (60° \le \theta_f \le 180°)$$
$$I_{pk} = I_0\ (30° \le \theta_f \le 90°)$$
$$I_{pk} = I_0 \sin\theta_f\ (90° \le \theta_f \le 180°)$$

Figure 196. Three-phase half-wave circuit using resistive load, and respective equations for device current.

Tunnel Diodes and Other Semiconductor Diodes

TUNNEL DIODES

A TUNNEL diode is a small p-n junction device having a very high concentration of impurities in the p-type and n-type semiconductor materials. This high impurity density makes the junction depletion region (or space-charge region) so narrow that electrical charges can transfer across the junction by a quantum-mechanical action called "tunneling". This tunneling effect provides a negative-resistance region on the characteristic curve of the device that makes it possible to achieve amplification, pulse generation, and rf-energy generation.

Construction

The structure of a tunnel diode is extremely simple, as shown in Fig. 197. A small "dot" of highly conductive n-type (or p-type) material is alloyed to a pellet of highly conductive p-type (or n-type) material to form the semiconductor junction. The pellet (approximately 0.025 inch square) is then soldered into a low-inductance, low-capacitance case. A very fine mesh screen is added to make the connection to the "dot". The device is then encapsulated, and a lid is welded over the cavity.

At the present time, most commercially available tunnel diodes are fabricated from either germanium or gallium arsenide. Germanium devices offer high speed, low noise, and low rise times (as low as 40 picoseconds). Gallium arsenide diodes have a voltage swing almost twice that of germanium devices, and, as a result, can provide power outputs almost four times as high. Because of their power-handling capability, gallium arsenide tunnel diodes are being used in an increasing number of applications, and appear to be particularly useful as microwave oscillators.

Characteristics

Typical current-voltage characteristics for a tunnel diode are shown in Fig. 198. Conventional diodes do

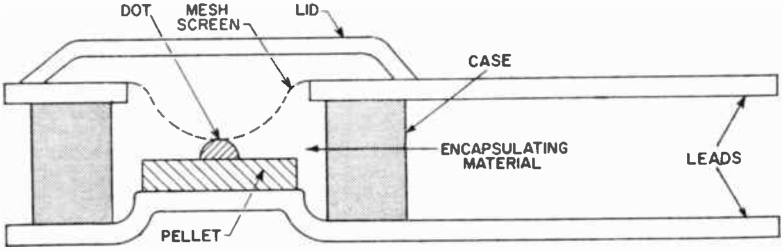


Figure 197. Structure of a tunnel diode.

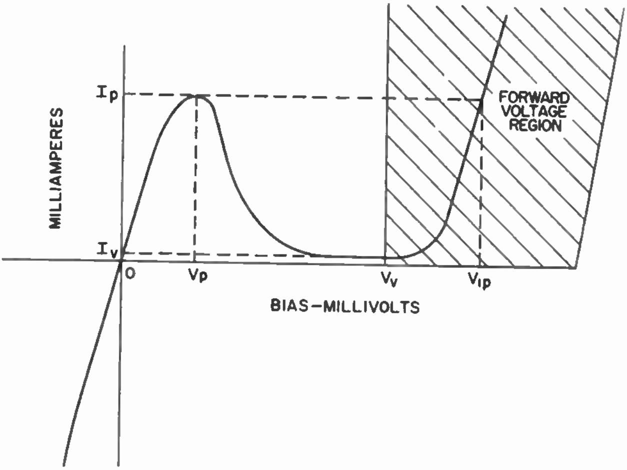


Figure 198. Typical current-voltage characteristic of a tunnel diode.

not conduct current under conditions of reverse bias until the breakdown voltage is reached; under forward bias they begin to conduct at approximately 300 millivolts. In tunnel diodes, however, a small reverse bias causes the valence electrons of semiconductor atoms near the junction to "tunnel" across the junction from the p-type region into the n-type region; as a result, the tunnel diode is highly conductive for all reverse biases. Similarly, under conditions of small forward bias, the electrons in the n-type region "tunnel" across the junction to the p-type region and the tunnel-diode current rises rapidly to a sharp maximum peak I_p. At intermediate values of forward bias, the tunnel diode exhibits a negative-resistance characteristic and the current drops to a deep minimum valley point I_v. At higher values of forward bias, the tunnel diode exhibits the diode characteristic associated with conventional semiconductor current flow. The decreasing current with increasing forward bias in the negative-resistance region of the characteristic provides the tunnel diode with its ability to amplify, oscillate, and switch.

Equivalent Circuit

In the equivalent circuit for a tunnel diode shown in Fig. 199, the n-type and p-type regions are shown as pure resistances r_1 and r_2. The transition region is represented as a voltage-sensitive resistance R(v) in parallel with a voltage-sensitive capacitance C(v) because tunneling is a function of both voltage and junction capacitance. This capacitance is similar to that of a parallel-plate capacitor having plates separated by the transition region.

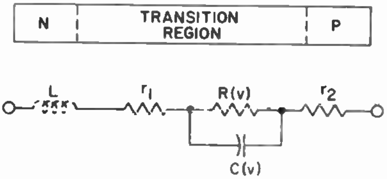


Figure 199. Equivalent circuit for a tunnel diode.

The dashed portion L in Fig. 199 represents an inductance which results from the case and mounting of the tunnel diode. This inductance is unimportant for low-frequency diodes, but becomes increasingly important at high frequencies (above 100 megacycles).

Fig. 200 shows the form of the equivalent circuit when the diode is biased so that its operating point is in the negative-resistance region; dynamic characteristics of tunnel diodes are defined with respect to this circuit. L_S represents the total series inductance, and R_S the total series resistance. C_D is the capacitance and $-R_D$ is the negative resistance of the diode. For small signal variations, both the resistance R_D and the capacitance C_D are constant.

The figure of merit F of a tunnel diode is equal to the reciprocal of $2\pi RC$, where R and C are the equivalent values $-R_D$ and C_D, respectively, shown in Fig. 200. This expression has two very useful interpretations: (1) it is the diode gain-bandwidth product for circuits operating in the linear negative-resistance region of the characteristic, and (2) its reciprocal is the diode switching time when the device is used as a logic element.

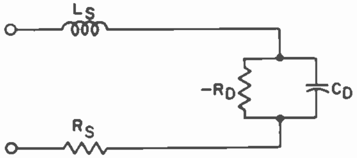


Figure 200. Equivalent circuit for a tunnel diode biased in the negative-resistance region.

Applications

When the tunnel diode is used in circuits such as amplifiers and oscillators, the operating point must be established in the negative-resistance region. The dc load line, shown as a solid line in Fig. 201, must be very steep so that it intersects the static characteristic curve at only one point A. The ac load line can be either steep with only one intersection B, as in the case of an amplifier, or relatively flat with three intersections C, D, and E, as in the case of an oscillator. The location of the operating point is determined by the anticipated signal swing, the required signal-to-noise ratio, and the operating temperature of the device. Biasing at the center of the linear portion of the negative-resistance slope permits the greatest signal swing. For high-temperature operation, a higher operating current is chosen; for low noise, the device is operated at the lowest possible bias current.

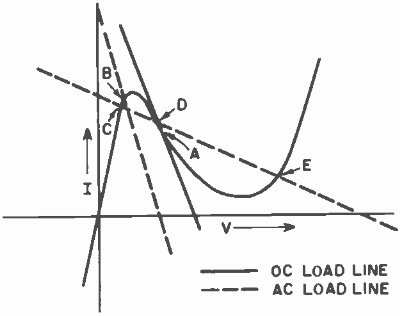


Figure 201. Typical load lines for tunnel-diode circuits.

Because tunnel diodes can operate effectively at frequencies above 300 megacycles, they are particularly suitable for use in microwave amplifiers and oscillators. In microwave amplifier circuits, tunnel diodes offer low noise, as well as small size and weight, low cost, and low power drain. In addition, bandwidths in excess of an octave can readily be obtained because of the wideband negative-resistance characteristic of tunnel diodes. However, this wideband negative resistance makes stabilization an important problem in the design of microwave tunnel-diode amplifiers.

In microwave oscillator circuits, tunnel diodes can provide useful power outputs at frequencies as high as 5000 megacycles. Compared to vacuum-tube microwave oscillators, tunnel-diode oscillators are inexpensive, require only a fraction of a volt dc bias, and are rugged and reliable in severe environments. Compared to transistor-driven varactor frequency-multiplier circuits, they are simple and compact, and afford higher dc-to-rf conversion efficiencies. (More detailed information on microwave tunnel-diode circuits, as well as on other tunnel-diode applications, is given in the RCA TUNNEL-DIODE MANUAL TD-30.)

As a two-terminal switch, the tunnel diode is particularly suited to computer applications because of its high speed, small size, and low power consumption. Switching operation is obtained by the use of a load line which intersects the diode characteristic in three points, as shown in Fig. 201; however, only points C and E are stable operating points. If the circuit is operated at point C and a positive current step of sufficient amplitude is applied, the operating point switches to point E. Correspondingly, a negative input signal switches the operating point back to point C.

An advantage of the switching mode is its nonsensitivity to the exact linearity of the negative-resistance region of the tunnel-diode characteristics. Slight irregularities in the negative characteristic have negligible effect on the switching action.

In the basic monostable circuit or "gate" shown in Fig. 202a, the static load line is determined by the resistance R_o and the voltage V_o. If R_o is less than the minimum dynamic negative resistance of the diode, only a single operating point exists. The gate is stable in its low state if V_o is adjusted so that the operating point is at E. The dynamic load line is determined by the inductive time constant L/R_o. When the inductive time constant is long compared to the switching time t_s, the current in the circuit is effectively constant.

If a small step of current I_{in} is applied to the diode, the operating point switches to the high-voltage point F along the constant-current path shown by the dashed line in Fig. 202b. Removal of the input causes the operating point to move to F′. At this point, the energy stored in the inductor L must be dissipated before the circuit can return to its original operating point. As the energy in the inductor decreases, the operating point moves along the diode characteristic to the point of minimum current at G. When this point is reached, switching again occurs along a constant-current path to point H. The cycle of operation is completed by a recovery region in which the energy in the inductor builds up to its original level; during this period the operating point moves up the diode characteristic to the starting point.

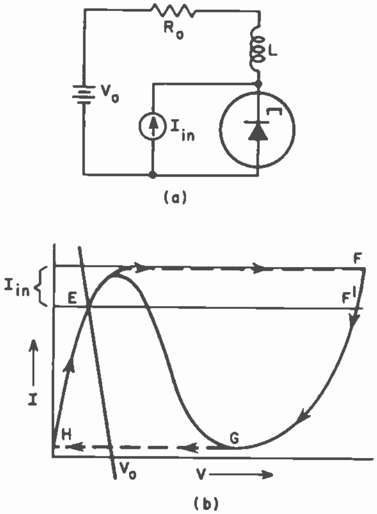


Figure 202. Basic tunnel-diode logic circuit.

Fig. 203a shows a simple tunnel-diode logic circuit. If the static operating bias is adjusted so that only one input is required to trigger the diode, an OR function is performed. If all inputs are required to trigger the diode, an AND function is performed. Because the coupling impedance is high compared to the diode impedance, the inputs can be considered as current sources during the triggering period. Fig. 203b shows the biasing for a three-input AND gate. If the operating-point bias is increased slightly, the circuit can be made to trigger on two of its inputs; the logical function performed would then be that of a "majority gate".

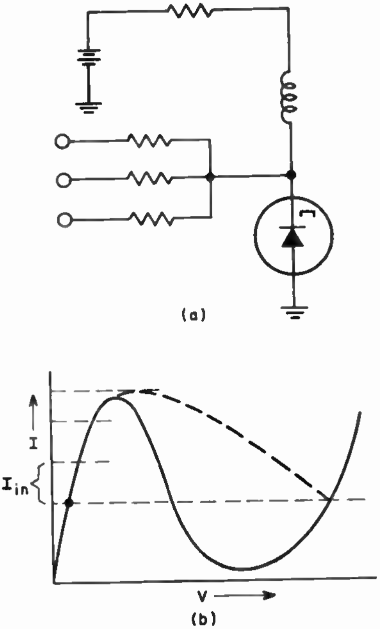


Figure 203. Tunnel-diode "AND" gate.

Radiation and Thermal Considerations

One of the most important features of the tunnel diode is its resistance to nuclear radiation. Experimental results have shown tunnel diodes to be at least ten times more resistant to radiation than transistors. Because the resistivity of tunnel diodes is so low initially, it is not critically affected by radiation until large doses have been applied. In addition, tunnel diodes are less affected by ionizing radiation because they are relatively insensitive to surface changes produced by such radiation.

In general, the tunnel-diode voltage-current characteristic is relatively independent of temperature. Specific tunnel-diode applications may be affected, however, by the relative temperature dependence of the various circuit components. In such applications, negative feedback or direct (circuit) compensation may be required.

HIGH-CURRENT TUNNEL DIODES

High-current tunnel diodes are basically the same as conventional tunnel diodes, except that they have a larger junction area to permit the flow of higher currents and have a much smaller value of series resistance (generally in the order of 0.010 ohm or less).

High-current tunnel diodes are used as low-voltage inverters in circuits having low-impedance dc power sources. They can also be used for efficient inversion of the output of solar cells, thermoelectric generators, or thermionic converters, and as overload detectors in dc and ac power supplies, pulse generators, high-speed switches, and oscillators.

Fig. 204 shows a simple overload-sensor circuit using a high-current tunnel diode. This circuit is a fast-acting sensitive overcurrent detector which can be used to protect sensitive loads from current surges or overloads. Other circuit arrangements can be used to protect the power supply rather than the load.

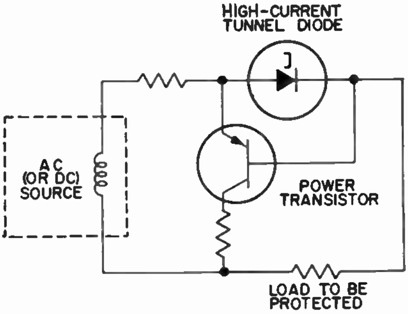


Figure 204. Overload sensor circuit using tunnel diode.

TUNNEL RECTIFIERS

In addition to its negative-resistance properties, the tunnel diode has an efficient rectification characteristic which can be used in many rectifier applications. When a tunnel diode is used in a circuit in such a way that this rectification property is emphasized rather than its negative-resistance characteristic, it is called a tunnel rectifier. In general, the peak current for a tunnel rectifier is less than one milliampere.

The major differences in the current-voltage characteristics of tunnel rectifiers and conventional rectifiers are shown in Fig. 205. In conventional rectifiers, current flow is substantial in the forward direction, but extremely small in the reverse direction (for signal voltages less than the breakdown voltage for the device). In tunnel rectifiers, however, substantial reverse current flows at very low voltages, while forward current is relatively small. Consequently, tunnel rectifiers can provide rectification at smaller signal voltages than conventional rectifiers, although their polarity requirements are opposite. (For this reason, tunnel rectifiers are sometimes called "back diodes.")

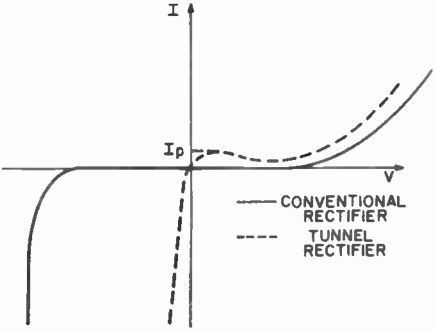


Figure 205. Current-voltage characteristics of tunnel rectifier and conventional rectifier.

Because of their high-speed capability and superior rectification characteristics, tunnel rectifiers can be used to provide coupling in one direction and isolation in the opposite direction. Fig. 206 shows the use of tunnel rectifiers to provide directional coupling in a tunnel-diode logic circuit.

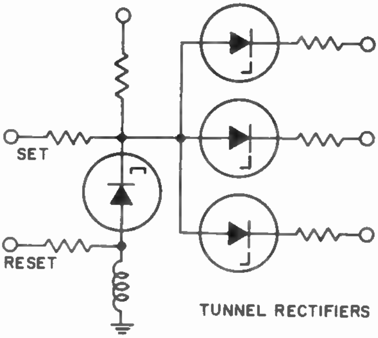


Figure 206. Logic circuit using a tunnel diode and three tunnel rectifiers.

VARACTOR DIODES

A varactor or variable-reactance diode is a microwave-frequency p-n junction semiconductor device in which the depletion-layer capacitance bears a nonlinear relation to the junction voltage, as shown in Fig. 207a. When biased in the reverse direction, a varactor diode can be represented by a voltage-sensitive capacitance C(v) in series with a resistance R_s, as shown in Fig. 207b. This nonlinear capacitance and low series resistance, which permit the device to perform frequency-multiplication, oscillation, and switching functions, result from a very high impurity concentration outside the depletion-layer region and a relatively low concentration at the junction. Very low noise levels are possible in circuits using varactor diodes because the dominant current across the junction is reactive and

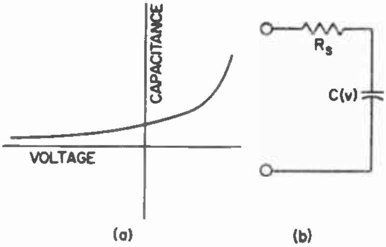


Figure 207. (a) Capacitance-voltage relationship and (b) equivalent circuits for a varactor diode.

shot-noise components are absent.

Reactive nonlinearity, without an appreciable series resistance component, enables varactor diodes to generate harmonics with very high efficiency in circuits such as the shunt-type frequency multiplier shown in Fig. 208. The circuit is driven by a sinusoidal voltage source V_s having a fundamental frequency f and an internal impedance Z_s. Because the ideal input filter is an open circuit for all frequencies except the fundamental frequency, only the fundamental component of current i_f can flow in the input loop. A second-harmonic current i_{2f} is generated by the varactor diode and flows toward the load Z_L; another ideal filter is used in the output loop to block the fundamental-frequency component of the input current.

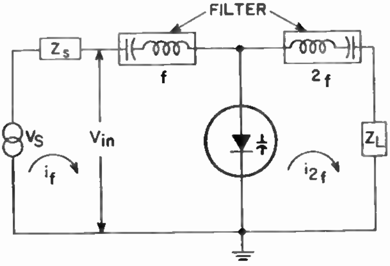


Figure 208. Varactor-diode frequency multiplier.

Varactor diodes can amplify signals when their voltage-dependent capacitance is modulated by an alternating voltage at a different frequency. This alternating voltage supply, which is often referred to as the "pump", adds energy to the signal by changing the diode capacitance in a specific phase relation with the stored signal charge so that potential energy is added to this charge. An "idler" circuit is generally used to provide the proper phase relationship between the signal and the "pump".

VOLTAGE-REFERENCE DIODES

Voltage-reference or zener diodes are silicon rectifiers in which the reverse current remains small until the breakdown voltage is reached and then increases rapidly with little further increase in voltage. The breakdown voltage is a function of the diode material and construction, and can be varied from one volt to several hundred volts for various current and power ratings, depending on the junction area and the method of cooling. A stabilized supply can deliver a constant output (voltage or current) unaffected by temperature, output load, or input voltage, within given limits. The stability provided by voltage-reference diodes makes them useful as stabilizing devices and as reference sources capable of supplying extremely constant current loads.

COMPENSATING DIODES

Excellent stabilization of collector current for variations in both supply voltage and temperature can be obtained by the use of a compensating diode operating in the forward direction in the bias network of amplifier or oscillator circuits. Fig. 209 shows the transfer characteristics of a transistor; Fig. 210 shows the forward characteristics of a compensating diode. In a typical circuit, the diode is biased in the forward direction; the operating point is represented on the diode characteristics by the dashed horizontal line. The diode current at this point determines a bias voltage which establishes the transistor idling current. This bias voltage shifts with varying temperature in the same direction and magnitude as the transistor characteristic, and thus provides an idling current that is essentially independent of temperature.

The use of a compensating diode also reduces the variation in transistor idling current as a result of supply-voltage variations. Because the diode current changes in proportion with the supply voltage, the bias voltage to the transistor changes in the same proportion and idling-current changes are minimized. (The use of diode compensation is discussed in more detail under "Biasing" in the Transistor Applications Section.)

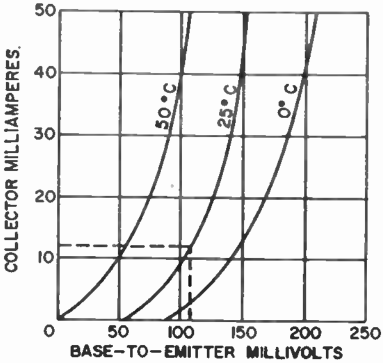


Figure 209. Transfer characteristics of transistor.

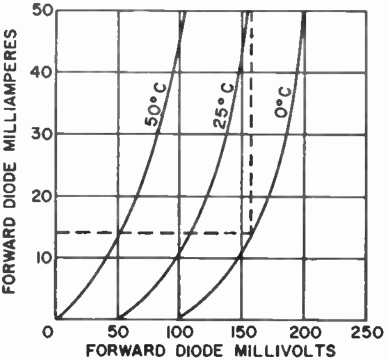


Figure 210. Forward characteristics of compensating diode.

Rectifier and Diode Symbols

Abbreviated data for RCA silicon rectifiers, silicon controlled rectifiers, and semiconductor diodes are given in the following section. The symbols used in the data are listed and defined below.

SILICON RECTIFIERS, PLUG-IN RECTIFIERS, STACKS, AND BRIDGES

C_S	shunt capacitance
I_{FAV}	average forward current
i_{FM}(rep)	peak recurrent forward current
i_{FM}(surge)	peak surge forward current
I_{RM}	maximum reverse current
V_{FM}	maximum dc forward voltage drop
V_M(block)	maximum dc blocking voltage
v_{RM}	peak reverse voltage
v_{RM}(non-rep)	non-repetitive (transient) peak reverse voltage
v_{RM}(rep)	repetitive peak reverse voltage
V_{RMS}	rms supply voltage

SILICON CONTROLLED RECTIFIERS (SCR's)

di/dt	rate of change of forward current
dv/dt	critical rate of applied forward voltage
i_F	instantaneous forward current
I_{FAV}	average forward current
i_{FBO}	instantaneous forward leakage current
I_{FBOAV}	average forward blocking current
i_{FBOM}	peak forward blocking current
i_{FM}(surge)	peak surge current
i_{FRMS}	rms forward current
i_{GKM}	peak forward gate current
I_{GT}	gate trigger current
i_{HOO}	holding current
i_{RBO}	instantaneous reverse leakage current
I_{RBOAV}	average reverse blocking current
i_{RBOM}	peak reverse blocking current
p_{GM}	peak forward and reverse gate power
P_{GAV}	average forward gate power
t_{on}	turn-on time
t_{off}	turn-off time
v_{BOO}	forward breakover voltage
v_F	instantaneous forward voltage drop
V_{FAV}	gate trigger voltage
v_{FBOM}	peak forward blocking voltage
v_{FBOM}(rep)	peak forward blocking voltage
v_{GKM}	peak forward gate voltage
V_{GT}	dc gate-trigger voltage (when anode is at 6 volts with respect to cathode)

V_{KGM}	peak reverse gate voltage
V_{RBOM}	peak reverse blocking voltage
V_{RM}(non-rep)	transient peak reverse voltage (nonrepetitive)
V_{RM}(rep)	peak reverse voltage (repetitive)

TUNNEL DIODES AND TUNNEL RECTIFIERS

C_j	junction capacitance
C_p	case capacitance
C_{tv}	valley-point terminal capacitance
f_c	characteristic frequency (figure of merit)
f_{max}	maximum frequency of oscillation
f_r	resistive cutoff frequency
g_j	junction resistance
I_I	inflection-point current
I_P	peak-point current
I_P/C_{tv}	speed index
I_V	valley-point current
L	series inductance
L_{ex}	excess series inductance
r_j	junction resistance
r_s	series resistance
t_{sw}	characteristic switching time
V_I	inflection-point voltage
V_P	peak-point voltage
V_{PP}	projected-peak-point voltage
V_V	valley-point voltage
Y_t	terminal admittance

Static (DC) Parameters

Inflection point—the point on the forward current-voltage characteristic at which the slope of the characteristic reaches its most negative value

Peak point—the point on the forward current-voltage characteristic corresponding to the lowest positive (forward) voltage at which $dI/dV = 0$

Projected peak point—the point on the forward current characteristic where the current is equal to the peak-point current and where the voltage is greater than the valley-point voltage

Valley point—the point on the forward current-voltage characteristic corresponding to the second lowest positive (forward) voltage at which $dI/dV = 0$

RCA Military—Specification Rectifiers

JAN-1N538	MIL-S-19500/202A
JAN-1N540	MIL-S-19500/202A
JAN-1N547	MIL-S-19500/202A
USAF-1N1183	MIL-E-1/1135(USAF)
JAN-1N1184	MIL-S-19500/297
USAF-1N1184	MIL-E-1/1135(USAF)
JAN-1N1184R	MIL-S-19500/297
USAF-1N1185	MIL-E-1/1135(USAF)
JAN-1N1186	MIL-S-19500/297
USAF-1N1186	MIL-E-1/1135(USAF)
JAN-1N1186R	MIL-S-19500/297
USAF-1N1187	MIL-E-1/1135(USAF)
JAN-1N1188	MIL-S-19500/297
USAF-1N1188	MIL-E-1/1135(USAF)
JAN-1N1188R	MIL-S-19500/297
USAF-1N1189	MIL-E-1/1135(USAF)
JAN-1N1190	MIL-S-19500/297
USAF-1N1190	MIL-E-1/1135(USAF)
JAN-1N1190R	MIL-S-19500/297
USAF-1N1199	MIL-E-1/1108(USAF)
USAF-1N1200	MIL-E-1/1108(USAF)
USAF-1N1201	MIL-E-1/1108(USAF)
USAF-1N1202	MIL-E-1/1108(USAF)
USAF-1N1203	MIL-E-1/1108(USAF)
JAN-1N1204	MIL-S-19500/260
USAF-1N1204	MIL-E-1/1108(USAF)
JAN-1N1204R	MIL-S-19500/260
USAF-1N1205	MIL-E-1/1108(USAF)
USAF-1N1206	MIL-E-1/1108(USAF)

Copies of rectifier specification sheets may be obtained by directing requests to Specifications Division, Naval Supply Depot, 5801 Tabor Avenue, Philadelphia 20, Pa., Attn: CDS

Technical Data for RCA Rectifiers and Diodes

SILICON DIFFUSED-JUNCTION RECTIFIERS

			MAXIMUM RATINGS						CHARACTERISTICS	
RCA TYPE	OUTLINE JEDEC	NO.	I_{FAV} at T_C A	°C	i_{FM} (rep) A	(surge) A	V_{RMS} V	V_{RM} and V_M (block) V	V_{FM} V	I_{RM} (dynamic) mA
1N248C■	DO-5	38	20	150	90	350	39	55▲	0.6	3.8
1N249C■	DO-5	38	20	150	90	350	77	110▲	0.6	3.6
1N250C■	DO-5	38	20	150	90	350	154	220▲	0.6	3.4
1N440B	DO-1	33	0.75	50	3.5	15	70	100	1.5	0.3●
1N441B	DO-1	33	0.75	50	3.5	15	140	200	1.5	0.75●
1N442B	DO-1	33	0.75	50	3.5	15	210	300	1.5	1●
1N443B	DO-1	33	0.75	50	3.5	15	280	400	1.5	1.5●
1N444B	DO-1	33	0.65	50	3.5	15	350	500	1.5	1.75●
1N445B	DO-1	33	0.65	50	3.5	15	420	600	1.5	2●
1N536	DO-1	33	0.75	50	—	15	35	50	1.1	5●
1N537	DO-1	33	0.75	50	—	15	70	100	1.1	5●
1N538	DO-1	33	0.75	50	—	15	140	200	1.1	5●
1N539	DO-1	33	0.75	50	—	15	210	300	1.1	5●
1N540	DO-1	33	0.75	50	—	15	280	400	1.1	5●
1N547	DO-1	33	0.75	50	—	15	420	600	1.2	5●
1N1095	DO-1	33	0.75	50	—	15	350	500	1.2	5●
1N1183A■	DO-5	38	40	150	195	800	35	50	0.65	2.5
1N1184A■	DO-5	38	40	150	195	800	70	100	0.65	2.5
1N1186A■	DO-5	38	40	150	195	800	140	200	0.65	2.5
1N1187A■	DO-5	38	40	150	195	800	212	300	0.65	2.5
1N1188A■	DO-5	38	40	150	195	800	284	400	0.65	2.2
1N1189A■	DO-5	38	40	150	195	800	355	500	0.65	2
1N1190A■	DO-5	38	40	150	195	800	424	600	0.65	1.8
1N1195A■	DO-5	38	20	150	90	350	212	300	0.6	3.2
1N1196A■	DO-5	38	20	150	90	350	284	400	0.6	2.5
1N1197A■	DO-5	38	20	150	90	350	355	500	0.6	2.2
1N1198A■	DO-5	38	20	150	90	350	424	600	0.6	1.5
1N1199A■	DO-4	37	12	150	50	240	35	50	0.55	3
1N1200A■	DO-4	37	12	150	50	240	70	100	0.55	2.5
1N1202A■	DO-4	37	12	150	50	240	140	200	0.55	2

■ Reverse-polarity version available.
▲ V_M (block) is 10% less.
● Static value in μA.

SILICON DIFFUSED-JUNCTION RECTIFIERS (cont'd)

RCA TYPE	OUTLINE JEDEC	OUTLINE NO.	MAXIMUM RATINGS I_{FAV} A	at T_C °C	i_{FM} (rep) A	i_{FM} (surge) A	V_{RMS} V	V_{RM} and V_M (block) V	CHARAC-TERISTICS V_{FM} V	I_{RM} (dynamic) mA
1N1203A■	DO-4	37	12	150	50	240	212	300	0.55	1.75
1N1204A■	DO-4	37	12	150	50	240	284	400	0.55	1.5
1N1205A■	DO-4	37	12	150	50	240	355	500	0.55	1.25
1N1206A■	DO-4	37	12	150	50	240	424	600	0.55	1
1N1341B■	DO-4	37	6	150	25	160	35	50	0.65	0.45
1N1342B■	DO-4	37	6	150	25	160	70	100	0.65	0.45
1N1344B■	DO-4	37	6	150	25	160	140	200	0.65	0.45
1N1345B■	DO-4	37	6	150	25	160	212	300	0.65	0.45
1N1346B■	DO-4	37	6	150	25	160	284	400	0.65	0.45
1N1347B■	DO-4	37	6	150	25	160	355	500	0.65	0.45
1N1348B■	DO-4	37	6	150	25	160	424	600	0.65	0.45
1N1612■	DO-4	37	5	135	15	—	35	50	1.5	1
1N1613■	DO-4	37	5	135	15	—	70	100	1.5	1
1N1614■	DO-4	37	5	135	15	—	140	200	1.5	1
1N1615■	DO-4	37	5	135	15	—	280	400	1.5	1
1N1616■	DO-4	37	5	135	15	—	420	600	1.5	1
1N1763A	DO-1	33	1	75	5	35	280	400	1.2	0.1
1N1764A	DO-1	33	1	75	5	35	350	500	1.2	0.1
1N2858A	DO-1	33	1	75	5	35	35	50	1.2	0.1
1N2859A	DO-1	33	1	75	5	35	70	100	1.2	0.1
1N2860A	DO-1	33	1	75	5	35	140	200	1.2	0.1
1N2861A	DO-1	33	1	75	5	35	210	300	1.2	0.1
1N2862A	DO-1	33	1	75	5	35	280	400	1.2	0.1
1N2863A	DO-1	33	1	75	5	35	350	500	1.2	0.1
1N2864A	DO-1	33	1	75	5	35	420	600	1.2	0.1
1N3193	TO-1‡	34	0.5*	75	6*	35*	140	200	1.2	0.2
1N3194	TO-1‡	34	0.5*	75	6*	35*	280	400	1.2	0.2
1N3195	TO-1‡	34	0.5*	75	6*	35*	420	600	1.2	0.2
1N3196	TO-1‡	34	0.4*	75	5*	35*	560	800	1.2	0.2
1N3253	TO-1°	35	Insulated version of 1N3193							
1N3254	TO-1°	35	Insulated version of 1N3194							
1N3255	TO-1°	35	Insulated version of 1N3195							
1N3256	TO-1°	35	Insulated version of 1N3196							
1N3563	TO-1°	35	0.3*	75	4*	35*	700	1000	1.2	0.2
1N3754	TO-1**	36	0.125	65	1.3	30	35	100	1	0.3
1N3755	TO-1**	36	0.125	65	1.3	30	70	200	1	0.3
1N3756	TO-1**	36	0.125	65	1.3	30	140	400	1	0.3
40108■	DO-4	37	10	150	40	140	—	50	0.6	2
40109■	DO-4	37	10	150	40	140	—	100	0.6	2
40110■	DO-4	37	10	150	40	140	—	200	0.6	1.5
40111■	DO-4	37	10	150	40	140	—	300	0.6	1.5
40112■	DO-4	37	10	150	40	140	—	400	0.6	1
40113■	DO-4	37	10	150	40	140	—	500	0.6	0.85
40114■	DO-4	37	10	150	40	140	—	600	0.6	0.75
40115■	DO-4	37	10	150	40	140	—	800	0.6	0.65

■ Reverse-polarity version available.
‡ Similar to TO-1 package with axial leads.
° Similar to TO-1 package with axial leads and insulated plastic sleeve over metal case.
** Similar to TO-1 package with lead 3 omitted. * With capacitive load.

SILICON DIFFUSED-JUNCTION RECTIFIERS (cont'd)

RCA TYPE	OUTLINE JEDEC	NO.	MAXIMUM RATINGS I_{FAV} at T_C A	°C	i_{FM} (rep) A	(surge) A	V_{RMS} V	V_{RM} and V_M (block) V	CHARACTERISTICS V_{FM} V	I_{RM} (dynamic) mA
40116■	DO-4	37	10	150	40	140	—	1000	0.6	0.5
40208■	DO-5	38	18	150	72	250	—	50	0.65	3
40209■	DO-5	38	18	150	72	250	—	100	0.65	3
40210■	DO-5	38	18	150	72	250	—	200	0.65	2.5
40211■	DO-5	38	18	150	72	250	—	300	0.65	2.5
40212■	DO-5	38	18	150	72	250	—	400	0.65	2
40213■	DO-5	38	18	150	72	250	—	500	0.65	1.75
40214■	DO-5	38	18	150	72	250	—	600	0.65	1.5
40259	DO-4	37	12	150	50	250	424	600	0.55	0.6
40265	TO-1**	36	0.125	65	1.8	30	140	400	1	0.4
40266	DO-1	33	2*	105	10	35	35	100	3	10†
40267	DO-1	33	2*	105	10	35	70	200	3	10†

■ Reverse-polarity version available.
** Similar to TO-1 package with lead 3 omitted.
* With capacitive load.
† Value in μA.

SILICON DIFFUSED-JUNCTION STACK RECTIFIERS

RCA TYPE	OUTLINE NO.	MAXIMUM RATINGS I_{FAV} at 100°C A	i_{FM} (rep) A	(surge) A	V_{RMS} V	V_{RM} (rep) and V_M (block) V	V_{RM}‡ (non-rep) V	CHARACTERISTICS V_{FM}■ V	I_{RM}■ (dynamic) A	C_S (max) pF
CR101	39a	0.385	5	20	895	1265	1520	1.2	0.3	600
CR102	39b	0.355	5	20	1790	2530	3035	2.4	0.3	320
CR103	39c	0.315	5	20	2240	3165	3800	3	0.3	250
CR104	39d	0.270	5	20	3130	4430	5315	4.2	0.3	175
CR105	39e	0.270	5	20	3580	5065	6080	4.8	0.3	160
CR106	39f	0.250	5	20	4475	6330	7600	6	0.3	125
CR107	39g	0.230	5	20	5370	7595	9115	7.2	0.3	105
CR108	39h	0.230	5	20	5820	8230	9875	7.8	0.3	100
CR109	39i	0.230	5	20	6710	9495	11395	9	0.3	90
CR110	39j	0.230	5	20	7160	10130	12155	9.6	0.3	80
CR201	40a	0.155	3	10	1345	1900	2280	1.8	0.1	—
CR203	40b	0.155	3	10	2240	3165	3800	3	0.1	—
CR204	40c	0.155	3	10	3395	4800	5760	3.6	0.1	—
CR206	40d	0.155	3	10	4475	6330	7600	6	0.1	—
CR208	40e	0.155	3	10	5655	8000	9600	6	0.1	—
CR210	40f	0.155	3	10	7070	10000	12000	7.2	0.1	—
CR212	40g	0.155	3	10	8485	12000	14400	9	0.1	—
CR301	41a	2.5	—	250	1695	2400	2880	—	1.5	**
CR302	41b	2.5	—	250	2545	3600	4320	—	1.5	**
CR303	41c	2.5	—	250	3395	4800	5760	—	1.5	**
CR304	41d	2.5	—	250	4240	6000	7200	—	1.5	**
CR305	41e	2.5	—	250	5090	7200	8640	—	1.5	**
CR306	41f	2.5	—	250	5935	8400	10080	—	1.5	**
CR307	41g	2.5	—	250	6785	9600	11520	—	1.5	**
CR311	41h	4.5	—	250	1695	2400	2880	—	1.5	**

‡ For duration of 5 ms max; T_C = 60 to 125°C.
■ At maximum rated operating conditions.
** C_S typically 0.01 μF per cell.

SILICON DIFFUSED-JUNCTION STACK RECTIFIERS (cont'd)

RCA TYPE	OUTLINE NO.	MAXIMUM RATINGS						CHARACTERISTICS		
		I_{FAV} at 100°C A	i_{FM} (rep) A	i_{FM} (surge) A	V_{RMS} V	V_{RM} (rep) and V_M (block) V	V_{RM}‡ (non-rep) V	V_{FM}■ V	I_{RM}■ (dynamic) A	C_S (max) pF
CR312	41i	4.5	—	250	2545	3600	4320	—	1.5	**
CR313	41j	4.5	—	250	3395	4800	5760	—	1.5	**
CR314	41k	4.5	—	250	4240	6000	7200	—	1.5	**
CR315	41l	4.5	—	250	5090	7200	8640	—	1.5	**
CR316	41m	4.5	—	250	5935	8400	10080	—	1.5	**
CR317	41n	4.5	—	250	6785	9600	11520	—	1.5	**
CR321	41o	6	—	400	1695	2400	2880	—	1.5	**
CR322	41p	6	—	400	2545	3600	4320	—	1.5	**
CR323	41q	6	—	400	3395	4800	5760	—	1.5	**
CR324	41r	6	—	400	4240	6000	7200	—	1.5	**
CR325	41s	6	—	400	5090	7200	8640	—	1.5	**
CR331	41t	8.5	—	400	1695	2400	2880	—	1.5	**
CR332	41u	8.5	—	400	2545	3600	4320	—	1.5	**
CR333	41v	8.5	—	400	3395	4800	5760	—	1.5	**
CR334	41w	8.5	—	400	4240	6000	7200	—	1.5	**
CR335	41x	8.5	—	400	5090	7200	8640	—	1.5	**
CR341	41y	11.5	—	850	1695	2400	2880	—	1.5	**
CR342	41z	11.5	—	850	2545	3600	4320	—	1.5	**
CR343	41aa	11.5	—	850	3395	4800	5760	—	1.5	**
CR344	41bb	11.5	—	850	4240	6000	7200	—	1.5	**
CR351	41cc	17.5	—	850	1695	2400	2880	—	1.5	**
CR352	41dd	17.5	—	850	2545	3600	4320	—	1.5	**
CR353	41ee	17.5	—	850	3395	4800	5760	—	1.5	**
CR354	41ff	17.5	—	850	4240	6000	7200	—	1.5	**

‡ For duration of 5 ms max; $T_C = 60$ to 125°C.

■ At maximum rated operating conditions.

** C_S typically 0.01 μF per cell.

SILICON BRIDGE RECTIFIERS

RCA TYPE	OUTLINE NO.	AVERAGE DC OUTPUT A	AVERAGE DC OUTPUT V	RMS SUPPLY V
CR401†	41a	18	200	222
CR402†	41a	18	400	444
CR403†	41c	18	800	888
CR404†	41o	34	200	222
CR405†	41o	34	400	444
CR406†	41v	34	800	888
CR407†	41y	70	200	222
CR408†	41y	70	400	444
CR409†	41aa	70	800	888
CR501‡	41b	24	300	222
CR502‡	41b	24	600	444
CR503‡	41p	46	300	222
CR504‡	41p	46	600	444
CR505‡	41z	92	300	222
CR506‡	41z	92	600	441

† Single-phase, full-wave types.

‡ Three-phase, full-wave types.

SILICON PLUG-IN RECTIFIERS

These high-voltage diffused-junction types are direct replacements for the mercury-vapor and gas rectifier tubes indicated. Data for the tube-type rectifiers are given in the **RCA Transmitting Tube Manual TT-5.**

RCA TYPE	OUTLINE NO.	REPLACES TYPE(S)
CR273/8008	44	8008
CR274/872A	45	872, 872A
CR275/866A/3B28	46	866, 866A, 3B28

SILICON CONTROLLED RECTIFIERS

	MAXIMUM RATINGS									
		V_{RM}								
RCA TYPE	I_{FRMS} A	non-rep V	(rep) V	V_{FBOM} (rep) V	i_{FM} (surge) A	I_{FAV} A	P_{GM} W	P_{GAV} W	T_{STG} °C	T_C °C
2N681	25	35	25	25	150	16	5	0.5	150	125
2N682	25	75	50	50	150	16	5	0.5	150	125
2N683	25	150	100	100	150	16	5	0.5	150	125
2N684	25	225	150	150	150	16	5	0.5	150	125
2N685	25	300	200	200	150	16	5	0.5	150	125
2N686	25	350	250	250	150	16	5	0.5	150	125
2N687	25	400	300	300	150	16	5	0.5	150	125
2N688	25	500	400	400	150	16	5	0.5	150	125
2N689	25	600	500	500	150	16	5	0.5	150	125
2N690	25	720	600	600	150	16	5	0.5	150	125
2N1770	7.4	35	25	600	60	4.7	5	0.5	150	125
2N1771	7.4	75	50	600	60	4.7	5	0.5	150	125
2N1772	7.4	150	100	600	60	4.7	5	0.5	150	125
2N1773	7.4	225	150	600	60	4.7	5	0.5	150	125
2N1774	7.4	300	200	600	60	4.7	5	0.5	150	125
2N1775	7.4	350	250	600	60	4.7	5	0.5	150	125
2N1776	7.4	400	300	600	60	4.7	5	0.5	150	125
2N1777	7.4	500	400	600	60	4.7	5	0.5	150	125
2N1778	7.4	600	500	600	60	4.7	5	0.5	150	125
2N1842A	16	35	25	25	125	10	5	0.5	125	125
2N1843A	16	75	50	50	125	10	5	0.5	125	125
2N1844A	16	150	100	100	125	10	5	0.5	125	125
2N1845A	16	225	150	150	125	10	5	0.5	125	125
2N1846A	16	300	200	200	125	10	5	0.5	125	125
2N1847A	16	350	250	250	125	10	5	0.5	125	125
2N1848A	16	400	300	300	125	10	5	0.5	125	125
2N1849A	16	500	400	400	125	10	5	0.5	125	125
2N1850A	16	600	500	500	125	10	5	0.5	125	125
2N3228	5	330	200	600	60	3.2	5	—	125	100
2N3525	5	660	400	600	60	3.2	5	—	125	100
2N3528	2	330	200	600	60	1.3	5	—	125	100
2N3529	2	660	400	600	60	1.3	5	—	125	100
2N3668	12.5	150	100	600	200	8	5	0.5	125	100
2N3669	12.5	330	200	600	200	8	5	0.5	125	100
2N3670	12.5	660	400	600	200	8	5	0.5	125	100
2N3870	35	150	100	600	350	22	40■	0.5	125	100
2N3871	35	330	200	700	350	22	40■	0.5	125	100
2N3872	35	660	400	700	350	22	40■	0.5	125	100
2N3873	35	700	600	700	350	22	40■	0.5	125	100
2N3896	35	150	100	700	350	22	40■	0.5	125	100
2N3897	35	330	200	700	350	22	40■	0.5	125	100
2N3898	35	600	400	700	350	22	40■	0.5	125	100
2N3899	35	700	600	700	350	22	40■	0.5	125	100
40216	900*	720	600	—	—	—	5	0.5	150	125
40378	7	330	200	600	80	4.5	13■	0.2	150	100
40379	7	660	400	600	80	4.5	13■	0.2	150	100

* Pulsed.

■ For pulse time $t_p = 10\ \mu s$.

SILICON CONTROLLED RECTIFIERS

CHARACTERISTICS							OUTLINE		
V_{BOO} V	I_{FBOAV} mA	I_{RBOAV} mA	V_F V	I_{GT} mA	V_{GT} V	i_{HOO} mA	JEDEC	NO.	RCA TYPE
25	6.5	6.5	0.86▲	25‡	3	15‡	TO-48	17	**2N681**
50	6.5	6.5	0.86▲	25‡	3	15‡	TO-48	17	**2N682**
100	6.5	6.5	0.86▲	25‡	3	15‡	TO-48	17	**2N683**
150	6.5	6.5	0.86▲	25‡	3	15‡	TO-48	17	**2N684**
200	6.0	6.0	0.86▲	25‡	3	15‡	TO-48	17	**2N685**
250	5.5	5.5	0.86▲	25‡	3	15‡	TO-48	17	**2N686**
300	5.0	5.0	0.86▲	25‡	3	15‡	TO-48	17	**2N687**
400	4.0	4.0	0.86▲	25‡	3	15‡	TO-48	17	**2N688**
500	3.0	3.0	0.86▲	25‡	3	15‡	TO-48	17	**2N689**
600	2.5	2.5	0.86▲	25‡	3	15‡	TO-48	17	**2N690**
25	4.5	4.5	1.85▲	15	2	10‡	TO-64	30	**2N1770**
50	4.5	4.5	1.85▲	15	2	10‡	TO-64	30	**2N1771**
100	4.5	4.5	1.85▲	15	2	10‡	TO-64	30	**2N1772**
150	4.0	4.0	1.85▲	15	2	10‡	TO-64	30	**2N1773**
200	3.0	3.0	1.85▲	15	2	10‡	TO-64	30	**2N1774**
250	2.5	2.5	1.85▲	15	2	10‡	TO-64	30	**2N1775**
300	2.0	2.0	1.85▲	15	2	10‡	TO-64	30	**2N1776**
400	1.0	1.0	1.85▲	15	2	10‡	TO-64	30	**2N1777**
500	1.0	1.0	1.85▲	15	2	10‡	TO-64	30	**2N1778**
25	22.5	22.5	1.2▲	45‡	3.7	8‡	TO-48	17	**2N1842A**
50	19.0	19.0	1.2▲	45‡	3.7	8‡	TO-48	17	**2N1843A**
100	12.5	12.5	1.2▲	45‡	3.7	8‡	TO-48	17	**2N1844A**
150	6.5	6.5	1.2▲	45‡	3.7	8‡	TO-48	17	**2N1845A**
200	6.0	6.0	1.2▲	45‡	3.7	8‡	TO-48	17	**2N1846A**
250	5.5	5.5	1.2▲	45‡	3.7	8‡	TO-48	17	**2N1847A**
300	5.0	5.0	1.2▲	45‡	3.7	8‡	TO-48	17	**2N1848A**
400	4.0	4.0	1.2▲	45‡	3.7	8‡	TO-48	17	**2N1849A**
500	3.0	3.0	1.2▲	45‡	3.7	8‡	TO-48	17	**2N1850A**
200	1.5●	0.75●	2.8	8	1.2	12	TO-66	22	**2N3228**
400	3.0●	1.5●	2.8	8	1.2	12	TO-66	22	**2N3525**
200	1.5●	0.75●	2.8	8	1.2	12	TO-8	5	**2N3528**
400	3.0●	1.5●	2.8	8	1.2	12	TO-8	5	**2N3529**
100	2.0●	1.0●	1.8	25	1.5	20	TO-3	2	**2N3668**
200	2.5●	1.25●	1.8	25	1.5	20	TO-3	2	**2N3669**
400	3.0●	1.5●	1.8	25	1.5	20	TO-3	2	**2N3670**
100	2.0●	3.0●	2.1	25	1.1■	20	—	31	**2N3870**
200	2.5●	3.0●	2.1	25	1.1■	20	—	31	**2N3871**
400	3.0●	3.0●	2.1	25	1.1■	20	—	31	**2N3872**
600	4.0●	3.0●	2.1	25	1.1■	20	—	31	**2N3873**
100	2.0	3.0	2.1	25	1.1■	20	—	32	**2N3896**
200	2.5	3.0	2.1	25	1.1■	20	—	32	**2N3897**
400	3.0	3.0	2.1	25	1.1■	20	—	32	**2N3898**
600	4.0	3.0	2.1	25	1.1■	20	—	32	**2N3899**
600	10.0	10.0	—	45	3.7†	8	TO-48	17	**40216**
200	1.0	0.5	2.5	8	1.2†	12	—	29	**40378**
400	2.0	1.0	2.5	8	1.2†	12	—	29	**40379**

▲ DC value. ‡ At $T_C = 125°C$. ● Maximum instantaneous value (i_{FBOM} or i_{RBOM}).
■ Critical dv/dt = 100 V/μs. † Critical dv/dt = 200 V/μs.

TUNNEL DIODES

Electrical Characteristics (At $T_A = 25°C$)

RCA Type	Peak Forward Current (mA)	Max Valley Current (mA)	Min Peak-to-Valley-Current Ratio	Peak Voltage (mV)	Min Valley Voltage (mV)	Forward Voltage (mV)	Max Capacitance* (pF)	Max Series Resistance (ohms)	Rise Time (ps)	
									max.	typ.
1N3128	4.75-5.25	0.6	8:1	40-80	280	445-530	15	3	5000	1000
1N3129	19-21	2.4	8:1	50-100	300	474-575	20	2.5	2000	300
1N3130	47.5-52.5	6	8:1	70-120	350	520-620	25	1.5	500	160
1N3847	4.5-5.5	0.75	6:1	—	—	430-590	25	3	—	900
1N3848	9-11	1.5	6:1	—	—	440-600	25	2.5	—	1800
1N3849	18-22	3	6:1	—	—	460-620	30	2	—	600
1N3850	45-55	7.5	6:1	—	—	530-640	40	1.5	—	350
1N3851	90-110	15	8:1	—	—	540-650	40	1	—	125
1N3852	4.75-5.25	0.6	8:1	50-90	330	490-560	15	3	—	1200
1N3853	9.5-10.5	1.2	8:1	55-95	350	510-580	15	2.5	—	600
1N3854	19-21	2.4	8:1	65-105	365	530-600	20	2	—	400
1N3855	47.5-52.5	6	8:1	80-130	380	550-620	25	1.5	—	200
1N3856	95-105	12	8:1	90-140	390	560-630	25	1	—	75
1N3857	4.75-5.25	0.6	8:1	50-90	330	490-560	8	3	—	600
1N3858	9.5-10.5	1.2	8:1	55-95	350	510-580	8	2.5	—	300
1N3859	19-21	2.4	8:1	65-105	365	530-600			—	150
1N3860	47.5-52.5	6	8:1	80-130	380	550-620			—	200

TUNNEL RECTIFIERS

Electrical Characteristics (At $T_A = 25°C$)

RCA Type	Material	Outline	Peak Current (mA)	Min Forward Voltage at 1 mA (mV)	Max Reverse Voltage at 10 mA (mV)	Max Reverse Voltage at 30 mA (mV)	Max Capacitance (pF)
1N3861	Ge	42	0.1-1	400	170	—	6■
1N3862	Ge	42	0.1-1	420	150	300	4■
1N3863	Ge	42	0.1-0.5	435	150	300	4■

* Includes case capacitance of 0.8 pF. ■ Includes case capacitance of 0.4 pF.

COMPENSATING DIODE—1N2326

Ge alloy-junction type used in temperature- and voltage-compensation applications. Similar to JEDEC TO-1 (2-lead), Outline No.36. Terminals: 1 - cathode, 2 - anode.

MAXIMUM RATINGS

Reverse Voltage	V_{RM}	−1	V
Peak Recurrent Current	i_{FM}(rep)	200	mA
DC Forward Current	I_{FM}	100	mA
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

		min	*typ*	*max*	
DC Forward Voltage Drop:					
$I_{FAV} = 2$ mA	V_{FAV}	120	135	150	mV
$I_{FAV} = 100$ mA	V_{FAV}	240	260	280	mV

TUNNEL DIODES

Maximum Ratings (At $T_A = 25°C$)

DC Current (mA) Forward	DC Current (mA) Reverse	Dissipation ‡ (mW)	Ambient-Temperature (°C) Range Operating	Ambient-Temperature (°C) Range Storage	Lead Temperature (°C) (3 seconds maximum)	Material	Out-line	RCA Type
40	70	20	−65 to 150	−65 to 175	175	Ge	43	1N3128
55	85	30	−65 to 150	−65 to 175	175	Ge	43	1N3129
70	100	40	−65 to 150	−65 to 175	175	Ge	43	1N3130
10	15	5	−35 to 100		175	Ge	43	1N3847
18	25	15	−35 to 100		175	Ge	43	1N3848
35	50	20	−35 to 100		175	Ge	43	1N3849
85	125	50	−35 to 100		175	Ge	43	1N3850
170	250	100	−35 to 100		175	Ge	43	1N3851
10	15	5	−35 to 100		175	Ge	43	1N3852
18	25	10	−35 to 100		175	Ge	43	1N3853
35	50	20	−35 to 100		175	Ge	43	1N3854
85	125	50	−35 to 100		175	Ge	43	1N3855
170	250	100	−35 to 100		175	Ge	43	1N3856
10	15	5	−35 to 100		175	Ge	43	1N3857
18	25	10	−35 to 100		175	Ge	43	1N3858
35	50	20	−35 to 100		175	Ge	43	1N3859
85	125	50	−35 to 100		175	Ge	43	1N3860

TUNNEL RECTIFIERS

Maximum Ratings (At $T_A = 25°C$)

DC Current (mA) Forward	DC Current (mA) Reverse	Dissipation ‡ (mW)	Ambient-Temperature (°C) Range Operating and Storage	Lead Temperature (3 seconds maximum)	RCA Type
10	30	10	−35 to 100	175	1N3861
10	30	10	−35 to 100	175	1N3862
10	30	10	−35 to 100	175	1N3863

‡ Above 25°C, derate linearly to 0 mW at 100°C.

DAMPER DIODE—1N4785

Ge diffused-junction type used in transistorized 114-degree, 18-kilovolt horizontal-deflection systems in television receivers with types 2N3730, 2N3731, and 2N3732. JEDEC TO-3, Outline No.2. Terminals: 1 - cathode, 2 - no connection, Mounting Flange - anode and case.

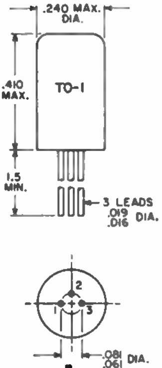
MAXIMUM RATINGS

Peak Reverse Voltage	v_{RM}	320	V
Continuous Reverse Voltage	V_{RM}	60	V
Peak Forward Current	i_{FM}	10	A
Average Forward Current	I_{FM}	7	A
Temperature Range:			
Operating (T_J) and Storage (T_{STG})		−65 to 85	°C
Pin-Soldering Temperature	T_P	230	°C

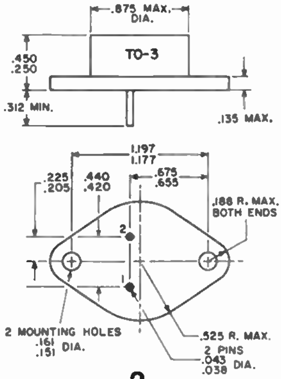
CHARACTERISTICS

Peak Reverse Voltage ($I_R = 1$ mA)	v_{RM}	320 min	V
Reverse Current, Static ($V_R = 10$ V)	I_R	150 max	µA
Forward Voltage Drop, Static ($I_F = 7$ A)	V_F	0.77 max	V

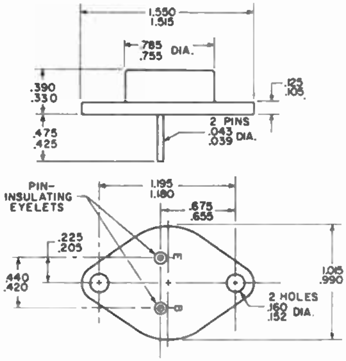
Outlines



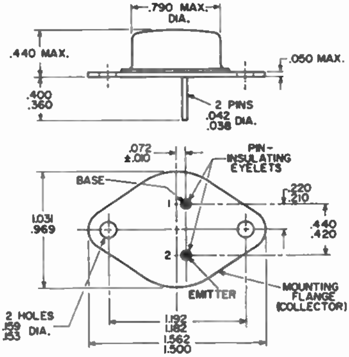
1



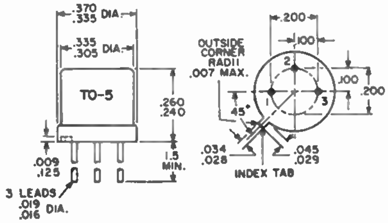
2



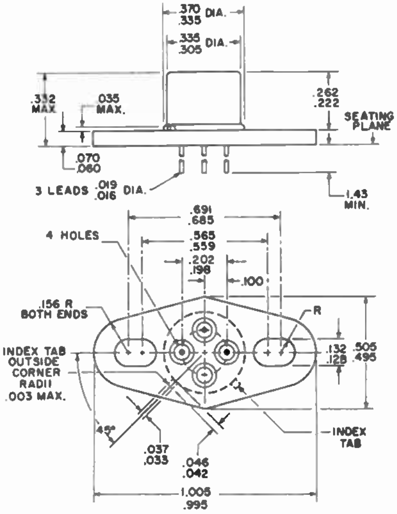
2 (Variant 1)



2 (Variant 2)

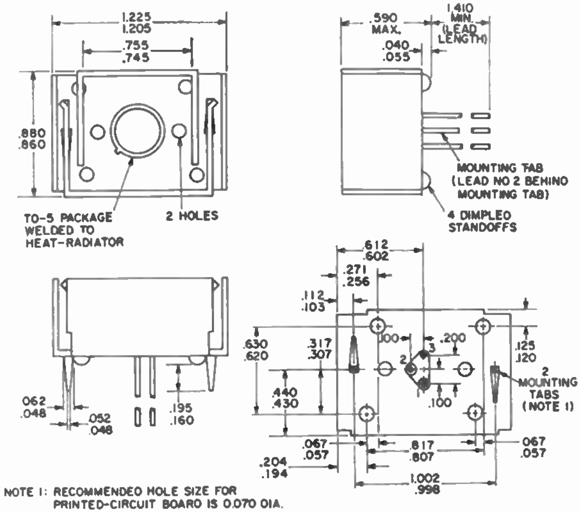


3



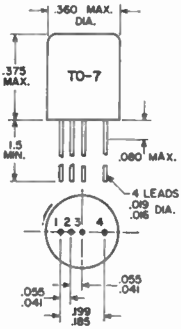
3 (With Flange)

Outlines (cont'd)

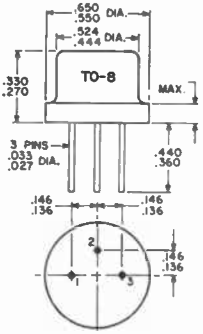


NOTE 1: RECOMMENDED HOLE SIZE FOR PRINTED-CIRCUIT BOARD IS 0.070 DIA.

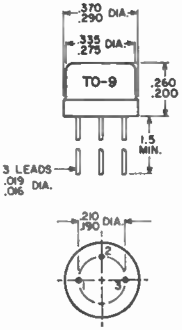
3 (With Heat Radiator)



4

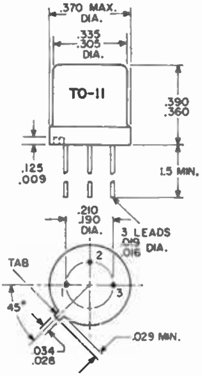


5

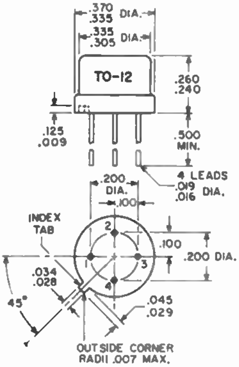


6

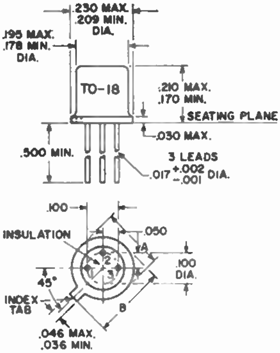
Outlines (cont'd)



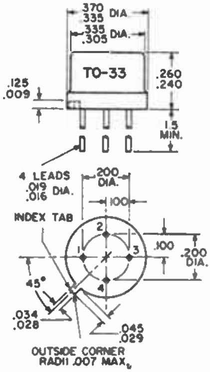
7



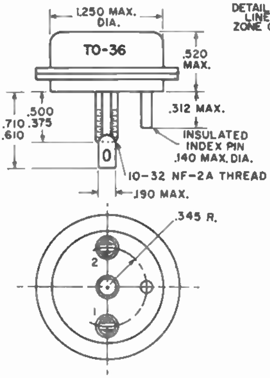
8



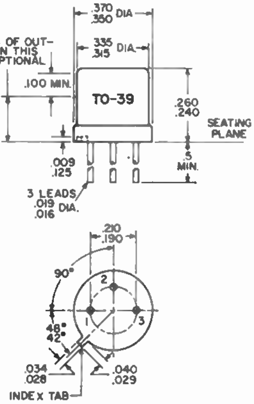
9



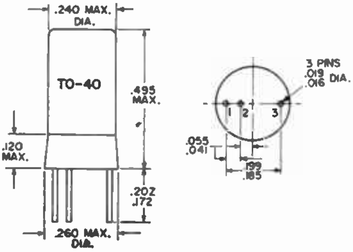
10



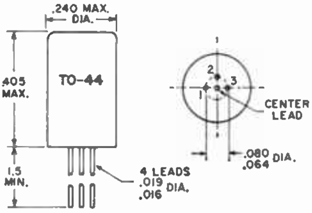
11



12

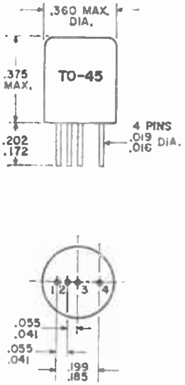


13

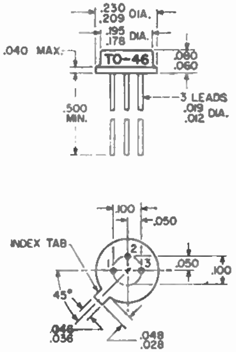


14

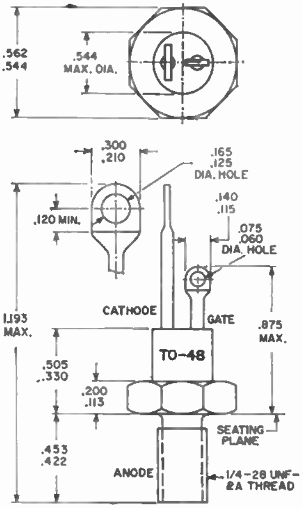
Outlines (cont'd)



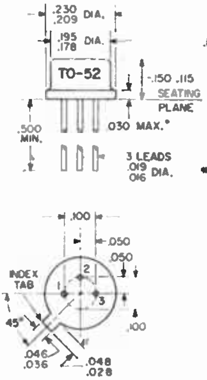
15



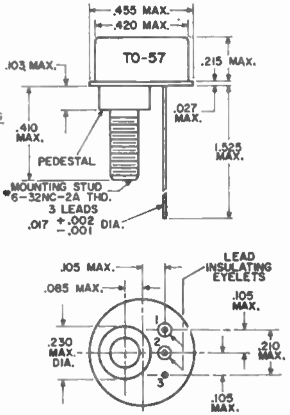
16



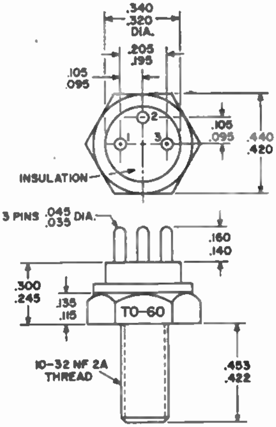
17



18

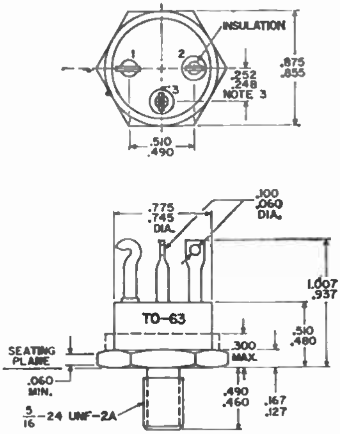


19

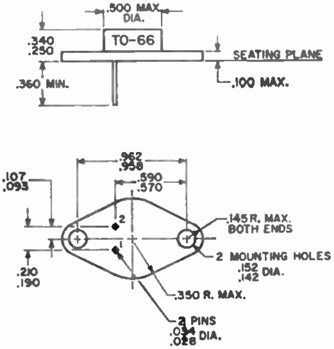


20

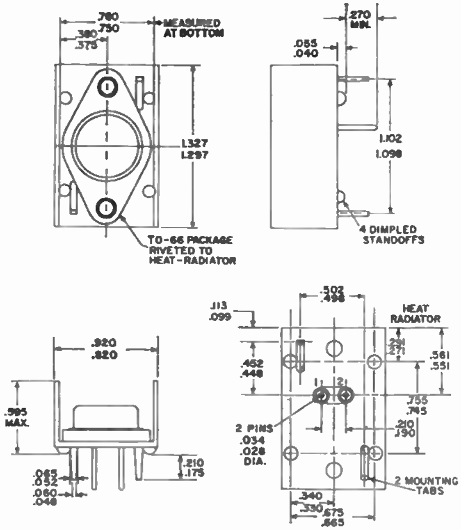
Outlines (cont'd)



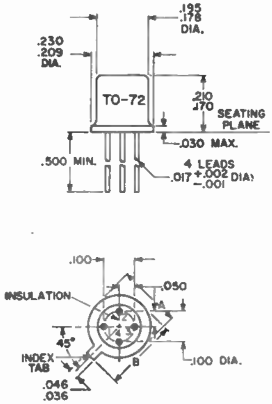
21



22

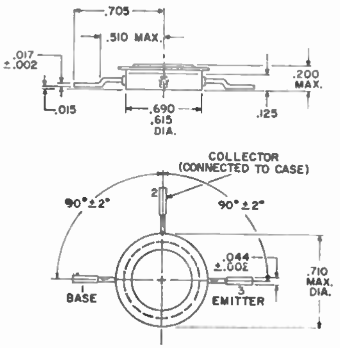


22 (With Heat Radiator)

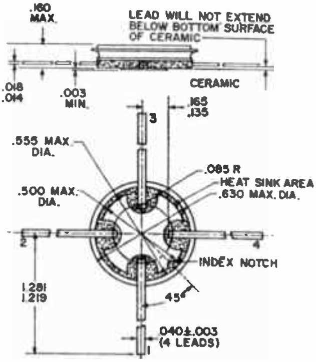


23

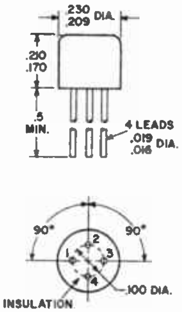
Outlines (cont'd)



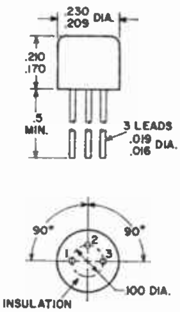
24



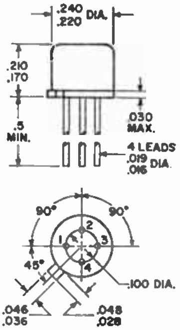
25



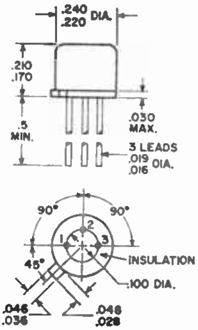
26 (4-Lead)



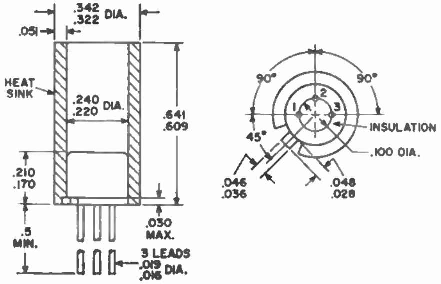
26 (3-Lead)



27 (4-Lead)

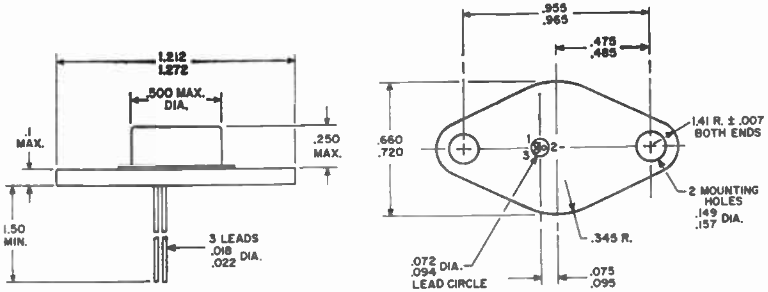


27 (3-Lead)

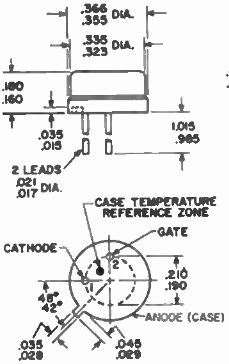


27 (3-Lead With Heat Sink)

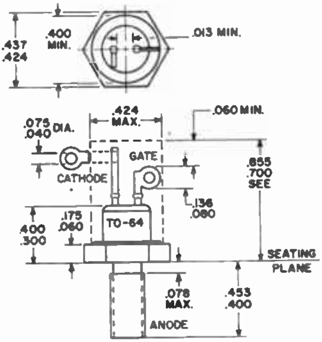
Outlines (cont'd)



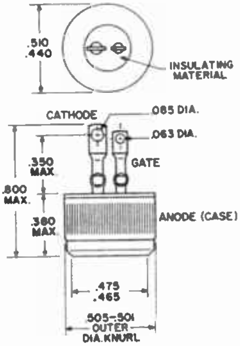
28



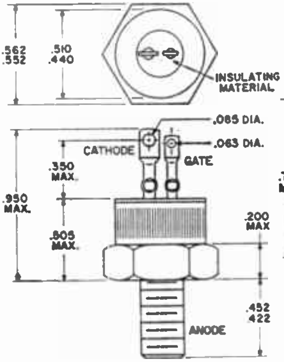
29



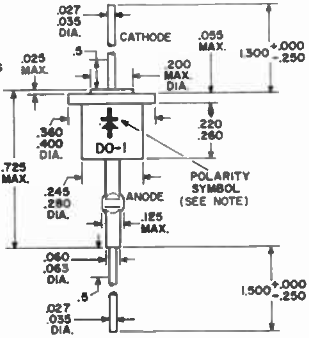
30



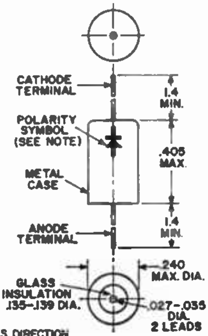
31 (Press Fit)



32



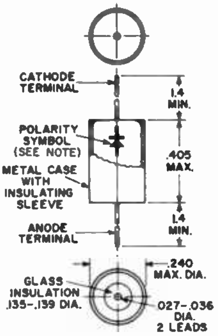
33



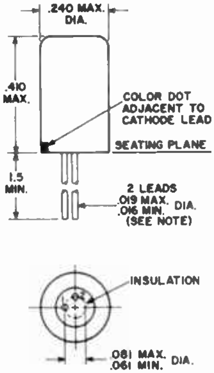
NOTE: ARROW INDICATES DIRECTION OF FORWARD CURRENT AS INDICATED BY DC AMMETER

34

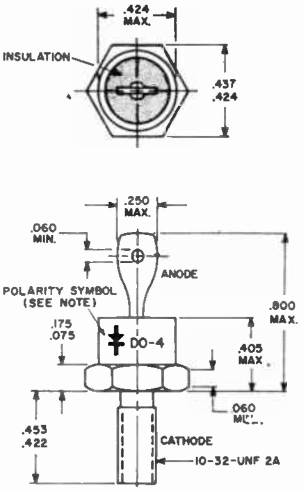
Outlines (cont'd)



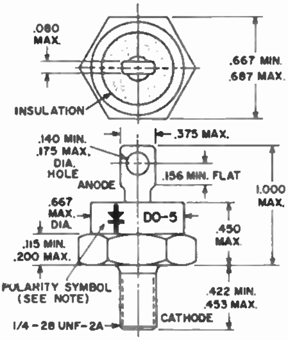
35



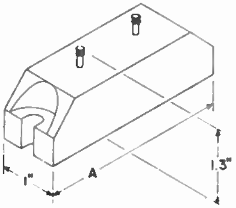
36



37

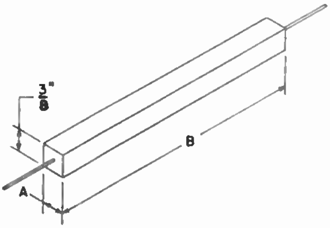


38



Outline No.	"A" (Inches)
39a	2⅜
39b	2⅜
39c	2⅜
39d	3¼
39e	3¼
39f	4½
39g	4½
39h	4½
39i	5½
39j	5½

39

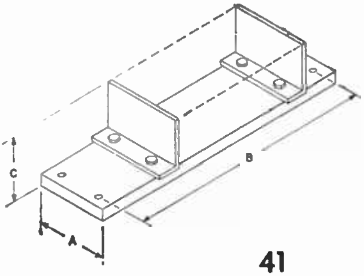


Outline No.	"A" (Inches)	"B" (Inches)
40a	⅜	2
40b	⅜	3½
40c	⅜	4½
40d	¾	3½
40e	¾	3½
40f	¾	4½
40g	¾	4½

NOTE: ARROW INDICATES DIRECTION OF FORWARD CURRENT AS INDICATED BY DC AMMETER

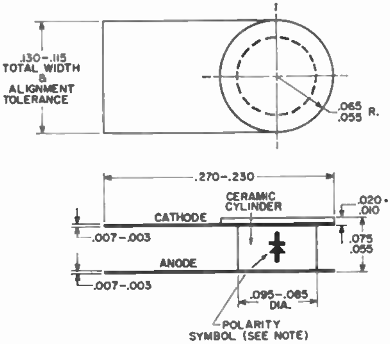
40

Outlines (cont'd)

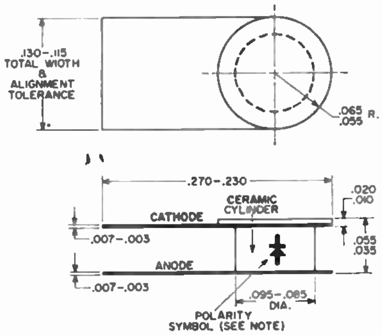


41

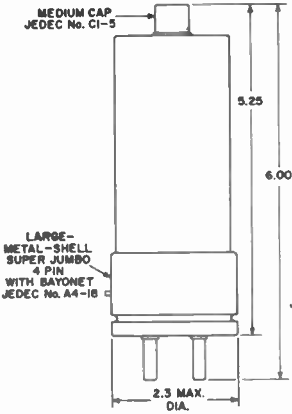
Outline No.	"A" (Inches)	"B" (Inches)	"C" (Inches)
41a	2¼	5¼	2
41b	2¼	7	2
41c	2¼	8¾	2
41d	2¼	10½	2
41e	2¼	12¼	2
41f	2¼	14	2
41g	2¼	15¾	2
41h	2¼	5¼	2
41i	2¼	7	2
41j	2¼	8¾	2
41k	2¼	10½	2
41l	2¼	12¼	2
41m	2¼	14	2
41n	2¼	15¾	2
41o	3	7⅛	3⅜
41p	3	9½	3⅜
41q	3	11⅞	3 3/16
41r	3	14¼	3 3/16
41s	3	16 5/16	3 3/16
41t	3	7⅛	3⅜
41u	3	9½	3 3/16
41v	3	11⅞	3 3/16
41w	3	14¼	3 3/16
41x	3	16 5/16	3 3/16
41y	5½	7 11/16	5 3/16
41z	5½	10¼	5 3/16
41aa	5½	12 13/16	5 3/16
41bb	5½	15 3/16	5 3/16
41cc	5½	7 11/16	5⅜
41dd	5½	10¼	5⅜
41ee	5½	12 13/16	5 3/16
41ff	5½	15⅜	5⅜



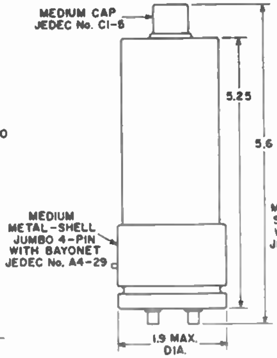
42



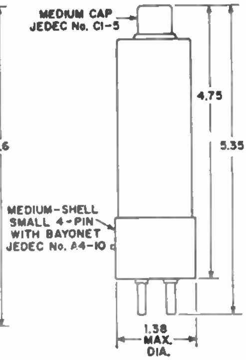
43



44



45

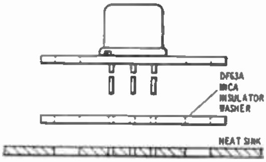


46

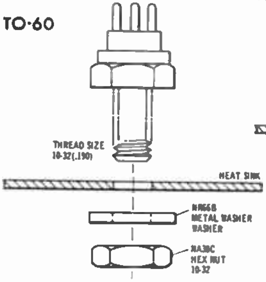
NOTE: ARROW INDICATES DIRECTION
OF FORWARD CURRENT AS
INDICATED BY DC AMMETER

Mounting Hardware

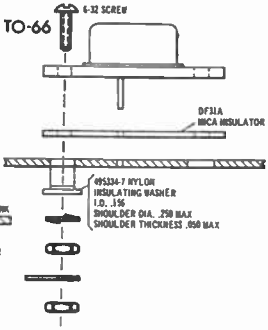
"Flange-Type TO-5"



TO-60

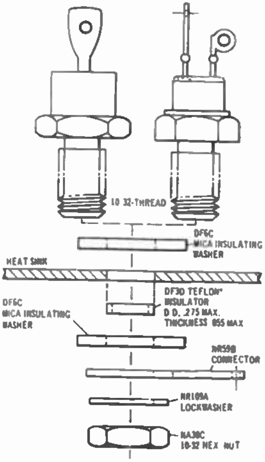


TO-66

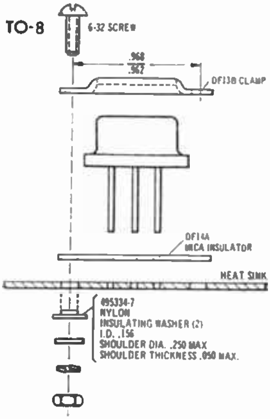


DO-4

TO-64

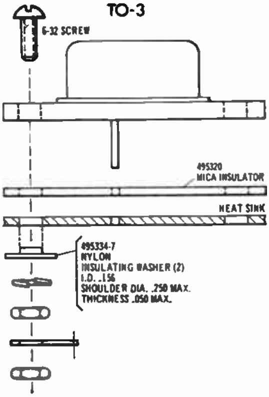


TO-8

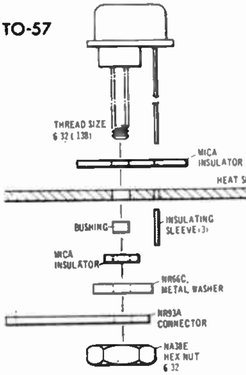


Mounting Hardware (cont'd)

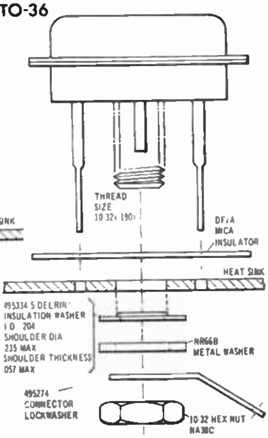
TO-3



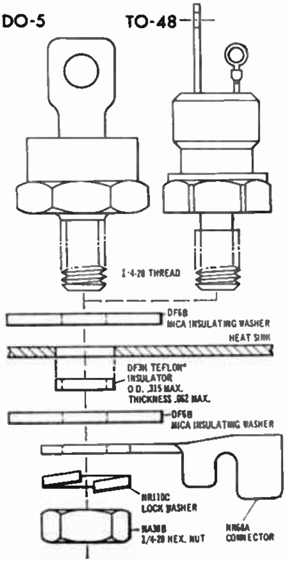
TO-57



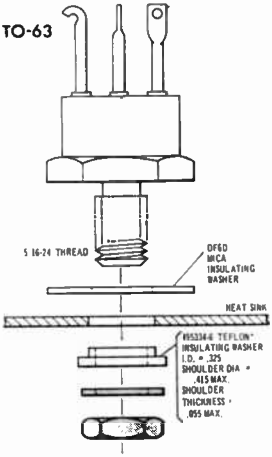
TO-36



DO-5 TO-48



TO-63



Circuits

THE CIRCUITS in this section illustrate some of the more important applications of RCA semiconductor devices; they are not necessarily examples of commercial practice. These circuits have been conservatively designed and are capable of excellent performance. The brief description provided with each circuit explains the functional relationships of the various stages and points out the intended applications, the major performance characteristics, and significant design features of the over-all circuit. Detailed descriptive information on individual circuit stages (such as detectors, amplifiers, or oscillators) is given in the section on **Transistor Applications** earlier in this Manual, as well as in many textbooks on semiconductor circuits.

Electrical specifications are given for circuit components to assist those interested in home construction. Layouts and mechanical details are omitted because they vary widely with the requirements of individual set builders and with the sizes and shapes of the components employed.

Performance of these circuits depends as much on the quality of the components selected and the care employed in layout and construction as on the circuits themselves. Good signal reproduction from receivers and amplifiers requires the use of good-quality speakers, transformers, chokes and input sources (microphones, phonograph pickups, etc.).

Coils for the receiver circuits may be purchased at local parts dealers by specifying the characteristics required: for rf coils, the circuit position (antenna or interstage), tuning range desired, and tuning capacitances employed; for if coils or transformers, the intermediate frequency, circuit position (1st if, 2nd if, etc.), and, in some cases, the associated transistor types; for oscillator coils, the receiver tuning range, intermediate frequency, type of converter transistor, and type of winding (tapped or transformer-coupled).

The voltage ratings specified for capacitors are the minimum dc working voltages required. Paper, mica, or ceramic capacitors having higher voltage ratings than those specified may be used except insofar as the physical sizes of such capacitors may affect equipment layout. However, if electrolytic capacitors having substantially higher voltage ratings than those specified are used, they may not "form" completely at the operating voltage, with the result that the effective capacitances of such units may be below their rated value. The wattage ratings specified for resistors assume methods of construction that provide adequate ventilation; compact installations having poor ventilation may require resistors of higher wattage ratings.

Circuits which work at very high frequencies or which are required to handle very wide bandwidths demand more than ordinary skill and experience in construction. Placement of component parts is quite critical and may require considerable experimentation. All rf leads to components including bypass capacitors must be kept short and must be properly dressed to minimize undesirable coupling and capacitance effects. Correct circuit alignment and oscillator tracking may require the use of a cathode-ray oscilloscope, a high-impedance vacuum-tube voltmeter, and a signal generator capable of supplying a properly modulated signal at the appropriate frequencies. Unless the builder has had considerable experience with broad-band, high-frequency circuits, he should not undertake the construction of such circuits.

LIST OF CIRCUITS

LIST OF CIRCUITS (cont'd)

MANUFACTURERS OF COILS AND ASSOCIATED MATERIALS

REFERRED TO IN PARTS LISTS

Arnold Magnetics
6050 West Jefferson Blvd.
Los Angeles, Calif.

Automatic Manufacturing Co.
Division of General Instrument Co.
65 Governeur Street
Newark, N. J.

Better Coil and Transformer Inc.
Goodland, Ind.

Columbus Process Co.
Columbus, Ind.

General Ceramic Corp.
Crows Mill Road
Keasby, N. J.

Lafayette Radio Electronics
Mail Order and Sales Center
111 Jericho Turnpike
Syosset, L. I., N. Y.

P. R. Mallory and Co. Inc.
3029 E. Washington Street
Indianapolis, Ind.

Microtran Co. Inc.
145 E. Mineola Avenue
Valley Stream, N. Y.

Mid-West Coil and Transformer Co.
1642 N. Halstead
Chicago, Ill.

Nytronics, Inc.
550 Springfield Ave.
Berkeley Hgts., N. J.

J. W. Miller Co.
5917 South Main Street
Los Angeles, Calif.

Radio Condenser Corp.
Davis and Copewood Street
Camden, N. J.

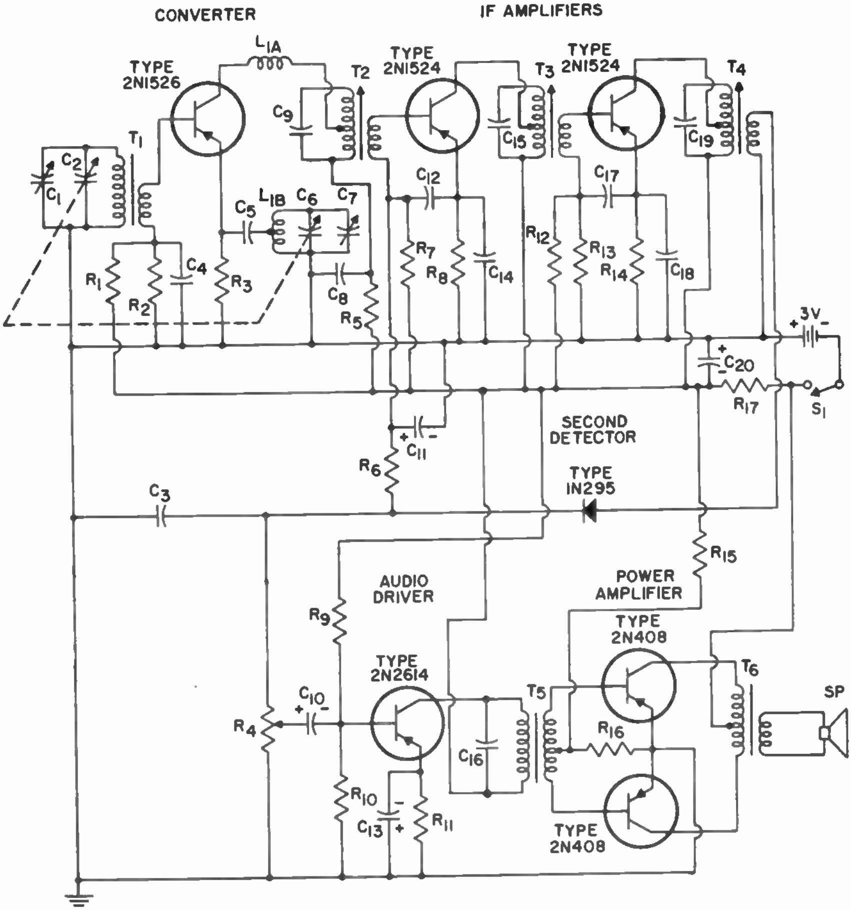
Stancor Electronics, Inc.
3501 West Addison Street
Chicago, Ill.

Triad
305 N. Briant Street
Huntington, Indiana

Thompson-Ramo-Wooldridge, Inc.
Electronic Components Division
666 Garland Place
Des Plaines, Ill.

Thordarson
7th and Bellmont
Mt. Carmel, Ill.

12-1 3-VOLT PORTABLE RADIO RECEIVER



Circuit Description

This portable superheterodyne receiver using low-voltage germanium transistors operates from a battery supply voltage of only 3 volts. A ferrite-rod antenna assembly, which includes the tuned antenna transformer T_1, selects the amplitude-modulated rf signal from the desired radio broadcast station and couples it to the base of the 2N1526 converter transistor. In the converter stage, the modulated rf signal

12-1 3-VOLT PORTABLE RADIO RECEIVER (cont'd)

Circuit Description (cont'd)

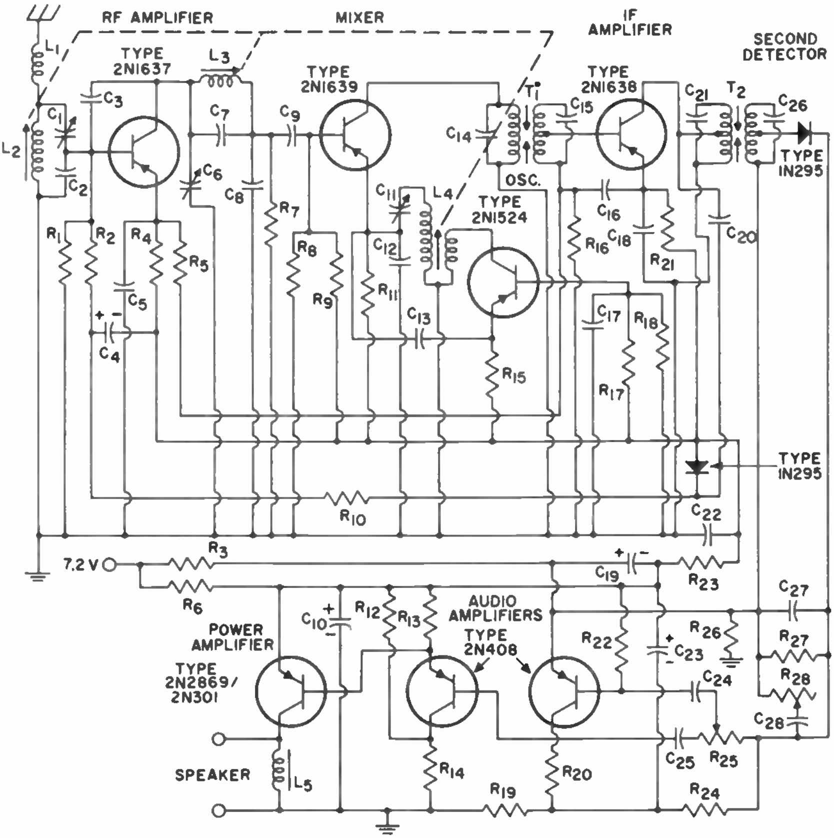
is mixed with a local-oscillator signal developed by the tuned circuit L_{1B}, C_6, and C_7 to produce the 455-kc/s difference frequency used as the intermediate frequency. The antenna and oscillator tuning capacitors C_2 and C_6 are mechanically ganged so that the antenna-input and oscillator circuits are adjusted together to maintain this difference frequency. Trimmer capacitors C_1 and C_7 are adjusted to maintain the required tracking relationship. Positive feedback for the oscillator circuit is provided by the inductive coupling between L_{1A} and L_{1B}.

The 455-kc/s signal from the converter stage is amplified by two if-amplifier stages using 2N1524 transistors. The amplified if signal is then demodulated in the second-detector circuit. The 1N295 detector diode rectifies the if signal, and capacitor C_3 filters out the rf components so that only the audio-frequency (modulating-signal) component remains. The audio signal voltage is developed across the volume-control potentiometer R_4. The portion of the audio signal at the wiper arm of R_4 is amplified by a 2N2614 audio voltage amplifier and then by a push-pull power amplifier that uses two 2N408 transistors. The power-amplifier output drives the speaker voice coil to produce an audible output from the receiver. This receiver is capable of supplying up to 25 milliwatts of audio power output.

Parts List

C_1 = trimmer, 3 to 15 pF
C_2, C_6 = ganged tuning capacitor, C_2 = 9.5 to 141 pF; C_6 = 7.2 to 109 pF
C_3, C_4 = 0.02 μF, ceramic
C_5 = 0.005 μF, ceramic
C_7 = trimmer, 3 to 20 pF
C_8, C_{12}, C_{14}, C_{17}, C_{18} = 0.05 μF, ceramic
C_9 = 128 pF (part of T_2)
C_{10} = 2 μF, electrolytic, 3 V
C_{11} = 10 μF, electrolytic, 3 v.
C_{13}, C_{20} = 100 μF, electrolytic, 3 V
C_{15} = 125 pF, (part of T_3)
C_{16} = 0.005 μF, ceramic
C_{19} = 125 pF, (part of T_4)
L_1 = oscillator coil; wound from No. 3/44 Litz wire on coil form suitable for a No. 10-32 slug; L_{1A}, 19 turns; L_{1B}, 155 turns, tapped at 8 turns from ground end, tunes with 100 pF at 990 kilocycles
R_1, R_9 = 10000 ohms, 0.5 watt
R_2 = 3900 ohms, 0.5 watt
R_3, R_{15} = 1500 ohms, 0.5 watt
R_4 = volume-control potentiometer, 5000 ohms, audio taper (part of assembly with ON-OFF switch S_1)
R_5 = 470 ohms, 0.5 watt
R_6 = 6800 ohms, 0.5 watt
R_7 = 39000 ohms, 0.5 watt
R_8 = 330 ohms, 0.5 watt
R_{10} = 2700 ohms, 0.5 watt
R_{11} = 270 ohms, 0.5 watt
R_{12} = 10000 ohms, 0.5 watt
R_{13} = 2200 ohms, 0.5 watt
R_{14} = 240 ohms, 0.5 watt
R_{16} = 100 ohms, 0.5 watt
R_{17} = 47 ohms, 0.5 watt
S_1 = ON-OFF switch (part of assembly with potentiometer R_4)
S_p = speaker; voice-coil impedance, 12 to 15 ohms
T_1 = antenna transformer: primary, 110 turns of No. 10/41 Litz wire wound on a ¾"-by-⅛"-by-4" ferrite rod (pitch, 50 turns per inch); secondary, 6 turns of No. 10/41 Litz wire wound at the start of the primary; Q = 100 with transformer mounted on chassis; transformer should tune with 135 pF at 535 kilocycles
T_2 = 1st if transformer: Thompson-Ramo-Wooldridge EO-13550, or equiv.
T_3 = 2nd if transformer; Thompson-Ramo-Wooldridge EO-13551, or equiv.
T_4 = 3rd if transformer: Thompson-Ramo-Wooldridge EO-13552, or equiv.
T_5 = driver transformer; primary impedance, 10000 ohms; secondary impedance, 2000 ohms, center-tapped
T_6 = output transformer; primary impedance, 100 ohms, center-tapped; secondary impedance, 15 ohms (to match voice-coil impedance of 12 to 15 ohms)

12-2 6-VOLT AUTOMOBILE RADIO RECEIVER



Circuit Description

This 7-transistor superheterodyne radio receiver operates from the storage battery in automobiles employing a 6-volt ignition system. The rf-amplifier stage uses a high-gain 2N1637 transistor to provide the increased sensitivity and higher signal-to-noise ratio required in

12-2 6-VOLT AUTOMOBILE RADIO RECEIVER (cont'd)

Circuit Description (cont'd)

automobile radio receivers. The tuned rf amplifier selects and amplifies the amplitude-modulated rf signal from the desired broadcast station picked up by the automobile whip antenna. The rf-amplifier output and a signal from the 2N1524 local-oscillator stages are mixed in the 2N1639 mixer stage to provide a signal at the receiver intermediate frequency of 262.5 kc/s (this value is used rather than 455 kc/s in auto radios because the tuned if amplifiers provide greater gain and selectivity at the lower frequency).

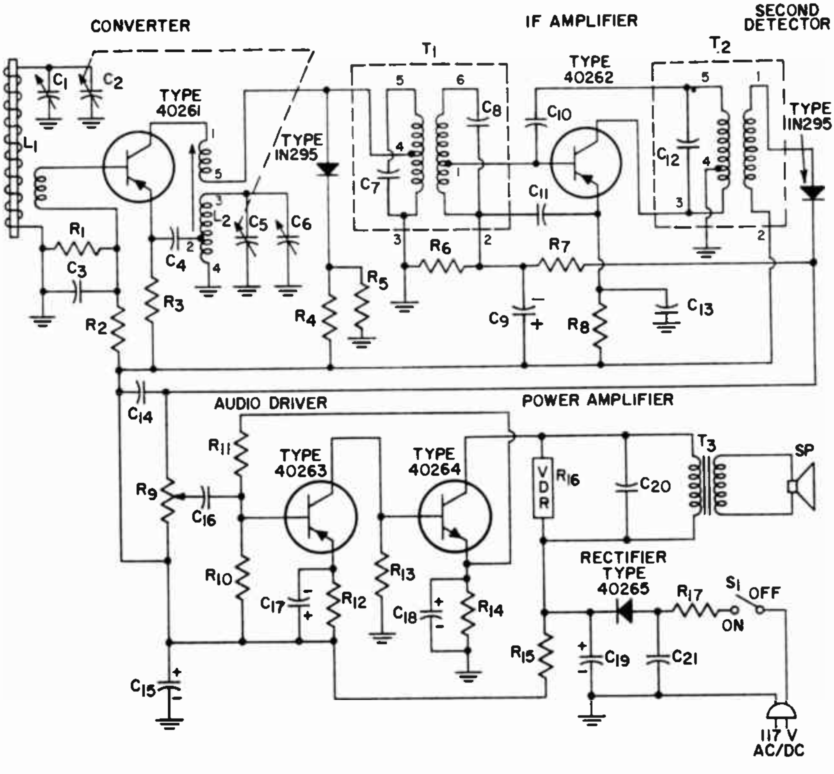
The rf amplifier, mixer, and local oscillator are tuned together by means of mechanically ganged variable inductors L_2, L_3, and L_4 so that the local-oscillator frequency is always 262.5 kc/s above the frequency to which the other circuits are tuned. Trimmer capacitors C_1, C_6, and C_{11} are adjusted to provide the proper tracking relationship.

The 262.5 kc/s output from the mixer is amplified by a single 2N1638 if amplifier, and is then demodulated in the 1N295 second-detector circuit. The audio signal output from the detector is developed across the volume-control potentiometer R_{28}, amplified by two 2N408 audio voltage amplifiers, and applied to the base of the 2N2869/2N301 power transistor, which drives the speaker.

Parts List

C_1 = 5 to 80 pF, variable trimmer
C_2 = 820 pF, mica, 100 V
C_3 = 2 pF, mica, 100 V
C_4, C_{23} = 25 µF, elecrolytic, 6 V
C_5, C_9, C_{13}, C_{16}, C_{17}, C_{18} = 0.05 µF, ceramic disc
C_6, C_{11} = 100-580 pF, variable trimmer
C_7 = 270 pF, mica
C_8 = 0.005 µF, ceramic disc
C_{10}, C_{22} = 50 µF, electrolytic, 6 V
C_{12} = 0.0047 µF, ceramic disc
C_{14}, C_{15} = supplied with T_1
C_{19} = 500 µF, electrolytic, 3 V
C_{20} = 180 pF, mica, 100 V
C_{21} C_{26} = supplied with T_2
C_{24}, C_{25} = 1 µF, ceramic disc, 3 V
C_{27} = 0.04 µF, ceramic disc, 25 V
C_{28} = 0.5 µF, ceramic disc, 25 V
L_1 = 5 µH, rf choke
L_2 L_3 L_4 = tuner assembly; manufactured by F. W. Sickles Co. and Radio Condenser Corp.
L_2 = antenna coil; variable inductor tuned with 110 pF; frequency range 535 to 1610 kc/s; Q = 65 at 1610 kc/s
L_3 = rf coil; variable inductor tuned with 600 pF; frequency range 535 to 1610 kc/s; Q = 65 at 1610 kc/s
L_4 = oscillator transformer; primary, variable inductor tuned with 470 pF; frequency range 797 to 1872 kc/s; Q = 65 at 1872 kc/s, secondary, 30 turns
L_5 = output coil; 20 mH; 1 ampere, 0.5 ohm max.
R_1 = 82000 ohms, 0.5 watt
R_2 = 2200 ohms, 0.5 watt
R_3 = 33 ohms, 0.5 watt
R_4 R_{21} = 330 ohms, 0.5 watt
R_5 R_{10} = 5600 ohms, 0.5 watt
R_6 = 0.33 ohm, 1 watt
R_7 = 180 ohms, 0.5 watt
R_8 = 10000 ohms, 0.5 watt
R_9 = 1500 ohms, 0.5 watt
R_{11} R_{22} = 1000 ohms, 0.5 watt
R_{12} R_{13} R_{14} = 68 ohms, 0.5 watt
R_{15} = 820 ohms, 0.5 watt
R_{16} = 47000 ohms, 0.5 watt
R_{17} = 1800 ohms, 0.5 watt
R_{18} = 8200 ohms, 0.5 watt
R_{20} R_{26} = 3300 ohms, 0.5 watt
R_{19} R_{27} = 1200 ohms, 0.5 watt
R_{23} = 120 ohms, 0.5 watt
R_{24} = 100000 ohms, 0.5 watt
R_{25} = volume control, potentiometer, 100000 ohms
R_{28} = tone control, potentiometer, 10000 ohms
T_1 = if transformer, Thompson-Ramo-Wooldridge No. E010173, Automatic Mfg. Co. No. E2740097 AX, or equivalent
T_2 = if transformer, Thompson-Ramo-Wooldridge No. E010174, Automatic Mfg. Co. No. E2740097 BX, or equivalent

12-3 LINE-OPERATED AC/DC RADIO RECEIVER



Circuit Description

This four-transistor ac/dc radio receiver operates directly from either an ac power line or a dc supply of 117 volts. AC power inputs are converted to dc power by the 40265 rectifier.

Amplitude-modulated rf signals from the desired radio broadcast

12-3 LINE-OPERATED AC/DC RADIO RECEIVER (cont'd)

Circuit Description (cont'd)

station are selected by the ferrite-rod antenna and input-transformer assembly L_1. The converter stage uses a 40261 drift-field transistor in a common-emitter circuit configuration. Ganged variable capacitors C_2 and C_5 permit simultaneous tuning of the input and local-oscillator resonant circuits in the converter. Variable capacitors C_1 and C_6 provide the trimmer adjustments.

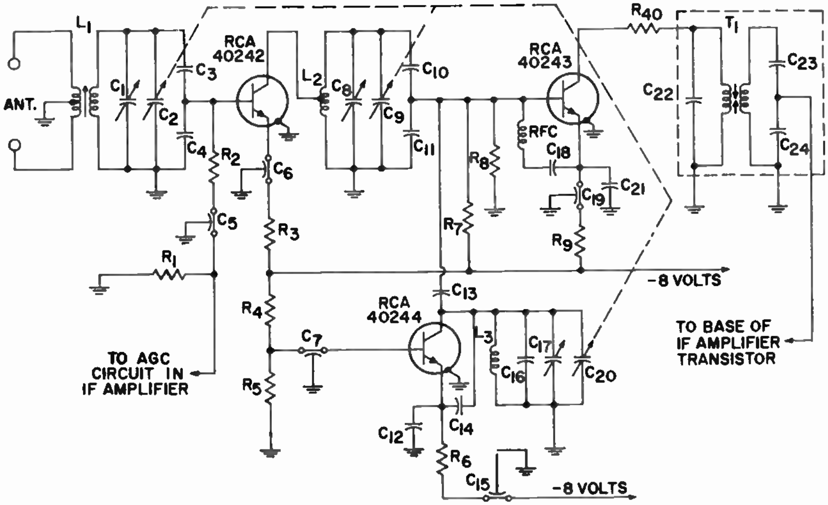
The 455-kc/s if output from the converter is amplified by a single if-amplifier stage which uses a 40262 drift-field transistor in a common-emitter circuit for optimum balance of signal gain and circuit stabilty. The if amplifier is made selective at 455 kc/s by a double-tuned input transformer T_1 and a single-tuned output transformer T_2. The audio-signal components are extracted from the if signal by the 1N295 detector diode and its associated components. The audio signal is amplified to the level required to drive the speaker by a 40263 driver stage and a 40264 power-output stage. A voltage-dependent resistor R_{16} is used as a damping resistor across the output transformer T_3 to protect the 40264 output transistor from the destructive effects of transient voltages.

Parts List

C_1, C_2, C_5, C_6 = ganged tuning capacitors; antenna section (C_1 and C_2), 10 to 152 pF; oscillator section (C_5 and C_6), 9.8 to 110 pF
C_3, C_4 = 0.02 μF, ceramic
C_7, C_8 = 110 pF, part of T_1
C_9 = 5 μF, electrolytic, 3 V
C_{10} = 1 pF, ceramic
C_{11}, C_{20} = 0.01 μF, ceramic
C_{12} = 170 pF, part of T_2
C_{13}, C_{14} = 0.05 μF, ceramic
C_{15} = 100 μF, electrolytic, 25 V
C_{16} = 1 μF, ceramic
C_{17} = 50 μF, electrolytic, 15 V
C_{18} = 250 μF, electrolytic, 12 V
C_{19} = 0.047 μF, "Mylar", 400 V
C_{21} = 80 μF, electrolytic, 150 V
L_1 = antenna coil, 150 turns of wire wound on 6-inch length of ⅜-inch-diameter ferrite rod, tunes with 135-pF capacitance at 535 kc/s
L_2 = oscillator coil; primary, 155 turns tapped 3 turns from bottom (term. 4) tunes with 100-pF capacitance at 990 kc/s; secondary, 10 turns; wound from Hy. Poly wire (no outer insulation) on slug (Arnold "E" or equiv.) 0.375 inch long and 0.181 inch in diameter
R_1, R_4 = 47000 ohms, 0.5 watt
R_2, R_{13}—2200 ohms, 0.5 watt
R_3—470 ohms, 0.5 watt
R_5—4700 ohms, 0.5 watt
R_6 = 0.22 megohm, 0.5 watt
R_7 = 10000 ohms, 0.5 watt
R_8 = 270 ohms, 0.5 watt
R_9 = potentiometer, 10000 ohms, 0.5 watt, audio taper
R_{10} = 56000 ohms, 0.5 watt
R_{11} = 18000 ohms, 0.5 watt
R_{12} = 820 ohms, 0.5 watt
R_{14} = 330 ohms, 0.5 watt
R_{15} = 8200 ohms, 0.5 watt
R_{16} = voltage-dependent resistor, Ferroxcube No. E299DD-P340 or equiv.
R_{17} = 250 ohms, 4 watts
S_1 = ON-OFF switch, single-pole, single-throw
T_1 = if transformer (includes C_7 and C_8), primary, 286 turns of No. 36 Gripeze wire tapped at 127 turns from bottom (term. 3): secondary, 286 turns of No. 36 Gripeze wire tapped at 8 turns from bottom (term. 2).
T_2 = if transformer; primary (includes C_{12}), 230 turns of No. 3/42 Litz wire tapped at 110 turns from bottom (term. 3); secondary, 17 turns of No. 3/42 Litz wire.
T_3 = audio output transformer; primary, 2500 ohms; secondary, 3.2 ohms; Triad No. S-12X or equiv.

12-4

HIGH-QUALITY FM TUNER FOR MULTIPLEX RECEIVER



Parts List

C_1, C_8 = trimmer capacitor, approximately 17 pF maximum

C_2, C_9, C_{20} = ganged tuning capacitor; C_2, C_9 = 7.25 to 19 pF, C_{20} = 6 to 21 pF

C_3 = 6.8 pF, ceramic

C_4 = 15 pF, ceramic

C_5, C_6, C_7, C_{15}, C_{19} = feed-through capacitor, 1000 pF

C_{10} = 3.3 pF, ceramic

C_{11} = 12 pF, ceramic disc

C_{12}, C_{14} = 4.7 pF, ceramic

C_{13} = 0.33 pF, ceramic

C_{16} = 15 pF, zero temperature coefficient, NPO ceramic

C_{17} = trimmer capacitor, 1.5 to 10 pF

C_{18} = 240 pF, ceramic disc

C_{21} = 0.005 μF, ceramic disc

C_{22} = 85.6 pF (part of T_1)

C_{23} = 39.3 pF (part of T_1)

C_{24} = 1000 pF (part of T_1)

L_1 = antenna coil; secondary, 4 turns of No. 22 bare tinned wire, approximately 1 wire diameter apart, wound on Oak antenna coil form, resonates with 27-pF capacitance at 100 Mc/s, tuning slug is an Arnold "J" (0.181 inch in diameter and 0.250 inch in length) or equiv.; primary, center-tapped, approximately 4 turns of No. 30 gripeze wire wound below cold end of secondary (primary winding may have to be shortened slightly to obtain optimum impedance match)

L_2 = rf interstage coil; approximately 3-½ turns of No. 18 bare tinned wire wound on a 5/16-inch-diameter coil form (remove coil form after winding) tapped approximately ⅓ turn from the cold end; exact winding length depends upon tracking requirements; coil should resonate with 27-pF capacitance at 100 Mc/s

L_3 = rf choke, 1 μF

L_4 = oscillator coil; approximately 3-½ turns of No. 18 bare tinned wire wound on a 7/32-inch-diameter coil form (remove coil form after winding); exact winding length depends on tracking requirements; coil resonates with 37-pF capacitance at 110.7 Mc/s

R_1 = 47000 ohms, 0.5 watt

R_2 = 2200 ohms, 0.5 watt

R_3, R_{13}, R_{23} = 330 ohms, 0.5 watt

R_4, R_7 = 4700 ohms, 0.5 watt

R_5 = 8200 ohms, 0.5 watt

R_6 = 1200 ohms, 0.5 watt

R_8 = 12000 ohms, 0.5 watt

R_9, R_{37} = 1000 ohms, 0.5 watt

R_{10}, R_{19}, R_{26}, R_{31} = 3300 ohms, 0.5 watt

R_{11}, R_{15} = 100 ohms, 0.5 watt

R_{12}, R_{18}, R_{25}, R_{30} = 560 ohms, 0.5 watt

R_{14}, R_{24}, R_{28}, R_{33} = 240 ohms, 0.5 watt

R_{17} = 0.68 megohm, 0.5 watt

R_{16} = 0.1 megohm, 0.5 watt

R_{20} = 8200 ohms, 0.5 watt

R_{21} = 10000 ohms, 0.5 watt

R_{22} = 20000 ohms, 0.5 watt

R_{27} = 220 ohms, 0.5 watt

R_{29}, R_{34} = 0.47 megohm, 0.5 watt

R_{32} = 470 ohms, 0.5 watt

R_{35} = 68 ohms, 0.5 watt

R_{36} = 1500 ohms, 0.5 watt

R_{38}, R_{39} = 6500 ohms, 0.5 watt

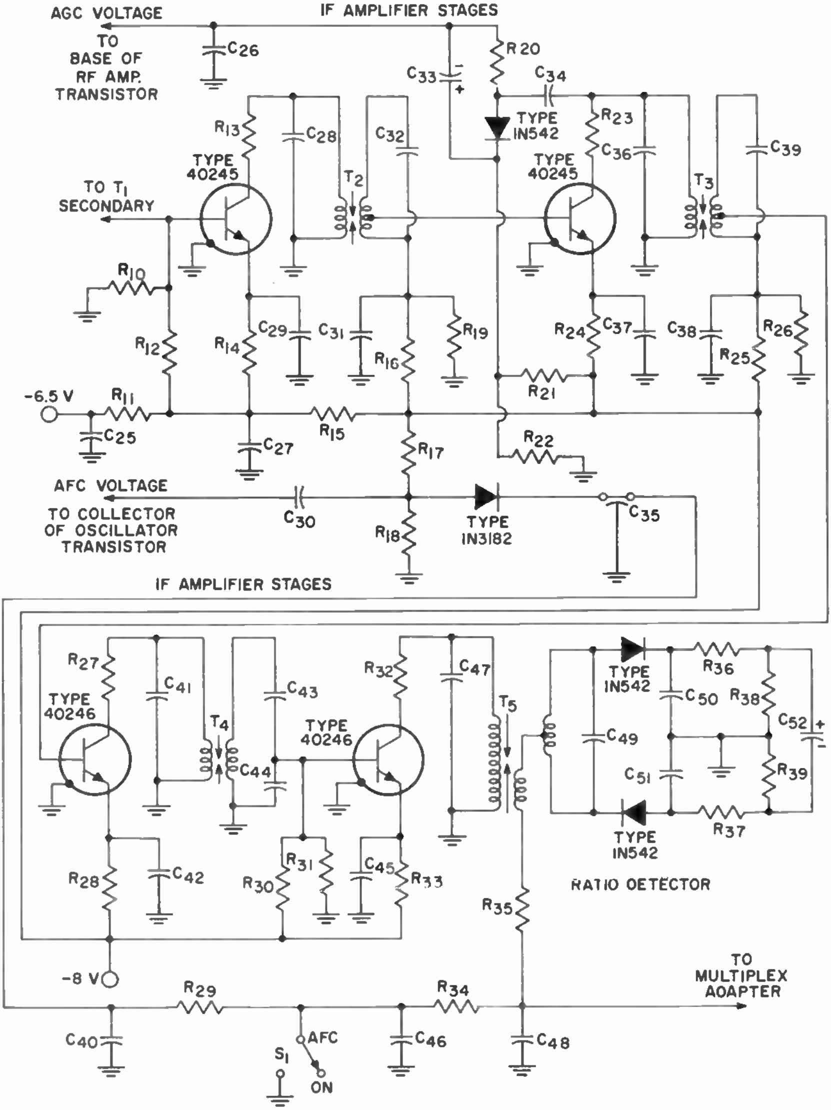
R_{40} = 100 ohms, 0.5 watt

S_1—AFC ON-OFF switch, single-pole, single-throw

T_1—if transformer, Thomas-Ramo-Wooldridge No. EO-18896, Automatic Mfg. Co. No. EX-11831, or equiv.

T_2—if transformer, Thomas-Ramo-Wooldridge No. EO-18897, Automatic Mfg. Co. No. EX-11832, or equiv.

12-4 HIGH-QUALITY FM TUNER (cont'd)



Parts List (cont'd)

T_3—if transformer, Thompson-Ramo-Wooldridge No. EO-18898, Automatic Mfg. Co. No. EX-11833, or equiv.

T_4—if transformer, Thompson-Ramo-Wooldridge No. EO-18900, Automatic Mfg. Co. No. EX-11834, or equiv.

T_5—ratio-detector transformer, Thompson-Ramo-Wooldridge No. EO-16786-R2. Automatic Mfg. Co. No. EX-11633, or equiv. equiv.

NOTE: See general considerations for construction of high-frequency and broadband circuits on page 391.

12-4 HIGH-QUALITY FM TUNER (cont'd)

Circuit Description

This high-quality FM tuner uses silicon n-p-n transistors that provide good receiver quieting and limiting performance because of their high usable gains and low noise levels (typical device noise is 3 dB at 100 Mc/s for a 300-ohm source impedance). These transistors provide excellent amplification in the FM band and are capable of sustained oscillation at frequencies up to 1100 Mc/s.

The rf-amplifier stage uses a 40242 transistor in a common-emitter circuit configuration to obtain the highest stable gain over the entire FM broadcast frequency range. This stage can provide an unneutralized gain of 15.4 dB. The operating point of the stage is chosen so that agc can be applied effectively.

The 40243 mixer transistor is also operated in a common-emitter configuration. An oscillator-signal injection voltage of approximately 90 millivolts is coupled across capacitor C_{11} to the base of the mixer transistor from the oscillator resonant circuit C_{14}, C_{15}, C_{18}, and L_4. A series-tuned trap L_3 and C_{12} between the base and emitter of the mixer transistor reduces degeneration at the intermediate frequency of 10.7 Mc/s and thus increases conversion gain. The 40244 oscillator stage is adjusted to provide a uniform injection voltage to the base of the mixer transistor over the entire FM oscillator-frequency range.

The four-stage if-amplifier strip uses two 40245 and two 40246 transistors in a common-emitter circuit configuration to provide 23.4 dB of stable gain per stage. The four double-tuned if transformers T_1, T_2, T_3, and T_4 provide a 6-dB bandwidth of 300 kc/s, which is adequate for reproduction of stereo signals.

The agc voltage is developed at the collector of the second if-amplifier transistor by a 1N542 diode, and is applied to the base of the 40242 rf-amplifier transistor. As a result, the final 40246 if-amplifier transistor can go into full limiting before appreciable agc is developed. This arrangement provides a relatively wide agc bandwidth which is helpful in tuning to strong signals.

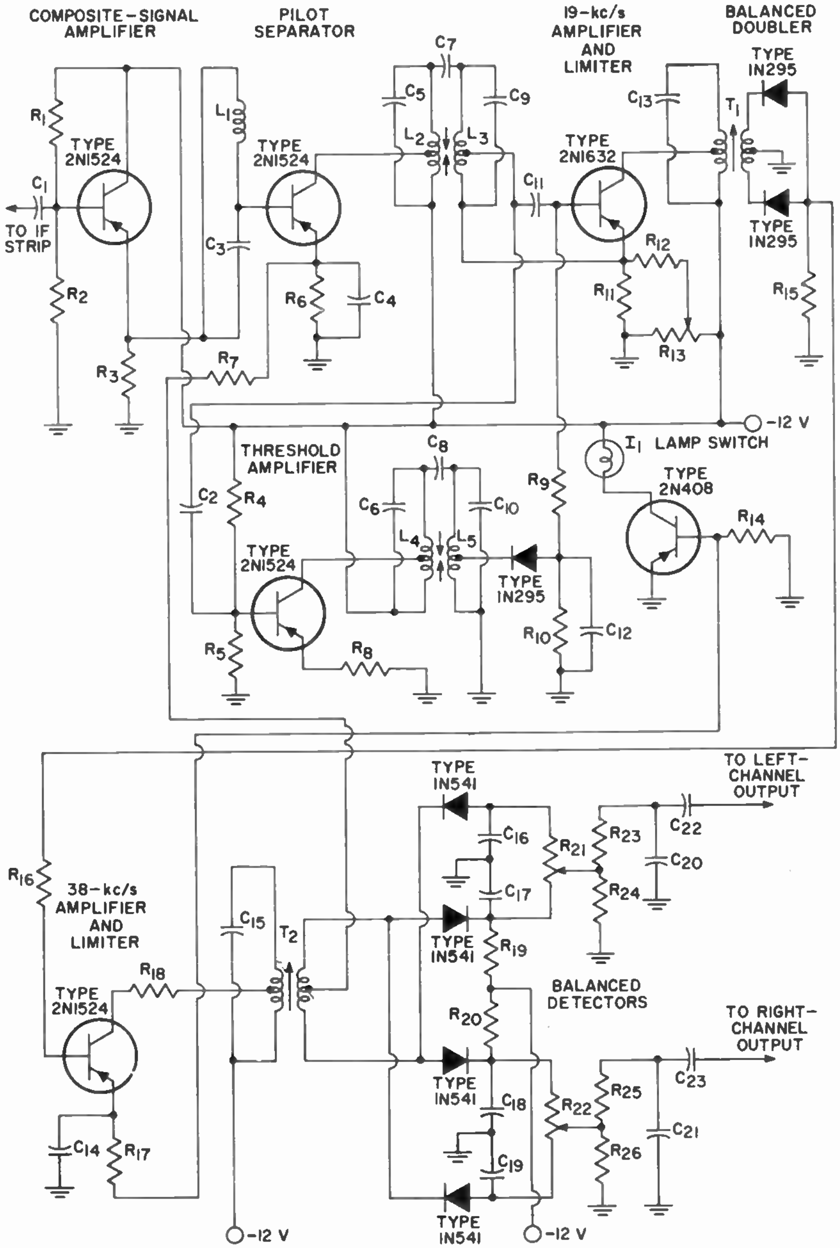
FM detection is accomplished by the ratio-detector circuit, which includes two 1N542 diodes and associated components. The detector transformer T_5 is designed to provide the wide peak-to-peak separation (450 kc/s) required for good stereo multiplex operation.

12-5 FM STEREO MULTIPLEX ADAPTER

Parts List

C_1 = 0.33 μF, fixed composition
C_2, C_{11}, C_{12} = 0.5 μF, disc ceramic
C_3 = 560 pF, mica
C_4 = 0.1 μF, ceramic
C_5 = 1000 pF, part of L_2
C_6 = 1000 pF, part of L_4
C_7, C_8 = 10 pF, NPO disc.
C_9 = 1000 pF, part of L_3
C_{10} = 1000 pF, part of L_5
C_{13} = 1000 pF, part of T_1
C_{14} = 2 μF, electrolytic, 12 V.
C_{15} = 390 pF, part of T_2
C_{16}, C_{17}, C_{18}, C_{19} = 7500 pF, mica
C_{20}, C_{21} = 0.02 μF, disc ceramic
C_{22}, C_{23} = 1 μF, disc ceramic
I_1 = incandescent lamp, 14-mA, 10-volt
L_1 = rf coil Thompson-Ramo-Wooldridge No. EO-14039 or equiv.
L_2 = rf coil (includes C_5) Thompson-Ramo-Wooldridge No. EO-15485-R_3 or equiv.
L_3 = rf coil (includes C_9) Thompson-Ramo-Wooldridge No. EO-15486-R_3 or equiv.
L_4 = rf coil (includes C_6) Thompson-Ramo-Wooldridge No. EO-17558 or equiv.
L_5 = rf coil (includes C_{10}) Thompson-Ramo-Wooldridge No. EO-17557 or equiv.
R_1 = 0.12 megohm, 0.5 watt
R_2, R_4, R_{15} = 47000 ohms, 0.5 watt
R_3, R_{23}, R_{25} = 3300 ohms, 0.5 watt
R_5, R_{24}, R_{26} = 8200 ohms, 0.5 watt
R_6, R_{18} = 470 ohms, 0.5 watt
R_7 = 180 ohms, 0.5 watt
R_8, R_{17} = 1000 ohms, 0.5 watt
R_9, R_{10} = 10000 ohms, 0.5 watt
R_{11} = 120 ohms, 0.5 watt
R_{12}, R_{14} = 560 ohms, 0.5 watt
R_{13} = potentiometer, threshold control, 50000 ohms
R_{16} = 2200 ohms, 0.5 watt
R_{19}, R_{20} = 39000 ohms, 0.5 watt
R_{21}, R_{22} = potentiometer, 38-kc/s and 76-kc/s null control, 5000 ohms
T_1 = transformer (includes C_{13}) Thompson-Ramo-Wooldridge No. EO-15360-R_9 or equiv.
T_2 = transformer (includes C_{15}) Thompson-Ramo-Wooldridge No. EO-15361-R_7 or equiv.

12-5 FM STEREO MULTIPLEX ADAPTER (cont'd)



12-5 FM STEREO MULTIPLEX ADAPTER (cont'd)

Circuit Description

This FM stereo multiplex adapter, or demodulator, separates composite multiplex signals supplied by an FM tuner, such as that shown by circuit 12-4, into right- and left-channel inputs for stereo audio-output stages. The adapter features a high input impedance, a noise-immunity circuit, and automatic switching for stereophonic or monaural reception.

The input to the composite-signal amplifier is obtained from the ratio detector in the FM tuner. The amplifier, which is essentially an isolation stage, uses a 2N1524 transistor in an emitter-follower circuit configuration to provide the high-input-impedance termination necessary to prevent excessive loading of the ratio detector. The composite signal is coupled from the emitter circuit of the amplifier through an SCA rejection filter (L_1 and C_3) to the base of a second 2N1524 used in a pilot-separator stage.

The collector circuit of the pilot separator consists of a double-tuned, top - capacitance - coupled, 19 - kc/s transformer (L_2 and L_3). This transformer presents a highly selective load to the 19-kc/s pilot-frequency component included in the composite signal. The pilot-separator stage also acts as an emitter follower for the composite signal.

The 2N1524 threshold amplifier and the 2N1632 19-kc/s amplifier and limiter comprise the noise-immunity circuit. During operation, reverse bias is applied to the 2N1632 through the threshold potentiometer R_{13}. When noise or insufficient pilot is available from the FM detector (as in the case of a weak station or of monaural reception), the forward bias developed by the 1N295 bias-rectifier circuit is insufficient to overcome the preset reverse bias on the 2N1632, and stereophonic switching is not accomplished. The presence of an acceptable pilot level (one that does not switch on interstation noise and yet provides adequate stereo reception) results in sufficient forward bias to make the 2N1632 conduct and thus to permit operation of the subcarrier regenerating stages.

The output of the 19-kc/s amplifier and limiter is coupled by transformer T_1 to a balanced frequency-doubler circuit. This circuit, which consists of two 1N295 diodes connected in a full-wave rectifier configuration, doubles the frequency of the 19-kc/s signal to regenerate the 38-kc/s subcarrier required for detection of the left- and right-channel information in the composite signal.

The 2N1534 38-kc/s amplifier and limiter supplies the bias current to turn on the 2N408 lamp switch that indicates stereo operation of the adapter. The 38-kc/s subcarrier from the balanced doubler is amplified by the 38-kc/s amplifier and limiter and applied to the primary of T_2, and the composite signal from the emitter of the pilot-separator transistor is applied to the secondary center tap of T_2. When a properly phased regenerated subcarrier is added to the composite signal, stereo demodulation is accomplished, and right- and left-channel information appears at the respective outputs.

Monaurally transmitted signals that appear at the emitter of the pilot separator are applied directly to the balanced-detector transformer T_2 without activating the subcarrier regenerating stages. The demodulated signal then appears with equal amplitude in both left and right channels of the receiver.

12-6 AM/FM AUTOMOBILE RADIO RECEIVER

Circuit Description

This AM/FM receiver operates directly from a 12-volt automobile battery supply. AM or FM operation is selected by means of switch S_1. A whip antenna picks up both AM and FM signals transmitted by radio broadcast stations. (The optimum antenna length for FM reception is 29 inches.) RF choke L_1 presents a high impedance at FM frequencies (88 to 108 Mc/s) so that FM signals cannot enter the AM tuner, but allows signals at AM frequencies (550 to 1600 kc/s) to pass relatively unimpeded. Capacitor C_1 provides low-impedance coupling of FM signals into the FM tuner, but blocks the passage of AM signals.

When S_1 is in the FM position, the FM tuner selects the frequency-modulated rf signal from the desired broadcast station, amplifies this signal, and converts it to the 10.7-Mc/s intermediate frequency. The 2N1177 rf amplifier and the 2N1179 autodyne converter transistors provide signal-power gains at the if output frequency of at least 25 dB for input frequencies in the 88-to-108-Mc/s FM band. Ganged tuning of the rf and converter stages insures that the local-oscillator frequency tracks the input tuning at 10.7 Mc/s above the center frequency of the FM channel selected. Trimmer adjustments are provided by capacitors C_5, C_{18}, and C_{31} and inductors L_2, L_5, and L_7. A 1N295 diode prevents oscillator blocking in the converter stage and thus extends the large-signal-handling capabilities of the FM tuner.

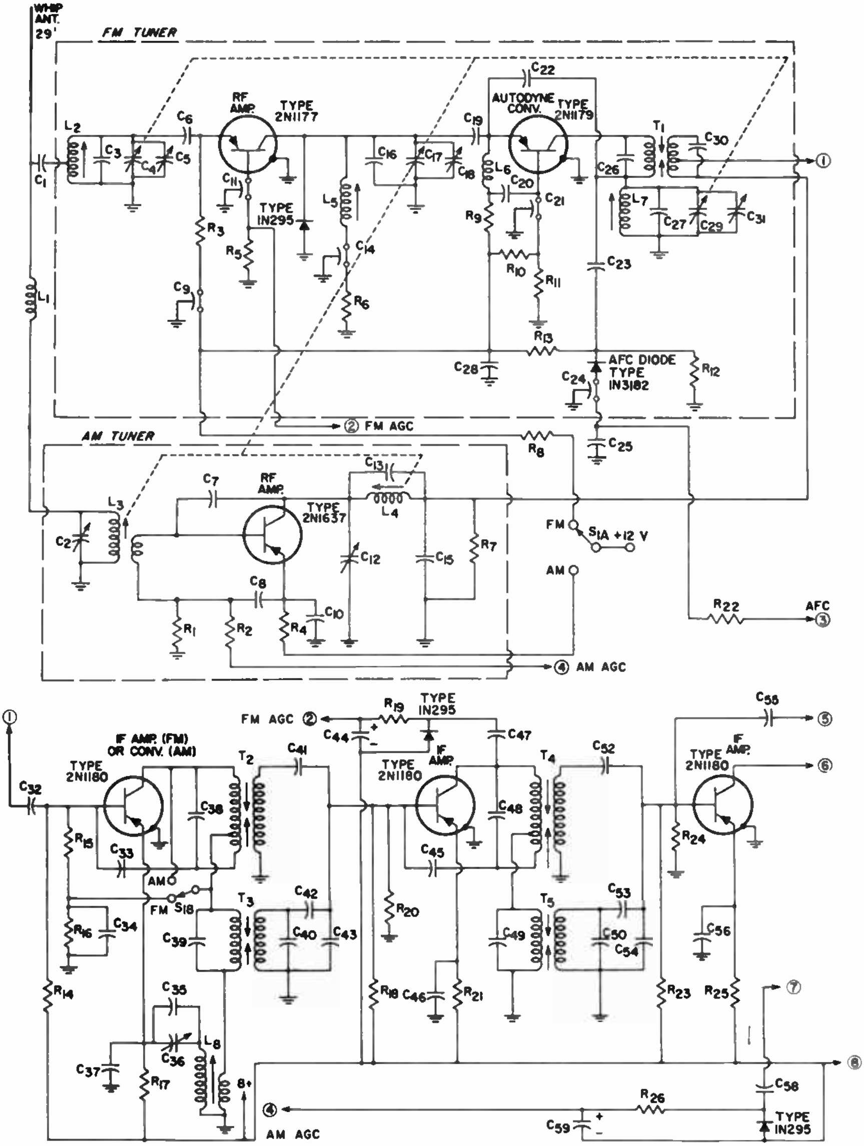
The 10.7-Mc/s output of the FM tuner is amplified by three 2N1180 tuned if-amplifier stages that provide an over-all signal gain of 69 dB. Good selectivity for FM signals is provided by four double-tuned transformers T_1, T_2, T_4, and T_6.

The if strip is also used for AM operation. At the 262.5-kc/s intermediate frequency used in AM automobile receivers, two of the 2N1180 if stages provide more than adequate gain. Therefore, the first 2N1180 stage is converted to an AM converter when S_1 is set to the AM position. This stage and the 2N1637 rf amplifier comprise the AM tuner. The 262.5-kc/s output from the AM tuner is amplified by the two remaining 2N1180 if amplifiers and coupled to the 1N295 AM second-detector circuit. Selectivity for AM signals is provided by the 262.5-kc/s if transformers T_3, T_5, and T_7.

FM if signals are demodulated and the amplitude distortion is removed in the 1N542 ratio-detector circuit. A 1N295 AM detector circuit separates the audio signal from (demodulates) the AM if signal. A third section of S_1 then selects the audio output from either the FM ratio detector or the AM detector. The selected audio output is amplified by 2N591 predriver and driver stages. The output of these stages drives a 2N2869/2N301 power amplifier to develop the power necessary to produce the required speaker output.

The agc network consisting of a 1N295 diode, R_{26}, and C_{39} develops a dc bias voltage proportional to the signal amplitude and applies it to the base of the 2N1637 transistor to provide automatic gain control for the AM receiver. The agc voltage for the FM receiver is developed by a 1N295 diode circuit and applied to the base of the 2N1177 rf transistor. A 1N3182 diode circuit rectifies the signal across the tertiary (reference) winding of the ratio-detector transformer. The resultant frequency-sensitive dc voltage, applied to the emitters of the FM converters and rf-amplifier transistors, provides automatic frequency control (afc) for the FM tuner.

12-6 AM/FM AUTOMOBILE RADIO RECEIVER (cont'd)



Parts List

C_1 = 18 pF, ceramic disc, 50 V

C_2 = 5-80 pF, mica, trimmer

C_3, C_6, C_{19}, C_{47} = 5 pF, ceramic disc, 50 V

C_4, C_{17}, C_{29} = 6-21 pF, tuning capacitor

C_5, C_{18}, C_{31} = 1-6 pF, mica, trimmer

C_7 = 1.5 pF, ceramic disc, 50 V

C_8 C_{10} C_{32} C_{46} C_{56} C_{69} C_{73} = 0.05 µF, ceramic disc, 50 V

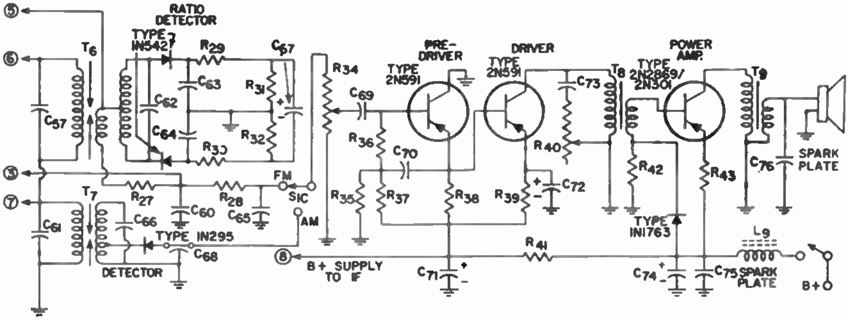
C_9 C_{11} C_{14} C_{21} C_{24} C_{68} = 0.002 µF, feedthrough, 50 V

C_{12} = 55-300 pF, mica, trimmer

C_{13} = 390 pF, ceramic disc, 50 V

C_{15} = 0.005 µF, ceramic disc, 50 V

12-6 AM/FM AUTOMOBILE RADIO RECEIVER (cont'd)

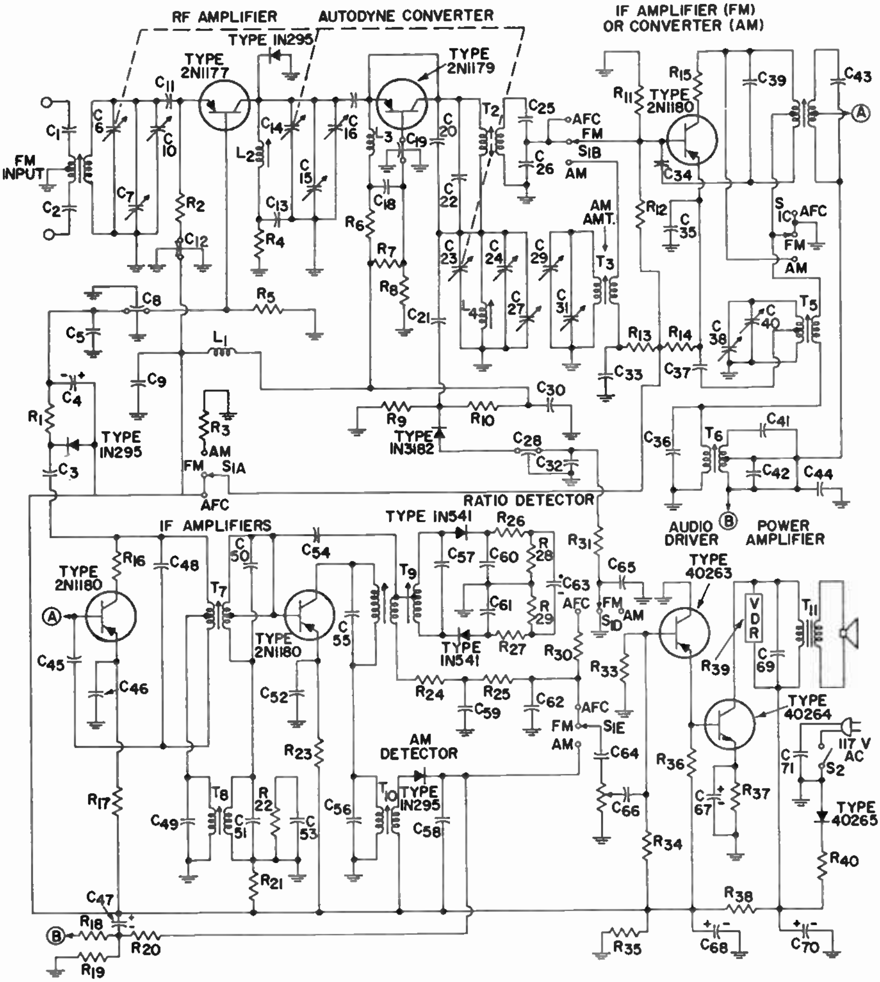


Parts List (cont'd)

C_{16}, C_{23} = 4 pF, ceramic disc, 50 V
C_{20} = 330 pF, ceramic disc, 50 V
C_{22} = 2.2 pF, ceramic disc, 50 V
C_{25}, C_{28}, C_{34}, C_{37}, C_{51}, C_{60}, C_{63}, C_{64} = 0.01 μF, ceramic disc, 50 V
C_{26} C_{30} = part of T_1
C_{27} = 15 pF, ceramic disc, 50 V
C_{33}, C_{45} = 3.3 pF, ceramic disc, 50 V
C_{35} = 180 pF, N750 ceramic
C_{36} = 80-550 pF, mica, trimmer
C_{38} C_{41} = part of T_2
C_{39} C_{40} C_{42} = part of T_3
C_{43}, C_{54} = 0.001 μF, ceramic disc, 50 V
C_{44} = 10 μF, electrolytic, 25 V
C_{48} C_{52} = part of T_4
C_{49} = 1800 pF, = 10%, ceramic disc
C_{50} C_{53} = part of T_5
C_{55} = 2 pF, ceramic disc, 50 V
C_{57} C_{62} = part of T_6
C_{58} = 200 pF, ceramic disc, 50 V
C_{59} = 20 μF, electrolytic, 25 V
C_{61} = 1500 pF = 10%, ceramic disc
C_{65} = 0.02 μF, ceramic disc, 50 V
C_{66} = part of T_7
C_{67} = 10 μF, electrolytic, 3 V
C_{70} = 2.2 μF, ceramic disc, 3 V
C_{71} = 200 μF, electrolytic, 25 V
C_{72} = 100 μF, electrolytic, 25 V
C_{74} = 500 μF, electrolytic, 25 V
C_{75}, C_{76} = spark plate
L_1 = 6.2 μH, radio-frequency choke
L_2 = antenna coil for FM tuner; 4 turns No. 16 HF on 0.220-inch form, spaced 5/16-inch (approx.); tapped at 1 turn; core "J" material Arnold A1-336 or equiv.
L_3 = antenna coil for AM tuner; variable inductor; tunes with 120 pF over the frequency range from 535 to 1610 kc/s; Q_0 = 60 at 1610 kc/s; secondary 8 turns
L_4 = rf coil for AM tuner; variable inductor; tunes with 560 pF over the frequency range from 535 to 1610 kc/s; Q_0 = 60 at 1610 kc/s, no secondary
L_5 = rf coil for FM tuner; same as L_2 except has no tap
L_6 = miniature radio-frequency choke, 1 μH (approx.)
L_7 = oscillator coil for FM tuner; 3 turns No. 16 HF on 0.220-inch form, spaced ¼-inch (approx.); core "J" material Arnold A1-336 or equiv.
L_8 = oscillator coil for AM tuner; variable inductor; tunes with 470 pF over the frequency range from 797 to 1872 kc/s; Q_0 = 45 at 1872 kc/s; secondary 30 turns
L_9 = filter choke, 125 μH (approx.)
R_1 R_{12} R_{22} = 100000 ohms, 0.5 watt
R_2 R_4 = 560 ohms, 0.5 watt
R_3 = 390 ohms, 0.5 watt
R_5 R_{11} R_{15} = 33000 ohms, 0.5 watt
R_6 R_{27} R_{41} = 180 ohms, 0.5 watt
R_7 = 68 ohms, 0.5 watt
R_8 = 220 ohms, 0.5 watt
R_9 = 680 ohms, 0.5 watt
R_{10} = 4300 ohms, 0.5 watt
R_{13} = 1 megohm, 0.5 watt
R_{14} R_{16} = 10000 ohms, 0.5 watt
R_{17} R_{29} = 1500 ohms, 0.5 watt
R_{18} R_{23} = 2200 ohms, 0.5 watt
R_{19} R_{26} = 5600 ohms, 0.5 watt
R_{20} R_{24} = 18000 ohms, 0.5 watt
R_{21} R_{25} R_{39} = 470 ohms, 0.5 watt
R_{28} = 3900 ohms, 0.5 watt
R_{30} = 1000 ohms, 0.5 watt
R_{31} R_{32} R_{37} = 6800 ohms, 0.5 watt
R_{34} = potentiometer, 100000 ohms, 0.5 watt, audio taper
R_{35} = 62000 ohms, 0.5 watt
R_{36} = 4700 ohms, 0.5 watt
R_{38} = 3300 ohms, 0.5 watt
R_{40} = potentiometer, 250000 ohms, 0.5 watt, audio taper
R_{42} = 270 ohms, 1 watt
R_{43} = 0.47 ohm, 0.5 watt
T_1 = FM if transformer; Thompson - Ramo - Wooldridge No. 12224 or Automatic Mfg. Co. No. E27-41353AX or equiv.
T_2 T_4 = FM if transformer; Thompson - Ramo - Wooldridge No. 12080R1 or Automatic Mfg. Co. No. E2741166BX or equiv.
T_3 = AM if transformer; Thompson - Ramo - Wooldridge No. 12414 or equiv.
T_5 = AM if transformer; Thompson - Ramo - Wooldridge No. 12415 or equiv.
T_6 = radio-detector transformer; Thompson-Ramo-Wooldridge No. 12007R1 or Automatic Mfg. Co. No. E2741166AB or equiv.
T_7 = AM if transformer; Thompson - Ramo - Wooldridge No. 12416 or equiv.
T_8 = driver transformer; primary 8000 ohms at 3 mA dc; secondary 60 ohms; Columbus Process Co. No. X5357 or equiv.
T_9 = output transformer; primary 20 ohms at 700 mA dc; secondary 4 ohms; Columbus Process Co. No. 5383 or equiv.

NOTE: See general considerations for construction of high-frequency and broadband circuits on page 391.

12-7 LINE-OPERATED (AC/DC) AM/FM RADIO RECEIVER



Circuit Description

This seven-transistor AM/FM radio receiver operates directly from either an ac power line or a dc supply of 117 volts. AC power inputs are converted to dc power by the 40265 rectifier. A series dropping resistor R_{38} reduces the rectifier output to the value of 9 volts required for the rf, if, and audio driver stages.

Operation of this ac/dc AM/FM receiver is essentially the same as that of the AM/FM automobile receiver shown in circuit 12-6, except that no rf-amplifier stage is required for AM operation. Demodulation of FM signals is accomplished by a conventional ratio detector which uses two 1N541 diodes. AM

12-7 LINE-OPERATED (AC/DC) AM/FM RADIO RECEIVER (cont'd)

Circuit Description (cont'd)

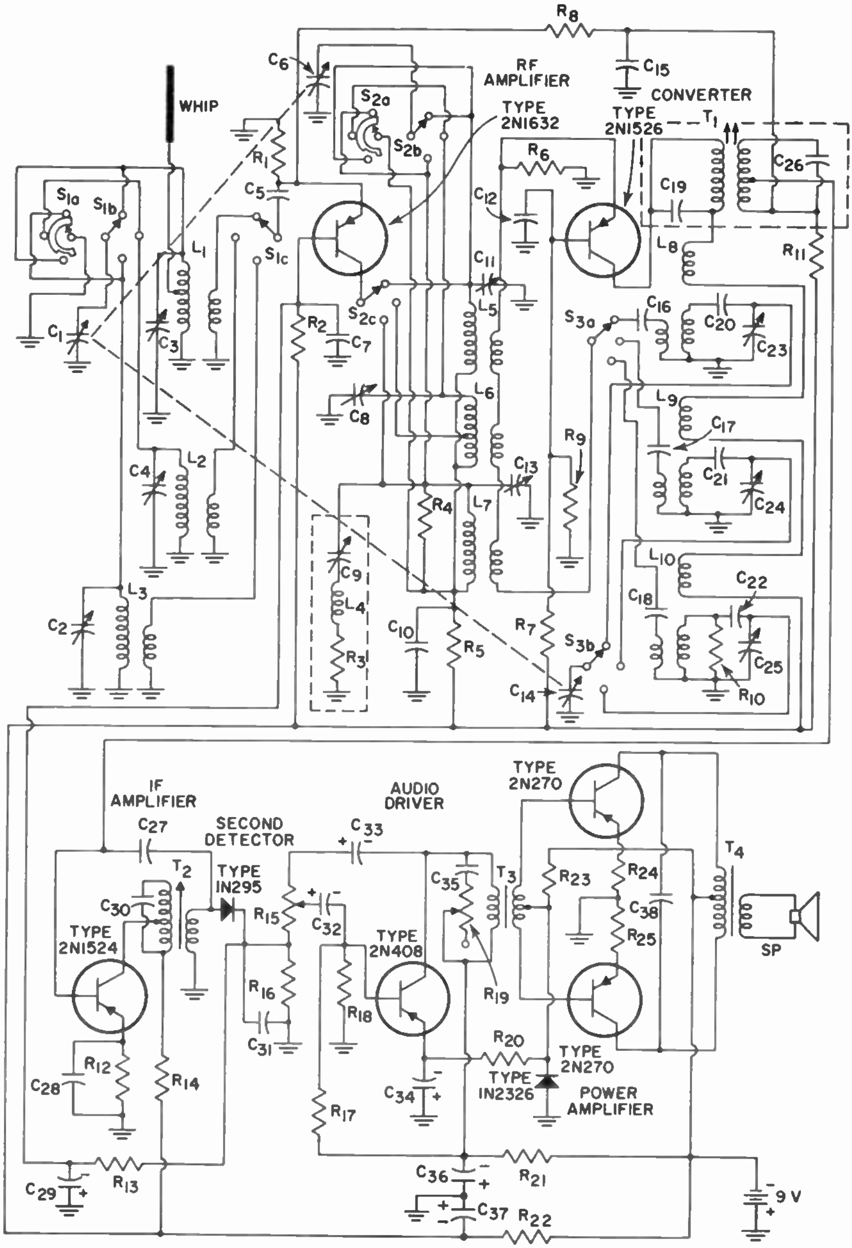
demodulation is provided by a 1N295 diode detector circuit. The audio amplifier uses a 40263 transistor in an emitter-follower driver stage and a 40264 high-voltage silicon transistor in a single-ended, common-emitter audio-output stage. The audio-output stage can deliver one watt of audio output to the speaker with less than 10 per cent distortion. A voltage-dependent resistor R_{39} provides transient-voltage protection for the output circuit.

Parts List

C_1, C_2 = 470 pF, mica
C_3, C_{20} = 2.2 pF, ceramic disc
C_4, C_{63} = 4 μF, electrolytic, 3 V
C_5, C_{46}, C_{52}, C_{71} = 0.05 μF, ceramic disc
C_6, C_{14}, C_{23} = ganged tuning capacitors, 7 to 20 pF
C_7, C_{45} = 5 pF, ceramic disc
C_8, C_{12}, C_{19} = feedthrough capacitors, 0.002 μF
C_9, C_{30}, C_{32}, C_{33}, C_{44}, C_{53}, C_{62}, C_{65} = 0.01 μF, ceramic
C_{10}, C_{16}, C_{27} = trimmer capacitors, 2 to 12 pF
C_{11} = 4.7 pF, ceramic disc
C_{13}, C_{28} = 1500 pF, ceramic disc
C_{15}, C_{21} = 4 pF, ceramic
C_{17} = 3.3 pF, ceramic disc
C_{18} = 270 pF, ceramic disc
C_{22}, C_{25} = 51 pF, mica
C_{24} = 15 pF, ceramic disc
C_{26} = 1200 pF, ceramic disc
C_{29}, C_{31} = tuning and trimmer capacitors for AM antenna coil, combined value 12 to 310 pF
C_{34}, C_{54} = 3.9 pF, ceramic
C_{35}, C_{58} = 0.005 μF, ceramic disc
C_{36} = 470 pF, mica
C_{37} = 0.003 pF, ceramic
C_{38}, C_{40} = tuning and trimmer capacitors for AM oscillator coil, combined value 12 to 128 pF
C_{39}, C_{43}, C_{50}, C_{55} = 56 pF
C_{41} = 220 pF, ceramic disc
C_{42}, C_{51} = 0.01 μF, ceramic disc
C_{47} = 10 μF electrolytic, 3 V
C_{49} = 2400 pF, mica
C_{56} = 3600 pF, ceramic
C_{57} = 47 pF, ceramic disc
C_{59}, C_{60}, C_{61} = 330 pF, ceramic disc
C_{64}, C_{66} = 0.47 μF, ceramic disc
C_{67} = 150 μF, electrolytic, 6 V
C_{68} = 150 μF, electrolytic, 15 V
C_{69} = 0.02 μF, ceramic disc
C_{70} = 80 μF, electrolytic, 150 V
L_1 = rf choke, 10 μH
L_2 = 4-½ turns of No. 16 wire, spaced to 9/16 inch, wound on a 0.220-inch-diameter coil form that takes a No. 10/32 slug (Arnold No. LRN8 or equiv.)
L_3 = rf coil, 1 μH
L_4 = FM oscillator coil; 3 turns of No. 16 wire, spaced to 0.4-inch, wound on 0.220-inch-diameter coil form that takes a No. 10/32 slug (Arnold No. LRN8 or equiv.)
R_1 = 5600 ohms, 0.5 watt
R_2 = 390 ohms, 0.5 watt
R_3, R_{21} = 2200 ohms, 0.5 watt
R_4, R_{15}, R_{16} = 100 ohms, 0.5 watt
R_5, R_9 = 47000 ohms, 0.5 watt
R_6, R_{14} = 680 ohms, 0.5 watt
R_7 = 2700 ohms, 0.5 watt
R_8 = 15000 ohms, 0.5 watt
R_{10}, R_{30}, R_{31} = 0.47 megohm, 0.5 watt
R_{11} = 18000 ohms, 0.5 watt
R_{12} = 4700 ohms, 0.5 watt
R_{13}, R_{26} = 1000 ohms, 0.5 watt
R_{17} = 330 ohms, 0.5 watt
R_{18} = 820 ohms, 0.5 watt
R_{19} = 68000 ohms, 0.5 watt
R_{20} = 10000 ohms, 0.5 watt
R_{22} = 12000 ohms, 0.5 watt
R_{23} = 470 ohms, 0.5 watt
R_{24} = 68 ohms, 0.5 watt
R_{25}, R_{28}, R_{29} = 6800 ohms, 0.5 watt
R_{27} = 1500 ohms, 0.5 watt
R_{32} = volume control, potentiometer, 40000 ohms
R_{33} = 39000 ohms, 0.5 watt
R_{34} = 82000 ohms, 0.5 watt
R_{35} = 560 ohms, 0.5 watt
R_{36} = 3900 ohms, 0.5 watt
R_{37} = 82 ohms, 0.5 watt
R_{38} = 3000 ohms, 5 watt
R_{39} = voltage-dependent resistor, Ferroxcube No. E299DD-340 or equiv.
R_{40} = 200 ohms, 5 watt
S_1 = selector switch, five-pole, three-position
S_2 = ON-OFF switch (part of R_{32})
T_1 = input matching transformer; 0.220-inch outer-diameter threaded coil form to take 10/32 slug (Arnold IRN8 or equiv.); secondary 4-½ turns No. 16 wire spaced to ½-inch; primary 3 turns, center-tapped, wound over ground end of secondary.
T_2 = 10.7-Mc/s if transformer, Thompson-Ramo-Wooldridge No. 17214-R_1 or equiv.
T_3—AM antenna coil; primary No. 2/38 Litz wire wound across length of General Ceramic, ceramic Q rod (0.33-inch dia. 6 inches long) to tune broadcast band with tuning capacitors as shown; secondary 10 turns No. 2/38 Litz wire bifilar wound at ground end of primary
T_4—10.7-Mc/s if transformer, Thompson-Ramo-Wooldridge No. 17215-R_2 or equiv.
T_5 = AM oscillator coil; secondary 20 turns No. 2/38 Litz wire wound on ¼-inch-dia. coil form; primary 95 turns wound over secondary tapped at 5 turns; slug, General Ceramic, ceramic Q rod ⅜-inch long
T_6 = 455-kc/s if transformer, Thompson-Ramo-Wooldridge No. 17217-R_2 or equiv.
T_7 = 10.7-Mc/s if transformer, Thompson-Ramo-Wooldridge No. 17216-R, or equiv.
T_8 = 455-kc/s if transformer, Thompson-Ramo-Wooldridge No. 17218 or equiv.
T_9 = ratio-detector transformer, Thompson-Ramo-Wooldridge No. 16786-R_2 or equiv.
T_{10} = 455-kc/s if transformer, Thompson-Ramo-Wooldridge No. 17219-R_1 or equiv.
T_{11} = audio output transformer, Triad S-12X or equiv.

NOTE: See general considerations for construction of high-frequency and broadband circuits on page 391.

12-8 THREE-BAND AM RADIO RECEIVER



12-8 THREE-BAND AM RADIO RECEIVER (con'td)

Parts List

B = 9 volts
C_1 C_6 C_{14} = variable, 26.1 to 251 pF
C_2 C_3 C_4 C_{23} C_{24} C_{25} = trimmer, 3-35 pF, Arco 403, or equivalent
C_5 = 0.25 μF, ceramic disc
C_7, C_{10}, C_{15}, C_{28} = 0.05 μF, ceramic disc
C_8 C_{11} C_{13} = trimmer, 1.5-20 pF, Arco 402, or equiv.
C_{12}, C_{38} = 0.01 μF, ceramic disc
C_{16} = 0.0005 μF, ceramic disc
C_{17}, C_{18}, C_{31} = 0.02 μF, ceramic disc
C_{19}, C_{26} = 350 pF, part of T_1
C_{20} = 900 pF, silver mica
C_{21} = 300 pF, silver mica
C_{22} = 91 pF, silver mica
C_{27} = 10 pF, ceramic disc
C_{29} = 10 μF, 3 volts, electrolytic
C_{30} = 220 pF, ceramic disc, supplied with T_2
C_{32} = 2 μF, 3 volts, electrolytic
C_{33} = 10 μF, 3 volts, electrolytic
C_{34} = 100 μF, 3 volts, electrolytic
C_{35} = 0.04 μF, ceramic disc
C_{36}, C_{37} = 100 μF, 10 volts, electrolytic
L_1 = 42 μH at 3100 kc, short-wave antenna coil, $Q_0 = 75$; turns ratio N_1/N_2, 1.67:1; N_2/N_3, 18:1
L_2 = 380 μH at 1000 kc/s, broadcast, antenna coil, $Q_0 = 184$; turns ratio N_1/N_2, 78:1
L_3 = 4600 μH at 270 kc/s, long-wave antenna coil, $Q_0 = 69$; turns ratio N_1/N_3, 91:1
L_4 = 5 μH, part of if trap
L_5 = 34 μH at 3100 kc/s, short-wave rf coil, $Q_0 =$ 81; turns ratio, N_1/N_3, 87:1
L_6 = 370 μH at 1000 kc/s, broadcast rf coil, $Q_0 = 80$; turns ratio, N_1/N_2, 2.5:1; N_2/N_3, 25:1
L_7 = 4200 μH at 270 kc/s, long-wave rf coil, $Q_0 =$ 10; turns ratio N_1/N_3, 91:1 (measured with 100000-ohm shunt)
L_8 = 29 μH at 3550 kc/s, short-wave oscillator coil, $Q_0 = 20$; turns ratio N_1/N_2, 25:1, N_1/N_3, 4:1
L_9 = 200 μH at 1455 kc/s, broadcast oscillator coil, $Q_0 = 39$; turns ratio N_1/N_2, 29:1, N_1/N_3, 13:1
L_{10} = 1100 μH at 725 kc/s, long-wave oscillator coil, $Q_0 = 17$; turns ratio N_1/N_2, 21:1, N_1/N_3, 12:1 (measured with 200000-ohm shunt)
R_1 = 270 ohms, 0.5 watt
R_2 = 150000 ohms, 0.5 watt
R_3 = 22000 ohms, 0.5 watt
R_4 = 100000 ohms, 0.5 watt
R_5 = 560 ohms, 0.5 watt
R_6 = 1800 ohms, 0.5 watt
R_7 = 18000 ohms, 0.5 watt
R_8 = 1200 ohms, 0.5 watt
R_9 = 3300 ohms, 0.5 watt
R_{10} = 200000 ohms, 0.5 watt
R_{11} = 47000 ohms, 0.5 watt
R_{12} = 270 ohms, 0.5 watt
R_{13} = 10000 ohms, 0.5 watt
R_{14} = 1000 ohms, 0.5 watt
R_{15} = volume control, 1 megohm, reverse log. taper
R_{16} = 4000 ohms, 0.5 watt
R_{17} = 27000 ohms, 0.5 watt
R_{18} = 4700 ohms, 0.5 watt
R_{19} = tone control, 1 megohm, audio taper
R_{20} = 560 ohms, 0.5 watt
R_{21} = 330 ohms, 0.5 watt
R_{22} = 100 ohms, 0.5 watt
R_{23} = 4.7 ohms, 0.5 watt
R_{24} = 3.9 ohms, 0.5 watt
R_{25} = 3.9 ohms, 0.5 watt
S_{1a}—S_{3b} = three-section wafer switch
S_p = speaker, 3.2 ohms
T_1 = first if transformer (455 kc/s): double-tuned critical coupling, Automatic Mfg. Co. No. E-2,749,067-EX, or equivalent
T_2 = second if transformer (455 kc/s): single-tuned, Automatic Mfg. Co. No. E-2,749,067CX, or equiv.
T_3 = driver transformer: primary 10000 ohms, secondary, 2000 ohms, center tapped; Mid-West Coil and Transformer Co. No. 20AT88, or equivalent
T_4 = output transformer: primary, 250 ohms center tapped; secondary, 3.2 ohms; Mid-West Coil and Transformer Co. No. 20-AT86, or equivalent

NOTE 1: Components C_9, L_4, and R, make up an if trap in the long-wave band and are used to improve if rejection and signal-to-noise ratio.

NOTE 2: For the antenna and rf coils. N_1 refers to the turns of the primary winding, N_2 to the tapped portion of the primary, and N_3 to the secondary. For the oscillator coils, N_1 refers to the tank winding, N_2 to the emitter winding, and N_3 to the collector winding.

NOTE: See general considerations for construction of high-frequency and broadband circuits on page 391.

Circuit Description

In this three-band superheterodyne AM receiver, three mechanically ganged, three-position, multiple-section wafer switches S_1, S_2, and S_3 select the proper combination of antenna, rf-amplifier, and converter tuned circuits for long-wave, broadcast-band, or shortwave operation. Each band uses a 455-kc/s intermediate frequency so that the same if amplifier can be used. The whip antenna is optimized for the shortwave band because the gain of the receiver is lower at these higher frequencies.

The signal received by the antenna is coupled by a single-tuned antenna transformer (L_1 for short-wave signals, L_2 for broadcast-band signals, or L_3 for long-wave signals, depending on the setting of the selector switch S_1) to the emitter of the 2N1632 rf-amplifier stage. Single-tuned coupling is used to transfer the received signal from the collector of the 2N1632 to the emitter of the 2N1526 converter stage. Switch S_2 selects L_5 and its associated tuning capacitors for shortwave operation, L_6 and its associated tuning capacitors for broadcast-band operation, or L_7 and its associated tuning capacitors for long-wave operation.

12-8 THREE-BAND AM RADIO RECEIVER (con'td)

Circuit Description (cont'd)

The oscillator signal is supplied to the converter transistor from the oscillator resonant circuit (L_8 and associated components for short-wave, L_9 and associated components for broadcast band, or L_{10} and associated components for long-wave, as determined by the setting of switch S_3). Tuning capacitors C_1, C_6, and C_{14}, which are common to the three bands, are ganged to assure that the oscillator frequency is always 455 kc/s above the frequency of the received signal. Trimmer capacitors are provided in each tuned-circuit network (in each band) to assure that proper tracking is maintained throughout the band.

The 455-kc/s intermediate-frequency signal is coupled from the collector of the 2N1526 converter to the base of the 2N1524 if amplifier by the double-tuned if transformer T_1. The single-tuned if transformer T_2 couples the amplified if signal to the anode of the detector diode. The diode circuit separates the audio signal from the modulated if signal to the anode of the 1N295 detector diode. The diode circuit separates the audio signal from the modulated if signal and develops an audio voltage across the volume-control potentiometer R_{15}. The portion of this audio signal coupled from the wiper arm of R_{15} to the 2N408 transistor is used to develop the driving power for the 2N270 transistors used in the push-pull audio-output stage. This push-pull stage develops the power to drive the speaker voice coil.

12-9 HIGH-QUALITY PREAMPLIFIER FOR PHONO, FM, OR TAPE PICKUP

Circuit Description

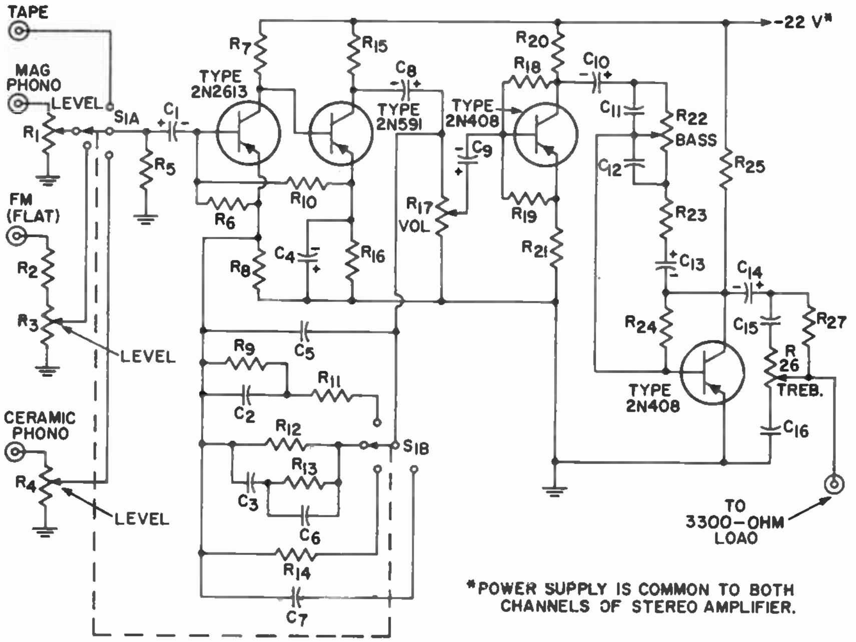
This preamplifier has equalized input circuits for FM stereo (flat), ceramic and magnetic phonograph pickups, and tape-recorder heads. Level controls are provided for FM and ceramic and magnetic phonograph inputs. High input impedance and input equalization are provided in each operating mode by a directly coupled two-stage input section that uses frequency-sensitive negative feedback to provide the desired input characteristics. The 2N2613 transistor used in the first stage has low noise, low saturation current, wide frequency response, and high gain. The 2N591 transistor used in the second stage has excellent linearity and better-than-average noise characteristics. The operating points selected for these stages provide both low noise performance and an adequate dynamic range.

Both tone controls in the preamplifier provide full-range boost and cut functions; interaction is negligible. Distortion is low for any tone-control setting. The collector-to-base feedback in the third and fourth stages works with the tone controls to provide the over-all tonal response of the preamplifier. The 2N408 stages amplify the signal to the input level required by most transistor audio power amplifiers. The sensitivity of the preamplifier at full volume is such that a 1-millivolt input (2-millivolt tape input) results in a 42-millivolt output. For a given input level, the output response (with controls flat) is constant within ± 1 dB from 10 to 20,000 c/s.

The dc power for the preamplifier may be obtained from the power supply for the audio amplifier. If necessary, a voltage-dropping resistor should be used to reduce the supply voltage to the —18 to —22 volts required for the preamplifier stages. This preamplifier is especially suited for use with the 15-watt and 35-watt high-quality audio amplifiers, circuits 12-12 and 12-14.

12-9

HIGH-QUALITY PREAMPLIFIER FOR PHONO, FM, OR TAPE PICKUP (cont'd)



*POWER SUPPLY IS COMMON TO BOTH CHANNELS OF STEREO AMPLIFIER.

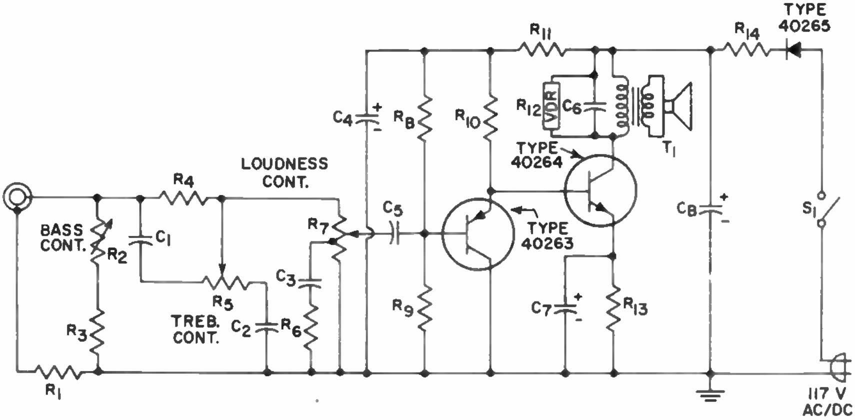
Parts List

C_1 = 25 μF, electrolytic, 3 V
C_2 = 0.06 μF ± 5%, ceramic, 50 V
C_3 = 0.2 μF ± 5%, ceramic, 25 V
C_4 = 50 μF, electrolytic, 3 V
C_5 = 270 pF, ceramic, 600 V
C_6, C_{16} = 0.05 μF ± 5%, ceramic, 50 V
C_7 = 0.25 μF, ceramic, 50 V
C_8 = 25 μF, electrolytic, 15 V
C_9 = 2 μF, electrolytic, 3 V
C_{10}, C_{14} = 2 μF, electrolytic, 10 V
C_{11} = 0.15 μF ± 5%, ceramic, 50 V
C_{12} = 0.12 μF ± 5%, ceramic, 50 V
C_{13} = 10 μF, electrolytic, 10 V
C_{15} = 0.003 μF ± 5%, ceramic, 500 V
R_1 = level control, potentiometer, 50000 ohms, 0.5 watt
R_2 = 51000 ohms, 0.5 watt
R_3 = level control, potentiometer, 1000 ohms, 0.5 watt
R_4 = level control, potentiometer, 5000 ohms, 0.5 watt
R_5 = 1 megohm, 0.5 watt
R_6 = 15000 ohms, 0.5 watt
R_7 = 47000 ohms, 0.5 watt
R_8 = 100 ohms, 0.5 watt
R_9 = 0.1 megohm ± 5%, 0.5 watt
R_{10} = 0.18 megohm, 0.5 watt
R_{11} = 820 ohms ± 5%, 0.5 watt
R_{12} = 27000 ohms ± 5%, 0.5 watt
R_{13} = 1500 ohms ± 5%, 0.5 watt
R_{14} = 1000 ohms, 0.5 watt
R_{15} = 1800 ohms, 0.5 watt
R_{16} = 330 ohms, 0.5 watt
R_{17} = volume control, potentiometer, 10000 ohms, 0.5 watt
R_{18} = 56000 ohms, 0.5 watt
R_{19} = 6800 ohms, 0.5 watt
R_{20}, R_{23} = 2700 ohms, 0.5 watt
R_{21} = 180 ohms, 0.5 watt
R_{22} = bass control, potentiometer, 50000 ohms, 0.5 watt
R_{24} = 0.1 megohm, 0.5 watt
R_{25} = 3300 ohms, 0.5 watt
R_{26} = treble control, potentiometer, 0.1 megohm, 0.5 watt
R_{27} = 27000 ohms, 0.5 watt
S_1 = selector switch; rotary type; 2-pole, 3-position

12-10

LINE-OPERATED TWO-STAGE PHONOGRAPH AMPLIFIER

Output 1 W



Parts List

C_1, C_2 = 1200 pF, ceramic
C_3 = 0.005 μF, ceramic
C_4 = 100 μF, electrolytic, 25 V
C_5 = 0.1 μF, ceramic
C_6 = 0.01 μF, ceramic
C_7 = 250 μF, electrolytic, 12 V
C_8 = 50 μF, electrolytic, 150 V
R_1 = 56000 ohms, 0.5 watt
R_2 = bass control, potentiometer, 3 megohms, audio taper
R_3, R_9 = 68000 ohms, 0.5 watt
R_4 = 0.33 megohm, 0.5 watt
R_5 = treble control, potentiometer, 1 megohm, audio taper
R_6, R_{10} = 10000 ohms, 0.5 watt
R_7 = loudness control, potentiometer, 2 megohms, linear taper; tapped at 1 megohm
R_8 = 0.18 megohm, 0.5 watt
R_{11} = 33000 ohms, 0.5 watt
R_{12} = voltage-dependent resistor, Ferroxcube No. E299DD-P340 or equiv.
R_{13} = 220 ohms, 0.5 watt
R_{14} = 250 ohms, 3 watts
S_1 = ON-OFF switch, single-pole, single-throw
T_1 = output transformer; primary 2500 ohms, secondary 3.2 ohms, efficiency 80 per cent; Triad S-12X or equiv.

12-10 LINE-OPERATED TWO-STAGE PHONOGRAPH AMPLIFIER (cont'd)

Circuit Description

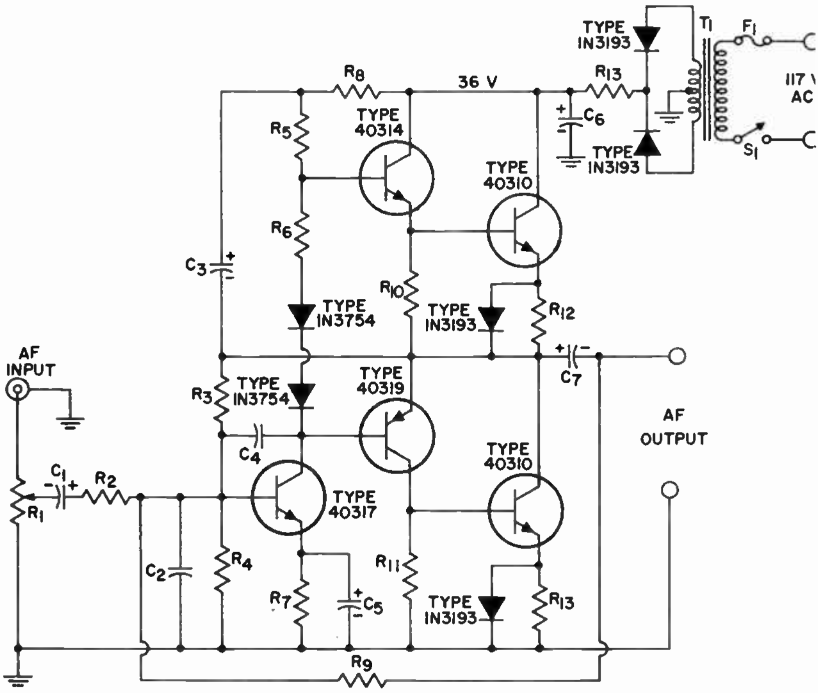
This two-transistor phonograph amplifier provides full output power of one watt at average record levels with a ceramic phonograph cartridge such as the Astatic model 314 or equivalent. It operates directly from either an ac power line or a dc supply of 117 volts. A 40265 diode is used in a half-wave rectifier circuit to convert ac inputs to the dc power required for the two transistor stages. Capacitor C_8 filters the rectifier output.

The 40264 n-p-n output transistor is driven by a 40263 p-n-p transistor operated in an emitter-follower stage. Because of the large, bypassed emitter resistor R_{13}, the amplifier can maintain a constant output-stage current for wide variations in current transfer ratio of the transistors without loss of ac gain. Moreover, the phase reversal between the collector currents of the two transistors tends to compensate for temperate effects. Any tendency for current in the 40264 transistor to increase with temperature is offset by an increase in emitter current of the 40263 transistor.

Output transformer T_1 is used to match the amplifier to the speaker to obtain an output of one watt. The electrolytic capacitors C_4, C_7, and C_8 can be sections of a multiple-section common-negative capacitor.

The power gain of the basic amplifier circuit is 68 dB. An input of 3 microamperes is required to a load of 15,000 ohms to obtain a power output of one watt. The stability of the circuit is excellent; the sensitivity remains relatively constant over the range of ambient temperatures from 25 to 70°C. Distortion is less than 1 per cent for outputs below 50 milliwatts, and approaches 10 per cent as the output rises to one watt, the point at which clipping begins. At a line voltage of 117 volts, the 40264 transistor idles at a dissipation of approximately 2.5 watts. The 40264 should be connected to a suitable heat sink so that the junction temperature will not exceed 150°C under worst-case conditions. The voltage-dependent resistor R_{12} provides transient-voltage protection for the output transistor.

12-11 HIGH-QUALITY 10-WATT AUDIO POWER AMPLIFIER



Parts List

C_1 = 50 μF, electrolytic, 6 V
C_2 = 250 pF, ceramic
C_3 = 50 μF, electrolytic, 25 V
C_4 = 100 pF, ceramic
C_5 = 100 μF, electrolytic, 6 V
C_6 = 1000 μF, electrolytic, 50 V
C_7 = 1000 μF, electrolytic, 25 V

F_1 = fuse, 1-ampere
R_1 = volume control, potentiometer, 5000 ohms, 0.5 watt (part of assembly with ON-OFF switch S_1)
R_2, R_8 = 1000 ohms, 0.5 watt
R_3 = 36000 ohms, 0.5 watt
R_4, R_5 = 4700 ohms, 0.5 watt
R_6 = 180 ohms, 0.5 watt
R_7 = 470 ohms, 0.5 watt
R_9 = 68000 ohms, 0.5 watt

R_{10}, R_{11} = 220 ohms, 0.5 wa
R_{12}, R_{13} = 1 ohm, 1 watt
S_1 = ON-OFF switch (pa of assembly with volume control potentiometer R
T_1 = power transforme primary, 117 volts rm secondary, center-tappe 27 volts rms from cente tap to each end at 5 mA dc

12-11 HIGH-QUALITY 10-WATT AUDIO POWER AMPLIFIER (cont'd)

Circuit Description

This high-quality audio amplifier can supply 10 watts (rms) of power to an 8-ohm speaker for an input of 1 volt rms. The output impedance of the amplifier is designed to match an 8-ohm speaker without the use of an output transformer. Series-connected 40310 n-p-n transistors are used in the output stage. The driver stage uses a 40319 p-n-p transistor and a 40314 n-p-n transistor connected in complementary symmetry to develop push-pull drive for the output stage so that no driver transformer is required. (The use of driver and output transformers would tend to limit the over-all frequency response of the amplifier.) The over-all negative feedback of 6 dB and other factors result in an amplifier frequency response that is flat within 1 dB from 15 to 25,000 c/s. The use of direct coupling between stages and local dc feedback for each stage results in stable quiescent operation of the amplifier at ambient temperatures up to 71°C.

The input stage of the amplifier employs a 40317 n-p-n transistor connected in a class A common-emitter circuit configuration. Negative feedback from collector to base of the transistor stabilizes operation of the input stage.

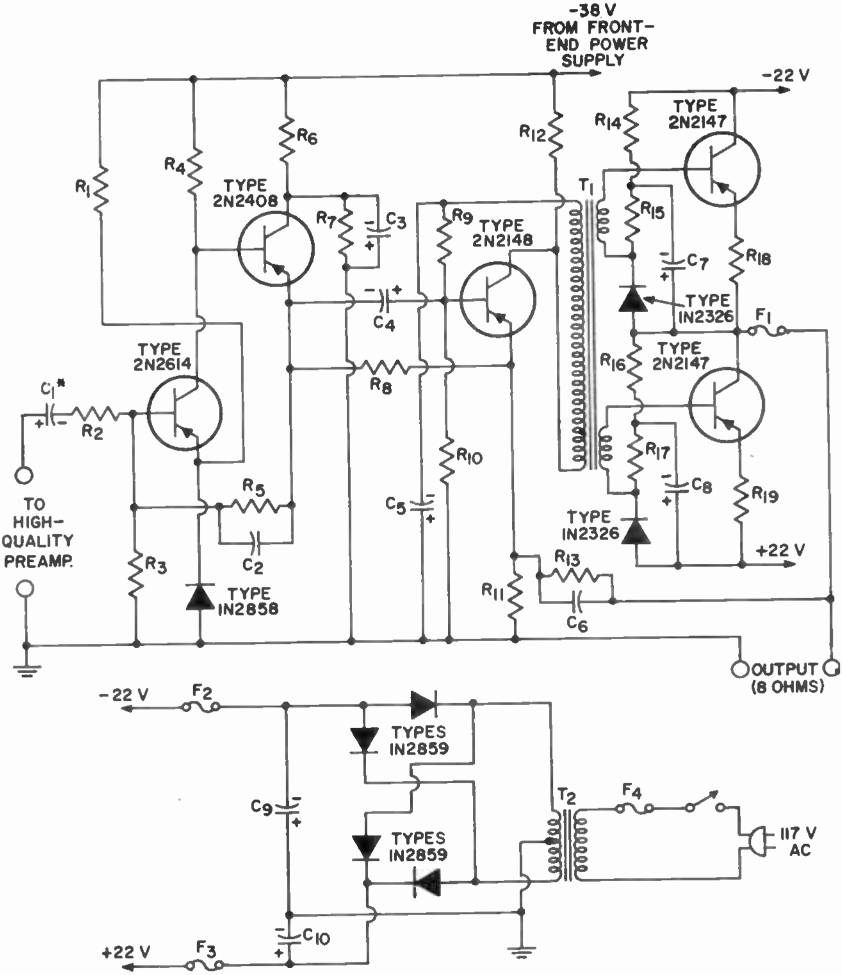
The amplified signal developed at the collector of the 40317 is directly coupled to the base of the 40319 driver transistor, and the signal at the junction of the collector load resistors R_5 and R_6 is directly coupled to the base of the 40314. Because these driver transistors are connected in complementary symmetry, the outputs developed across resistor R_{10} and R_{11} are 180 degrees out of phase. The 1N3754 diodes connected between the bases of the driver transistors are used to compensate for the effect of temperature variations on the performance of the output transistors.

The 40310 series-connected output transistors are operated in class AB rather than class B to prevent cross-over distortion. The drive input from the 40314 driver transistor is applied between the emitter and base terminals of its output transistor so that this output transistor is effectively operated in a common-emitter configuration. As a result, both output transistors provide equal voltage gain. The small amount of degenerative feedback developed across emitter resistors R_{12} and R_{13} helps to stabilize the output stage. The limiting action of the 1N3193 diodes connected in shunt with the emitter resistors prevents excessive power losses across these resistors when the amplifier is operated to provide the full rated output of 10 watts.

This audio power amplifier operates from a 117-volt, 60-c/s ac power input. The input is coupled by power transformer T_1 to a conventional full-wave rectifier using two 1N3193 diodes. The rectifier provides a 36-volt dc output for use as the collector supply voltage for the amplifier.

12-12 HIGH-QUALITY 15-WATT AUDIO POWER AMPLIFIER

IHFM Music Power Rating 36 W



Parts List

C_1* = 200 μF, electrolytic, 3 V
C_2 = 82 pF, ceramic
C_3 = 100 μF, electrolytic, 15 V
C_4 = 200 μF, electrolytic, 6 V
C_5 = 250 μF, electrolytic, 15 V
C_6 = 0.015 μF, ceramic
C_7, C_8 = 100 μF, electrolytic, 25 V
C_9, C_{10} = 2500 μF, electrolytic, 25 V
F_1 = fuse, small enough to protect speaker
F_2, F_3 = fuse, 3-ampere
F_4 = fuse; 1-ampere, slo-blo
R_1 = 18000 ohms, 0.5 watt
R_2 = 3300 ohms, 0.5 watt
R_3 = 10000 ohms, 0.5 watt
R_4 = 27000 ohms, 0.5 watt
R_5 = 33000 ohms, 0.5 watt
R_6 = 1500 ohms, 1 watt
R_7 = 1200 ohms, 0.5 watt
R_8 = 330 ohms, 0.5 watt
R_9 = 2700 ohms, 0.5 watt
R_{10} = 180 ohms, 0.5 watt
R_{11} = 4.7 ohms, 0.5 watt
R_{12} = 560 ohms, 2 watts
R_{13} = 150 ohms, carbon, 5 watts
R_{14}, R_{16} = 180 ohms, 2 watts
R_{15}, R_{17} = 120 ohms, 1 wat
R_{18}, R_{19} = 0.27 ohms, 1 wat
T_1 = driver transformer Better Coil and Trans-former Company No 99A7 or equiv.
T_2 = power transformer Better Coil and Trans-former Company No 99P5 or equiv.
* Capacitor C_1 should not b used when the amplifie is driven by preamplifie circuit 12-9 or any othe preamplifier circuit tha has a capacitively couple output.

12-12 HIGH-QUALITY 15-WATT AUDIO POWER AMPLIFIER (cont'd)

Circuit Description

This audio power amplifier can deliver 15 watts of sine-wave power to an 8-ohm speaker; its IHFM music power rating is 36 watts. Two of these amplifiers can be used in a stereo system to provide a total sine-wave power of 30 watts, or total IHFM music power of 72 watts. In this four-stage unit, two directly coupled input stages are used as a predriver for the driver-output combination. An emitter-follower circuit is used in the second stage of the predriver section to provide the low source impedance required for the voltage feedback to the driver stage.

The 2N2614 transistor used in the first predriver stage has high gain, low saturation current, and wide frequency response. The 2N408 used in the second stage improves linearity. Negative feedback coupled from the output (emitter) of the 2N408 emitter-follower stage to the input (base) of the 2N2614 stage provides dc stabilization for the predriver section.

The driver-output section of the amplifier consists of a class B output stage driven by a transformer-coupled driver stage. Both stages use drift-field power transistors that feature excellent linearity (as a function of current and voltage swing), high gain, low saturation and leakage current, and a high common-emitter cutoff frequency. Because the negative feedback coupled from the output (speaker) terminal back to the emitter of the driver stage is applied in series with the input voltage, a low source impedance is required at the 2N2148 driver stage. The emitter-follower 2N408 second stage provides this low impedance.

Two 1N2326 compensating diodes are used in the output stage to prevent changes in the 2N2147 idling current with variations in temperature. A decoupling network is used between the collector of each 2N2147 output transistor and its compensating diode to prevent the diode from becoming back-biased during the signal swing and causing premature clipping.

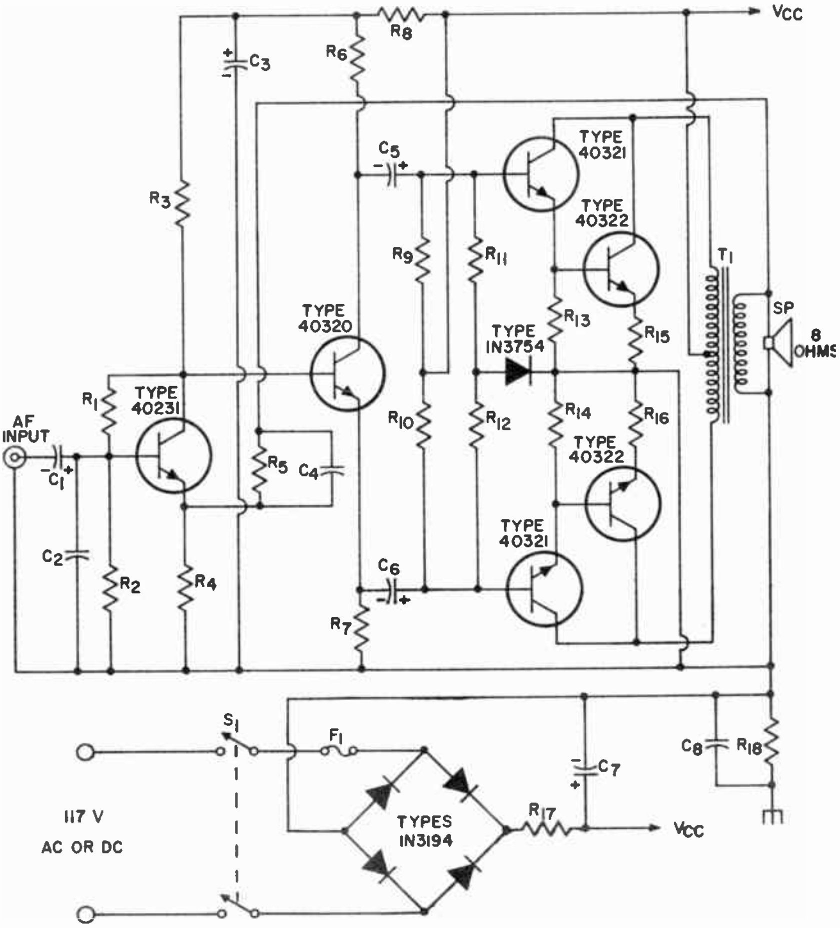
The power for the output stage is obtained from a center-tapped bridge rectifier that provides both positive and negative 22-volt outputs with respect to the grounded center tap. The direct signal-return path through the supply reduces low-frequency phase shift. Two 1N2859 100-volt flanged axial-lead silicon rectifiers mounted on heat sinks are used in the power supply. If two amplifiers are combined in a stereo system, this power supply is common to both channels. A separate power supply that provides a well-filtered dc voltage of —38 volts should be used for the predriver and driver circuits.

This audio power amplifier should be used with a high-quality preamplifier such as that shown in circuit 12-9. Typical performance data for the 15-watt amplifier (with an 8-ohm load impedance) are as follows:

Distortion at 25 watts output:
  0.35% at 25 c/s
  0.35% at 1000 c/s
  0.75% at 15,000 c/s
  0.80% at 20,000 c/s at 1 dB below 15 watts
IHFM music power: 36 watts
Sensitivity: 42 millivolts into 3300-ohm input for 15-watt output
Hum and noise: 70 dB below 15 watts
Frequency response (3-dB-down points): 6 to 30,000 c/s
Intermodulaton distortion (with 60- and 4000-c/s signals mixed 4:1; output equivalent to 15 watts): 1.0%

12-13

LINE-OPERATED (AC/DC) 25-WATT AUDIO POWER AMPLIFIER



Circuit Description

This amplifier is intended primarily for use in public-address systems and other audio applications in which flexibility with respect to load impedance is important. The amplifier provides more than 60 dB of power gain and has a flat frequency response from 35 to 15,000

12-13 LINE-OPERATED (AC/DC) 25-WATT AUDIO POWER AMPLIFIER (cont'd)

Circuit Description (cont'd)

c/s. Total harmonic distortion at the output is less than 1 per cent, and the hum and noise level is 63 dB below the output for operation at the rated power level. The high breakdown voltage of the silicon transistors used in the output and driver stages permits the amplifier to be operated directly from either an ac power line or a dc supply of 117 volts. AC inputs are converted to a smooth dc supply voltage by four 1N3194 diodes in a full-wave bridge rectifier, together with a simple RC filter network R_{17} and C_7.

The input stage of the amplifier uses a 40231 transistor in a class A common-emitter configuration. This configuration, together with negative feedback of approximately 10 dB from the output (speaker terminal) to the emitter of the 40231, results in an amplifier input impedance of 2500 ohms. The amplified signal at the collector of the input transistor is directly coupled to the base of a 40320 transistor used in a simple phase-splitter circuit to develop the out-of-phase signals required to drive the push-pull output stage. Because the collector and emitter load resistors in the phase-splitter stage are of equal value, the signals developed at the emitter and collector of the 40320 are equal in amplitude but 180 degrees out of phase. These signals are capacitively coupled to the bases of the 40321 driver transistors.

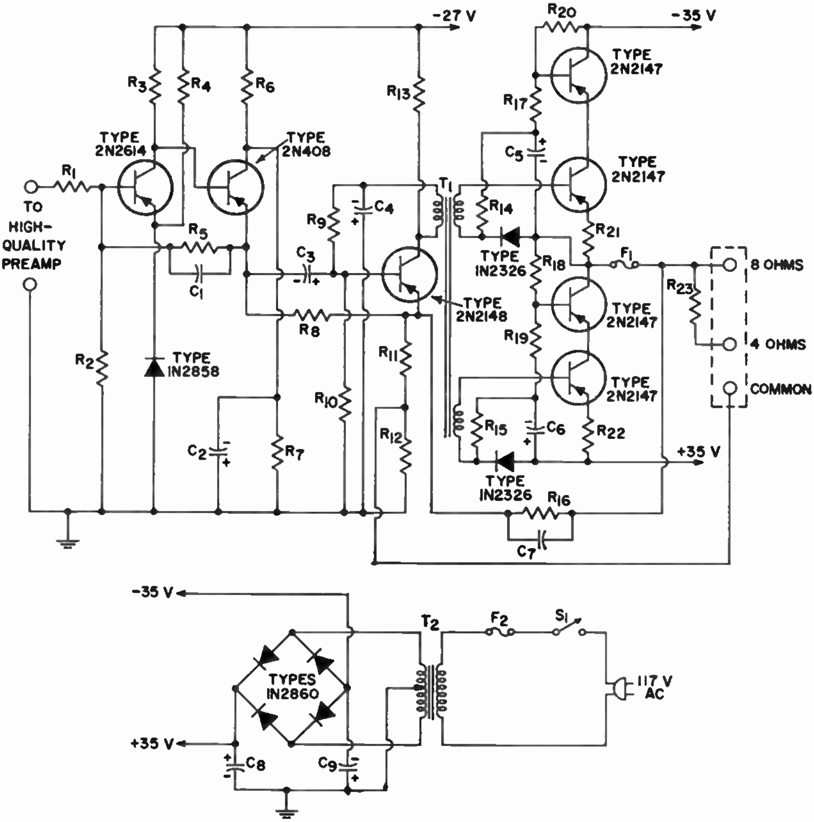
The driver transistors are connected to the 40322 high-voltage output transistors in a Darlington configuration which provides the high power gain required to develop the desired power output from the signals supplied from the phase-splitter. Resistors R_9, R_{10}, R_{11}, and R_{12} and the 1N3754 diode bias the driver and output stages for class AB operation. These stages are operated in class AB rather than class B to minimize cross-over distortion. The 1N3754 diode also provides the temperature compensation required to maintain a relatively constant quiescent current with small changes in temperature or line voltage. At the rated output, the dissipation in each output transistor is less than 15 watts at room temperature; therefore, the amplifier can be operated at temperatures up to 70°C without transistor derating.

Parts List

C_1 = 1 μF, electrolytic, 3 V
C_2 = 0.02 μF, ceramic disc
C_3 = 250 μF, electrolytic, 25 V
C_4 = 0.002 μF, ceramic disc
C_5, C_6 = 2 μF, electrolytic, 25 V
C_7 = 250 μF, electrolytic, 150 V
C_8 = 0.1 μF, ceramic disc
F_1 = fuse, 1.5-ampere
R_1 = 15000 ohms, 0.5 watt
R_2 = 3000 ohms, 0.5 watt
R_3 = 2200 ohms, 0.5 watt
R_4 = 51 ohms, 0.5 watt
R_5 = 5100 ohms, 0.5 watt
R_6, R_7 = 300 ohms, 0.5 watt
R_8 = 4000 ohms, 5 watts
R_9, R_{10} = 0.18 megohm, 0.5 watt
R_{11}, R_{12}, R_{13}, R_{14} = 510 ohms, 0.5 watt
R_{15}, R_{16} = 5 ohms, 5 watts
R_{17} = 10 ohms, 20 watts
R_{18} = 0.22 megohm, 0.5 watt
S_1 = ON-OFF switch, double-pole, single-throw
T_1 = audio output transformer; primary, 600 ohms, center tapped; secondary, 8 ohms; Columbus Process Co. No. DD176525 or equiv.

12-14 HIGH-QUALITY 35-WATT AUDIO POWER AMPLIFIER

IHFM Music Power Rating 72 W



Circuit Description

This audio power amplifier can deliver 35 watts of sine-wave power to an 8-ohm speaker; its IHFM music power ratings is 72 watts. Two of these amplifiers can be used in a stereo system to provide a

12-14

HIGH-QUALITY 35-WATT AUDIO POWER AMPLIFIER (cont'd)

Circuit Description (cont'd)

total sine-wave power of 70 watts, or total IHFM music power of 144 watts. The predriver and driver stages are essentially identical to those used in the 15-watt amplifier of circuit 12-12; however, the output stages of the two amplifiers are significantly different.

The output stage of the 35-watt amplifier employs four 2N2147 transistors in a single-ended, series-arranged, push-pull configuration. Two of the transistors are base-driven by the driver stage through the driver transformer T_1. Each of these transistors, in turn, drives the emitter of another 2N2147. The two transistors in each half of the push-pull amplifier are series arranged and biased to permit large-signal operation. Two 1N2326 germanium diodes are used to compensate for changes in transistor idling current with temperature. These diodes also improve transient response by preventing shifts in the operating point of the transistors, and reduce crossover distortion that may result from phase shifts across capacitors C_5 and C_6.

A center-tapped, full-wave bridge rectifier using four 1N2860 diodes provides the symmetrical positive and negative voltage for the power-output stage. If two amplifiers are combined in a stereo system, this power supply is common to both amplifiers. The voltage of —27 volts required for the predriver and driver should be obtained from a separate, well-filtered supply.

This audio power amplifier should be used with a high-quality preamplifier such as that shown in circuit 12-9. Typical performance data for the 35-watt amplifier (with an 8-ohm load impedance) are as follows:

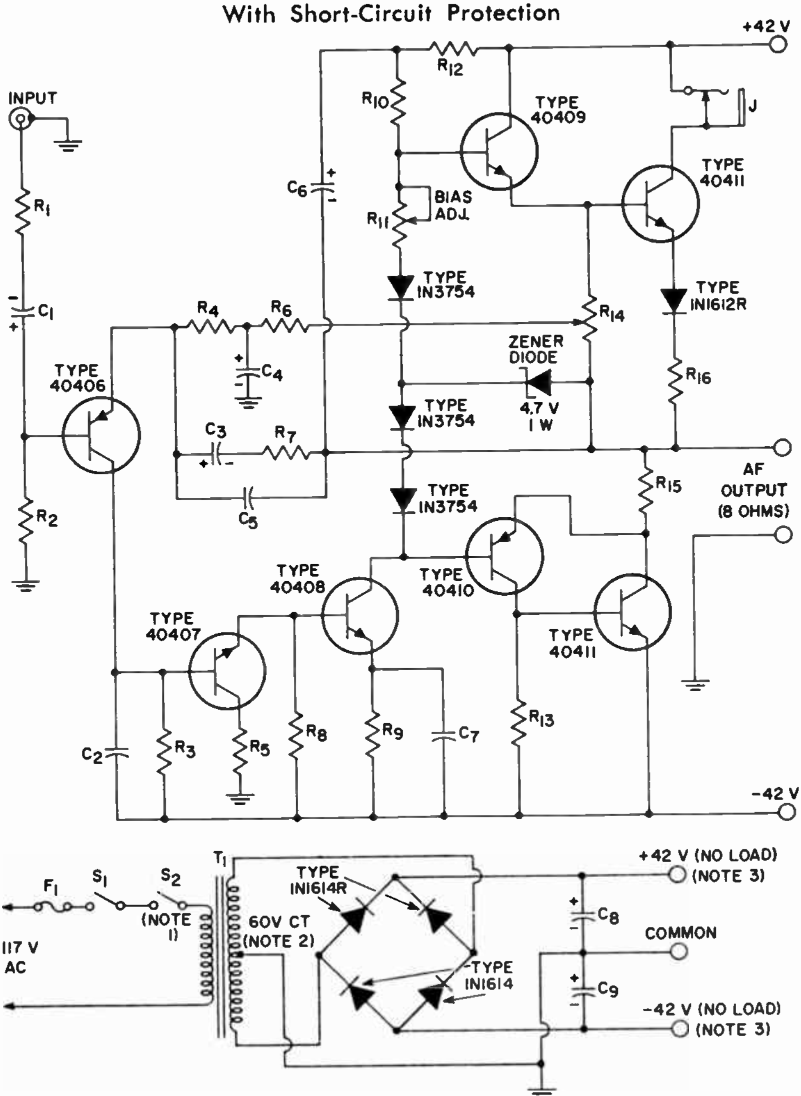
Distortion at 35 watts output:
  0.3% at 25 c/s
  0.3% at 1000 c/s
  1.0% at 15,000 c/s
IHFM music power: 72 watts
Sensitivity: 65 millivolts into 3300-ohm input for 35-watt output
Hum and noise: more than 85 dB below 35 watts
Frequency response (3-dB-down points): 3 to 40,000 c/s

Parts List

C_1 = 82 pF, mica
C_2 = 150 μF, electrolytic, 15 V
C_3 = 250 μF, electrolytic, 15 V
C_4 = 250 μF, electrolytic, 25 V
C_5, C_6 = 50 μF, electrolytic, 20 V
C_7 = 0.005 μF, ceramic disc
C_8, C_9 = 2500 μF, electrolytic, 50 V
F_1 = fuse, small enough to protect speaker
F_2 = fuse, 2-ampere, slo-blo
R_1, R_9 = 3300 ohms, 0.5 watt
R_2, R_4 = 10000 ohms, 0.5 watt
R_3 = 18000 ohms, 0.5 watt
R_5 = 47000 ohms, 0.5 watt
R_6 = 330 ohms, 1 watt
R_7 = 330 ohms, 0.5 watt
R_8 = 220 ohms, 0.5 watt
R_{10} = 180 ohms, 0.5 watt
R_{11} = 4.7 ohms, 0.5 watt
R_{12} = 0.18 ohms, 0.5 watt
R_{13}, R_{18}, R_{20} = 270 ohms, 2 watts
R_{14}, R_{15} = 150 ohms, 1 watt
R_{16} = 270 ohms, carbon, 5 watts
R_{17}, R_{19} = 100 ohms, 1 watt
R_{21}, R_{22} = 0.51 ohms, 1 watt
R_{23} = 4 ohms, 25 watts
S_1 = ON-OFF switch, single-pole, single-throw
T_1 = driver transformer, Better Coil and Transformer Company No. 99A5, Columbus Process Company No. X7601, or equiv.
T_2 = power transformer, Better Coil and Transformer Company No. 99P6, Columbus Process Company No. X8300, or equiv.

12-15 HIGH-FIDELITY 70-WATT AUDIO POWER AMPLIFIER

With Short-Circuit Protection



Parts List

C_1 = 5 μF, electrolytic, 6 V
C_2 = 180 μF, mica, 60 V
C_3 = 2 μF, electrolytic, 6 V
C_4 = 100 μF, electrolytic, 3 V
C_5 = 100 pF, mica, 60 V
C_6 = 100 μF, electrolytic, 50 V
C_7 = 250 μF, electrolytic, 6 V
C_8, C_9 = 3000 μF, electrolytic, 75 V
F_1 = fuse, 3-ampere
R_1 = 82000 ohms, 0.5 watt
R_2 = 18000 ohms, 0.5 watt
R_3 = 0.1 megohm, 0.5 watt
R_4 = 180 ohms, 0.5 watt
R_5, R_6 = 10000 ohms, 0.5 watt
R_7 = 33000 ohms, 0.5 watt
R_8 = 4700 ohms, 0.5 watt
R_9 = 270 ohms, 0.5 watt
R_{10} = 5600 ohms, 0.5 watt
R_{11} = bias adjustment, potentiometer, 250 ohms, linear taper
R_{12} = 3900 ohms, 0.5 watt
R_{13} = 100 ohms, 0.5 watt
R_{14} = zero adjustment, potentiometer, 100 ohms,

12-15 HIGH-FIDELITY 70-WATT AUDIO POWER AMPLIFIER (cont'd)

Parts List (cont'd)

linear taper
R_{15}, R_{16} = 0.3 ohm, 10 watts
S_1 = ON-OFF switch, single-pole, single-throw
S_2 = thermal cutout switch, opens automatically when temperature rises above 100°C
T_1 = power transformer; primary, 117 volts rms; secondary, center-tapped, 62 volts from center tap to each end at 1.5 A dc (with no external load on power supply)

Circuit Description

This amplifier has a frequency response that is flat within 1 dB from 5 to 25,000 c/s. Total harmonic distortion at the full rated output of 70 watts is less than 0.25 per cent at 1000 c/s. The amplifier requires no driver or output transformer, and has built-in short-circuit protection that prevents damage to the driver and output stages from high currents and excessive power dissipation.

The driver and output stages of this amplifier are similar to those of the 10-watt amplifier in circuit 12-11. The driver stage uses a 40409 n-p-n transistor and a 40410 p-n-p transistor connected in complementary symmetry to develop push-pull drive for the output stage. Two 40411 silicon power transistors used in the output stage are connected in series with separate positive and negative supply voltages. The output is directly coupled to an 8-ohm speaker from the common point between the two transistors. Negative feedback of 35 dB is provided by R_5 and C_3.

The input stage uses a 40406 p-n-p transistor in a common-emitter circuit. This stage also provides the dc feedback through C_4, R_4, R_6, and R_{14} (the dc zero adjustment) for maintaining the quiescent voltage of the output stage at zero plus or minus 0.1 volt.

The predriver stage employs a 40407 transistor and a 40408 transistor connected as a Darlington pair. This circuit has a minimum loading effect on the input stage and provides the necessary voltage amplification for the entire amplifier. The subsequent stages do not provide voltage gain.

Bias-voltage adjustment for the complementary driver stages is provided by the three 1N3754 diodes and the 250-ohm potentiometer R_{11}. The bias control R_{11} permits adjustment for variations in device parameters; it is adjusted so that the output-stage quiescent current measured at the monitor jack J is 20 milliamperes. The forward voltage drop across the three diodes, together with the voltage drop across the bias control, provides the bias voltage necessary to maintain the output stages in class AB operation to avoid cross-over distortion. The 1N3754 diodes are connected thermally to the heat sinks of the output transistors to provide the necessary thermal feedback to stabilize the quiescent current at its preset value at all case temperatures up to 100°C. Because of the high-temperature compensation provided by this thermal feedback network, the required stability in the output stages can be provided by small emitter resistors, and losses are held to a minimum.

Short-circuit protection for this amplifier is provided by a current-limiting circuit that consists of the Zener diode and emitter resistors R_{15} and R_{16}. If any condition exists which causes a current of more than five amperes to flow through either resistor, the voltage potential across the Zener diode will cause it to conduct in the forward direction during the negative-going output half-cycle and cause it to break down at the diode reference voltage during the positive-going output half-cycle. The driving voltage, therefore, is clamped at that level and any further increase in output current is pre-

12-15

HIGH-FIDELITY 70-WATT AUDIO POWER AMPLIFIER (cont'd)

Circuit Description (cont'd)

vented. In this way, both the driver and the output transistors are protected from high currents and excessive power dissipation such as would be caused by a reduced load resistance or, in the worst case, a short circuit.

This amplifier operates from a full-wave power supply which provides symmetrical positive and negative dc outputs of 42 volts. The thermal cutout S_2 in the power-supply circuit is attached to the heat sink of one of the output transistors. In the event of sustained higher-than-normal dissipations, S_2 will turn off power to the amplifier when the temperature rises to 100°C.

12-16

THREE-STAGE 1-WATT STEREO PHONOGRAPH AMPLIFIER

IHFM Music Power Rating 2.5 W Per Channel

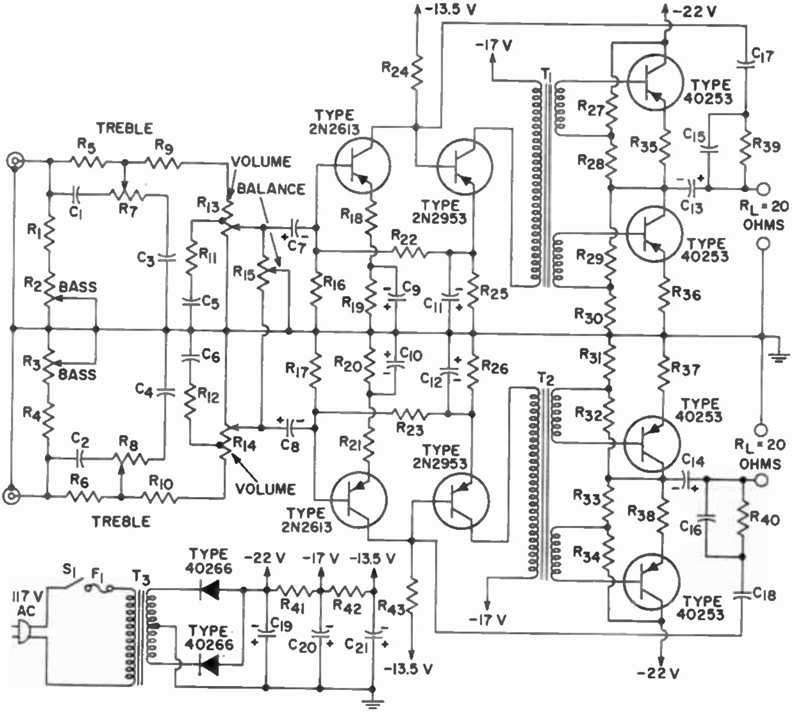
Circuit Description

This three-stage stereo amplifier delivers a sine-wave power output of more than 1 watt per channel to a 20-ohm speaker; its IHFM music power rating is 2.5 watts per channel, or 5 watts total. The input to the amplifier is obtained from a conventional 0.5-volt, 1000-picofarad ceramic pickup; full power output is attained at average record levels for the maximum volume setting. The amplifier incorporates bass and treble tone controls, as well as a tapped loudness (volume) control for bass boosting at low volume settings. It has high gain, operates at low noise levels, and provides stable operation at temperatures up to 55°C.

Each channel employs a 2N2613 low-noise input stage, a 2N2953 transformer-coupled driver stage, and a conventional transformerless class B output stage using two 40253 transistors. The output power is coupled to the speakers through 100-microfarad electrolytic capacitors C_{13} and C_{14}. A frequency-sensitive feedback loop in each channel is connected from the speaker terminal to the base of the driver stage. Because the 330-picofarad series capacitors C_{17} and C_{18} attenuate the feedback at low frequencies but allow high-frequency signals to be fed back relatively unimpeded, they effectively provide a fixed amount of bass boost. The 10-picofarad capacitors C_{15} and C_{16} provide feedback stabilization at high frequencies.

The low-noise input and driver stages are directly coupled. Each stage uses bypassed emitter resistors, and dc feedback is coupled from the emitter of the driver to the base of the input stage. The tone, volume, and balance controls are grouped together at the input. The 1-megohm resistors R_5 and R_6 and the 0.1-megohm resistors R_9 and R_{10} provide the high input impedance required for equalization and also form the divider for the full-range treble control. Bass cut is obtained by loading the pickup at low frequencies. Because of the bass boost in the loudness function and in the feedback loop, the bass cut acts in a manner similar to that of a boost-cut control. The loudness function is provided by 15,000-ohm potentiometers (volume controls) tapped at 10,000 ohms (R_{13} and R_{14}). The armature of each potentiometer is connected to the base of the input stage so that the source impedance is low and the noise is reduced at low volume settings. The balance-control potentiometer R_{15} can be adjusted so that it completely shorts the input stage of the attenuated channel to ground or, with less at-

12-16 THREE-STAGE 1-WATT STEREO PHONOGRAPH AMPLIFIER (cont'd)



Circuit Description (cont'd)

tenuation, exactly balances the inputs to the two channels.

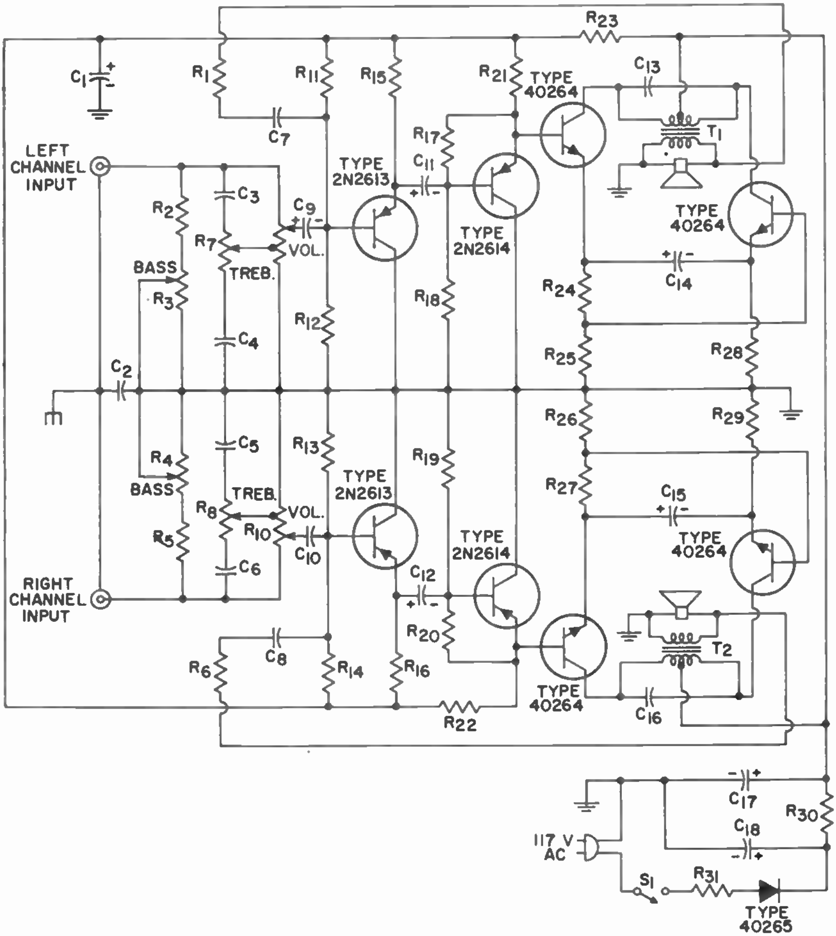
The dc power for the amplifier is provided by a conventional full-wave center-tapped 22-volt supply using 40266 rectifier diodes; decoupling networks provide filtered dc voltages for the front-end stages.

Parts List

C_1, C_2 = 100 pF, ceramic disc, 25 V
C_3, C_4 = 0.001 μF, paper, 25 V
C_5, C_6 = 0.5 μF, paper, 25 V
C_7, C_8 = 10 μF, electrolytic, 3 V
C_9, C_{10} = 100 μF, electrolytic, 3 V
C_{11}, C_{12} = 500 μF, electrolytic, 6 V
C_{13}, C_{14} = 100 μF, electrolytic, 25 V
C_{15}, C_{16} = 10 pF, ceramic disc, 25 V
C_{17}, C_{18} = 330 pF, ceramic disc, 25 V
C_{19} = 1000 μF, electrolytic, 25 V
C_{20} = 100 μF, electrolytic, 20 V
C_{21} = 100 μF, electrolytic, 15 V
F_1 = fuse, 1-ampere, slo-blo
R_1, R_4 = 0.18 megohms, 0.5 watt
R_2, R_3 = bass control, potentiometer, 3 megohms, 0.5 watt, audio taper
R_5, R_6, R_{39}, R_{40} = 1 megohm, 0.5 watt
R_7, R_8 = treble control, potentiometer, 3 megohms, 0.5 watt, audio taper
R_9, R_{10} = 100000 ohms, 0.5 watt
R_{11}, R_{12} = 180 ohms, 0.5 watt
R_{13}, R_{14} = volume control, potentiometer, 15000 ohms, tapped at 10000 ohms
R_{15} = balance control, potentiometer, 20000 ohms, 0.5 watt
R_{16}, R_{17}, R_{24}, R_{43} = 10000 ohms, 0.5 watt
R_{18}, R_{21} = 47 ohms, 0.5 watt
R_{19}, R_{20} = 470 ohms, 0.5 watt
R_{22}, R_{23} = 56000 ohms, 0.5 watt
R_{25}, R_{26} = 390 ohms, 0.5 watt
R_{27}, R_{29}, R_{32}, R_{34} = 270 ohms, 0.5 watt
R_{28}, R_{30}, R_{31}, R_{33} = 3.9 ohms, 0.5 watt
R_{35}, R_{36}, R_{37}, R_{38} = 0.51 ohm, 0.5 watt
R_{41} = 220 ohms, 0.5 watt
R_{42} = 2200 ohms, 0.5 watt
S_1 = ON-OFF switch, single-pole, single-throw
T_1, T_2 = driver transformer, Better Coil and Transformer Co. No. 99A4, Columbus Process Co. No. 7602, or equiv.
T_3 = Power transformer, Better Coil and Transformer Co. No. EX4744P, Columbus Process Co. No. 8970, or equiv.

12-17

LINE-OPERATED (AC/DC) 3-WATT STEREO PHONOGRAPH AMPLIFIER



Circuit Description

This three-stage stereo phonograph amplifier operates directly from either an ac power line or a dc supply of 117 volts. AC power inputs are converted to dc power by the 40265 rectifier. When used with a ceramic phonograph cartridge such as the Sonotone model 21-T or the Astatic model 17-D, the amplifier can deliver continuous sine-wave power of 3 watts per channel with a total harmonic distortion of 10 per cent or less at average record levels. At an output level of 1 watt, distortion is 1.5 per cent or less. The maximum power output (into hard clipping) is about 4.5 watts of power output per channel.

The input stage in each channel

12-17 LINE-OPERATED (AC/DC) 3-WATT STEREO PHONOGRAPH AMPLIFIER (cont'd)

Circuit Description (cont'd)

uses a high-gain, low-noise 2N2613 transistor in a common-emitter circuit configuration to provide a high input impedance and to maintain a constant input sensitivity for the amplifier over a wide range of variation in transistor parameters. The emitter output from each 2N2613 is applied to the base of a 2N2614 transistor operated in an emitter-follower configuration that develops the driving power for direct coupling to the output stage. With this arrangement, the emitter current in the output stage is maintained relatively constant for a wide range of transistor parameters and for normal variations in line voltage. The 2N2614 driver transistors provide a phase reversal which tends to cancel any variation in output-stage idling current with changes in temperature.

Each output stage of the amplifier employs two 40264 high-voltage silicon power transistors in a class A push-pull configuration. Because both output-stage transistors are biased with a constant emitter current, dc unbalance in the output transformer is negligible. Therefore, a low-cost, ⅜-inch output transformer can be used.

The sensitivity of the amplifier is such that full rated power output may be obtained for an input less than 425 millivolts. Any 800-to-1500-picofarad ceramic cartridge that provides an output from 250 to 600 millivolts may be used. The RIAA frequency response of the circuit (between the 3-dB-down points) extends from 100 to 9500 c/s with the tone controls in the flat position.

Treble boost and cut are obtained from a tap on the volume control. Boost or cut of 9.5 dB is available at normal listening levels. Negative feedback from the speaker terminals to the base of each 2N2613 input transistor provides a bass boost of about 6 dB at 100 c/s. This feedback permits the use of bass-cut controls (R_3 and R_4) which load the cartridges at low frequencies in the flat position. As a result, bass boost of about 9 dB and bass cut of about 15 dB are available at 100 c/s at normal listening levels. Because the feedback is a function of the source impedance, it does not appreciably affect the full-volume sensitivity.

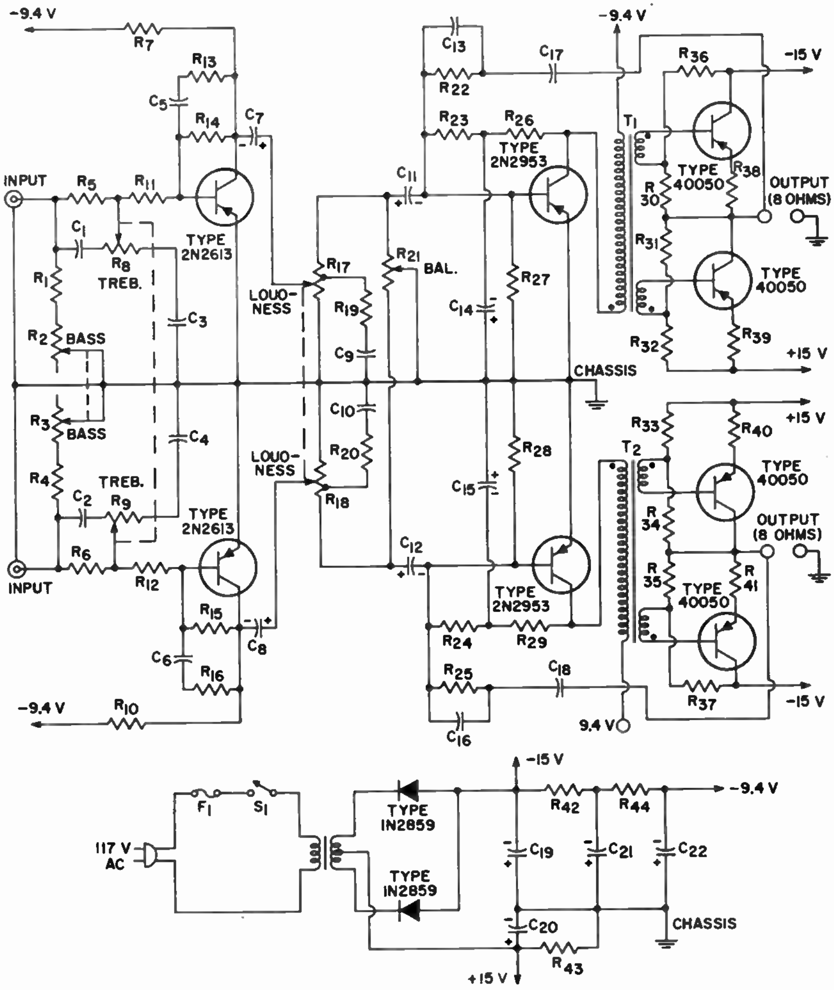
Parts List

C_1 = 100 μF, electrolytic, 25 V
C_2 = 0.05 μF, paper, 200 V
C_3, C_6 = 180 pF, ceramic, 25 V
C_4, C_5 = 390 pF, ceramic, 25 V
C_7, C_8 = 82 pF, ceramic, 25 V
C_9, C_{10} = 0.1 μF, ceramic disc, 25 V
C_{11}, C_{12} = 5 μF, electrolytic, 6 V
C_{13}, C_{16} = 2200 pF, paper, 400 V
C_{14}, C_{15} = 500 μF, electrolytic, 3 V
C_{17}, C_{18} = ½ dual section, 100 μF, electrolytic, 250 V
R_1, R_6 = 5.6 megohms, 0.5 watt
R_2, R_5, R_{15}, R_{16} = 82000 ohms, 0.5 watt
R_3, R_4 = bass control, dual potentiometers, 5 megohms, 0.5 watt, audio taper
R_7, R_8 = treble control, dual potentiometers, 5 megohms, 0.5 watt, linear taper
R_9, R_{10} = volume control, concentric potentiometers, 3 megohms, 0.5 watt, tapped down 0.9 megohm, linear taper
R_{11}, R_{14} = 3.9 megohms, 0.5 watt
R_{12}, R_{13} = 1.5 megohms, 0.5 watt
R_{17}, R_{20} = 1500 ohms ± 5%, 0.5 watt
R_{18}, R_{19} = 75000 ohms ± 5%, 0.5 watt
R_{21}, R_{22} = 8200 ohms, 0.5 watt
R_{23} = 22000 ohms, 0.5 watt
R_{24}, R_{27} = 82 ohms, 0.5 watt
R_{25}, R_{26} = 200 ohms ± 5%, 0.5 watt
R_{28}, R_{29} = 180 ohms ± 5%, 0.5 watt
R_{30} = 56 ohms, 0.5 watt
R_{31} = 4.7 ohms, fuse resistor
S_1 = ON-OFF switch, single-pole, single-throw
T_1, T_2 = audio output transformer, Columbus Process Co. No. X-9445 or equiv.

12-18

THREE-STAGE 5-WATT STEREO PHONOGRAPH AMPLIFIER

IHFM Music Power Rating 10 W Per Channel



Circuit Description

This three-stage amplifier delivers a sine-wave power output of 5 watts per channel to an 8-ohm speaker; its IHFM music power rating is 10 watts per channel, or 20 watts total. The amplifier develops full rated power output from each channel with very little distortion, and clips at a level of 8 watts for a 1-kc/s input. At average record levels, full output of 5 watts per channel is obtained for a drive input provided by

12-18

THREE-STAGE 5-WATT STEREO PHONOGRAPH AMPLIFIER (cont'd)

Circuit Description (cont'd)

a typical 0.5-volt, 1000-picofarad ceramic phonograph pickup.

Each channel of the amplifier consists of a low-noise 2N2613 input stage, a 2N2953 driver stage, and a class B output stage using two 40050 power transistors. The high input impedance of the 2N2613 stages eliminates the need for equalization of the ceramic pickup, and also permits the use of simple full-range treble controls R_8 and R_9 that have zero insertion loss. The zero-insertion-loss bass controls R_2 and R_3 provide bass-cut action by loading the ceramic pickup at low frequencies. The combination of this action and the bass-boost action provided by the feedback loops is similar to that of a conventional cut-and-boost control.

The loudness controls R_{17} and R_{18} are interlinked with the input-stage feedback loops. Because the amount of feedback below 1 kc/s is proportional to frequency, the frequency response of the input stage can be controlled, to a limited degree, by the loudness setting. When the loudness setting is decreased, the feedback becomes higher at the mid and high frequencies than at low frequencies. In this way, the loudness controls and the frequency-sensitive feedback provide a bass-boost action at reduced loudness settings. The boost from the loudness controls (tone controls flat) is 18 dB at low settings.

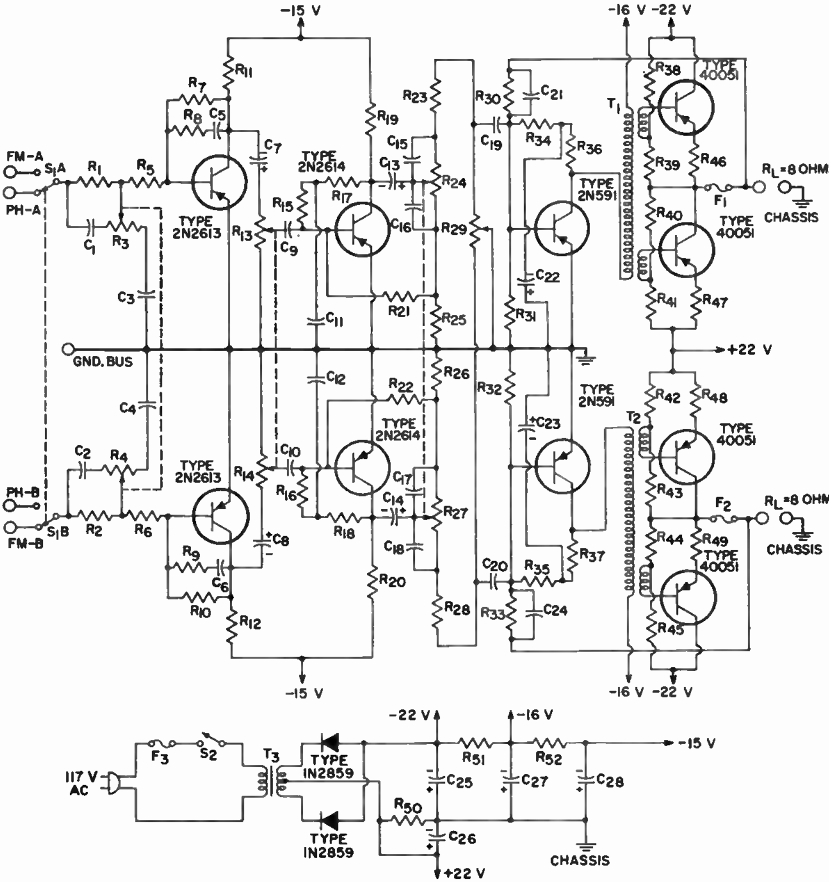
The power supply consists of a full-wave rectifier using 1N2859 rectifier diodes. A capacitive voltage divider provides the required dc voltages. The center of the capacitive divider is grounded so that both positive and negative voltages are obtained with respect to ground. Because the dc voltage drop across each transistor in the output stage is the same, the dc voltage coupled to the speaker terminal is essentially zero and no coupling capacitor to the speaker is required. The ripple components to the speaker from the positive and negative terminals of the power supply are equal and out of phase, and thus cancel each other.

Parts List

C_1, C_2 = 180 pF, ceramic disc
C_3, C_4 = 1800 pF, ceramic disc
C_5, C_6 = 0.005 μF, ceramic disc
C_7, C_8 = 5 μF, electrolytic, 6 V
C_9, C_{10} = 0.47 μF, ceramic
C_{11}, C_{12} = 4 μF, electrolytic, 3 V
C_{13}, C_{16} = 22 pF, ceramic disc
C_{14}, C_{15} = 10 μF, electrolytic, 6 V
C_{17}, C_{18} = 0.001 μF, ceramic
C_{19}, C_{20} = 1000 μF, electrolytic, 15 V
C_{21} = 100 μF, electrolytic, 15 V
C_{22} = 3000 μF, electrolytic, 10 V
F_1 = fuse, 1-ampere, slo-blo
R_1, R_4 = 0.1 megohm, 0.5 watt
R_2, R_3 = bass control, dual potentiometers, 3 megohms, 0.5 watt, audio taper
R_5, R_6 = 0.82 megohm, 0.5 watt
R_7, R_{10}, R_{27}, R_{28} = 4700 ohms, 0.5 watt
R_8, R_9 = treble control, dual potentiometers, 3 megohms, 0.5 watt, audio taper
R_{11}, R_{12} = 82000 ohms, 0.5 watt
R_{13}, R_{16} = 68000 ohms, 0.5 watt
R_{14}, R_{15} = 0.56 megohm, 0.5 watt
R_{17}, R_{18} = loudness control, dual potentiometers, 15000 ohms, 0.5 watt, linear taper; tapped at 10000 ohms
R_{19}, R_{20} = 470 ohms, 0.5 watt
R_{21} = balance control, potentiometer, 5000 ohms, 0.5 watt, S taper
R_{22}, R_{25} = 0.22 megohm, 0.5 watt
R_{23}, R_{24}, R_{26}, R_{29} = 47000 ohms, 0.5 watt
R_{30}, R_{32}, R_{33}, R_{35} = 22 ohms, 0.5 watt
R_{31}, R_{34}, R_{36}, R_{37} = 1800 ohms, 0.5 watt
R_{38}, R_{39}, R_{40}, R_{41} = 0.27 ohm, 0.5 watt
R_{42} = 180 ohms, 0.5 watt
R_{43} = 560 ohms, 0.5 watt
R_{44} = 100 ohms, 0.5 watt
S_1 = ON-OFF switch, single-pole, single-throw
T_1, T_2 = driver transformer, Columbus Process Co. No. 7602, Better Coil and Transformer Co. No. 99A4, or equiv.
T_3 = power transformer, Columbus Process Co. No. X8441, Better Coil and Transformer Co. No. 99P9, or equiv.

12-19 HIGH-QUALITY 15-WATT STEREO AMPLIFIER

IHFM Music Power Rating 25 W Per Channel



Circuit Description

This four-stage amplifier is designed for operation with either a ceramic phonograph pickup or an FM-stereo type of input. At the clipping level, the amplifier can supply sine-wave power output of 15

12-19 HIGH-QUALITY 15-WATT STEREO AMPLIFIER (cont'd)

Circuit Description (cont'd)

watts per channel to an 8-ohm speaker; its IHFM music power rating is 25 watts per channel, or 50 watts total. Sensitivity is such that each channel supplies full rated power output to the speaker for an input of 0.28 volt.

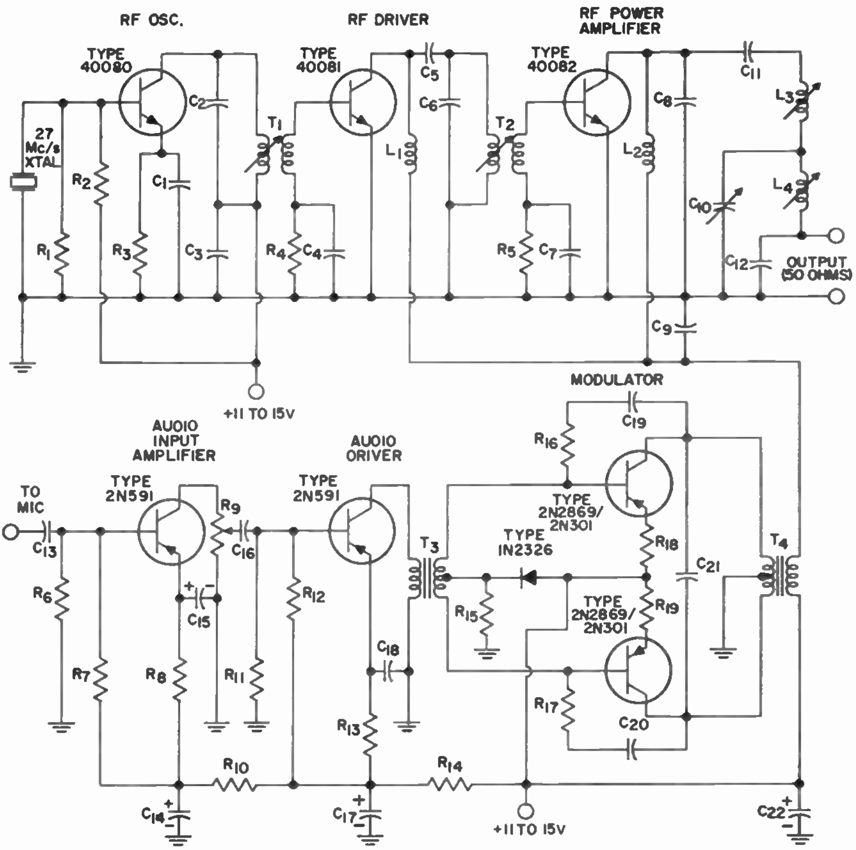
Each channel consists of a low-noise 2N2613 input stage, a 2N2614 preamplifier stage, a 2N591 driver stage, and a class B output stage employing two 40051 alloy-junction power transistors. As in the 5-watt stereo amplifier in circuit 12-18, the high input impedance of the 2N2613 stages eliminates the need for equalization of the ceramic pickup and also permits the use of simple, full-range treble controls R_3 and R_4 that have zero insertion loss. The full-range, insertion-loss type of cut-and-boost bass controls R_{24} and R_{27} operate in conjunction with the feedback around the 2N2614 preamplifier stage. This method of bass control provides the required bass action and simultaneously improves the performance of the preamplifier.

The loudness controls R_{13} and R_{14} are interlinked with the input-stage feedback loop. As in the 5-watt amplifier of circuit 12-18, the frequency response of the input stage can be controlled, to a limited degree, by the loudness setting. The power supply for this 15-watt stereo amplifier is similar to that for the 5-watt amplifier in circuit 12-18.

Parts List

C_1, C_2 = 180 pF, ceramic
C_3, C_4, C_5, C_6 = 1800 pF, ceramic
C_7, C_8 = 2 μF, electrolytic, 10 V
C_9, C_{10}, C_{11}, C_{12}, C_{19}, C_{20} = 5 μF, electrolytic, 3 V
C_{13}, C_{14} = 5 μF, electrolytic, 3 V
C_{15}, C_{18} = 0.5 μF, ceramic
C_{16}, C_{17} = 4 μF, Mylar
C_{21}, C_{24} = 47 pF, ceramic
C_{22}, C_{23} = 50 μF, electrolytic, 3 V
C_{25}, C_{26} = 1000 μF, electrolytic, 25 V
C_{27} = 250 μF, electrolytic, 20 V
C_{28} = 10000 μF, electrolytic, 15 V (or equiv.)
F_1, F_2 = fuse, 3-ampere
F_3 = fuse, 1-ampere, slo-blo
R_1, R_2 R_7, R_{10} = 1 megohm, 0.5 watt
R_3, R_4 = treble control, dual potentiometers, 3 megohms, 0.5 watt, audio taper
R_5, R_6 = 0.1 megohm, 0.5 watt
R_8, R_9 = 0.22 megohm, 0.5 watt
R_{11}, R_{12} = 4700 ohms, 0.5 watt
R_{13}, R_{14} = loudness control, dual potentiometers, 25000 ohms, 0.5 watt, linear taper
R_{15}, R_{16} = 27000 ohms, 0.5 watt
R_{17}, R_{18} = 33000 ohms, 0.5 watt
R_{19}, R_{20} = 1000 ohms, 0.5 watt
R_{21}, R_{22} = 10000 ohms, 0.5 watt
R_{23}, R_{28} = 270 ohms, 0.5 watt
R_{24}, R_{27} = bass control, dual potentiometers, 5000 ohms, 0.5 watt, audio taper
R_{25}, R_{26} = 39 ohms, 0.5 watt
R_{29} = balance control, potentiometer, 5000 ohms, 0.5 watt, S taper
R_{30}, R_{33} = 0.12 megohm, 0.5 watt
R_{31}. R_{32} = 1500 ohms, 0.5 watt
R_{34}, R_{35} = 12000 ohms, 0.5 watt
R_{36}, R_{37} = 15000 ohms, 0.5 watt
R_{38}, R_{40}, R_{43}, R_{45} = 560 ohms, 1 watt
R_{39}, R_{44} = 3.9 ohms, 0.5 watt
R_{46}, R_{47}, R_{48}, R_{49} = 0.27 ohm, 0.5 watt
R_{50} = 330 ohms, 2 watts
R_{51} = 100 ohms, 0.5 watt
R_{52} = 82 ohms, 0.5 watt
S_1 = selector switch, double-pole, double-throw
S_2 = ON-OFF switch, single-pole, single-throw
T_1, T_2 = driver transformer, Columbus Process Co. No. X7602, Better Coil and Transformer Co. No. 99A4, or equiv.
T_3 = power transformer, Columbus Process Co. No. 7603, Better Coil and Transformer Co. No. 99P3, or equiv.

12-20 27-Mc/s, 5-WATT CITIZENS-BAND TRANSMITTER



NOTE: The 40082 transistor used in the rf power amplifier should be mounted on a good heat sink.

Circuit Description

This transmitter operates directly from a 12-volt supply without the need for dc-to-dc converters, and is thus adaptable to mobile operations employing 12-volt systems. Its low power drain also makes it adaptable to portable use with small storage batteries.

The rf section of the transmitter, which consists of a 40080 crystal-controlled oscillator, a 40081 driver, and a 40082 power amplifier, de-

12-20 27-Mc/s 5-WATT CITIZENS-BAND TRANSMITTER (cont'd)

Circuit Description (cont'd)

velops 5 watts of rf power output at 27 Mc/s. Both the driver and the power amplifier are modulated to achieve 100-per-cent amplitude modulation.

The 40080 crystal-controlled oscillator stage is a Colpitts type of circuit that provides excellent frequency stability with respect to collector supply voltage and temperature (well within the 0.005-per-cent tolerance permitted by F.C.C. regulations) and delivers a minimum rf power of 100 milliwatts to the input of the driver stage.

The 40081 driver stage uses a class C common-emitter configuration. The modulation input is applied to the collector circuit. This stage delivers a minimum of 400 milliwatts of modulated rf power to the power amplifier. A heat dissipator should be mounted on the case of the 40081. The 40082 power-amplifier stage also uses a class C common-emitter configuration and is modulated through the collector circuit. The double-π network used as the output resonant circuit provides harmonic rejection of 50 dB, as required by F.C.C. regulations. The minimum rf power output supplied to the antenna from the power amplifier is 3 watts.

In the audio (modulator) section of the transmitter, two 2N591 class A amplifier stages are used to drive a class AB push-pull output stage using two 2N2869/2N301 transistors. This design provides maximum efficiency with low distortion. A 1N2326 compensating diode is used in the biasing network to provide thermal stability. The modulation transformer T_4 is designed to match the collector-to-collector load impedance of the modulator to the impedance of the rf driver and power-amplifier stages.

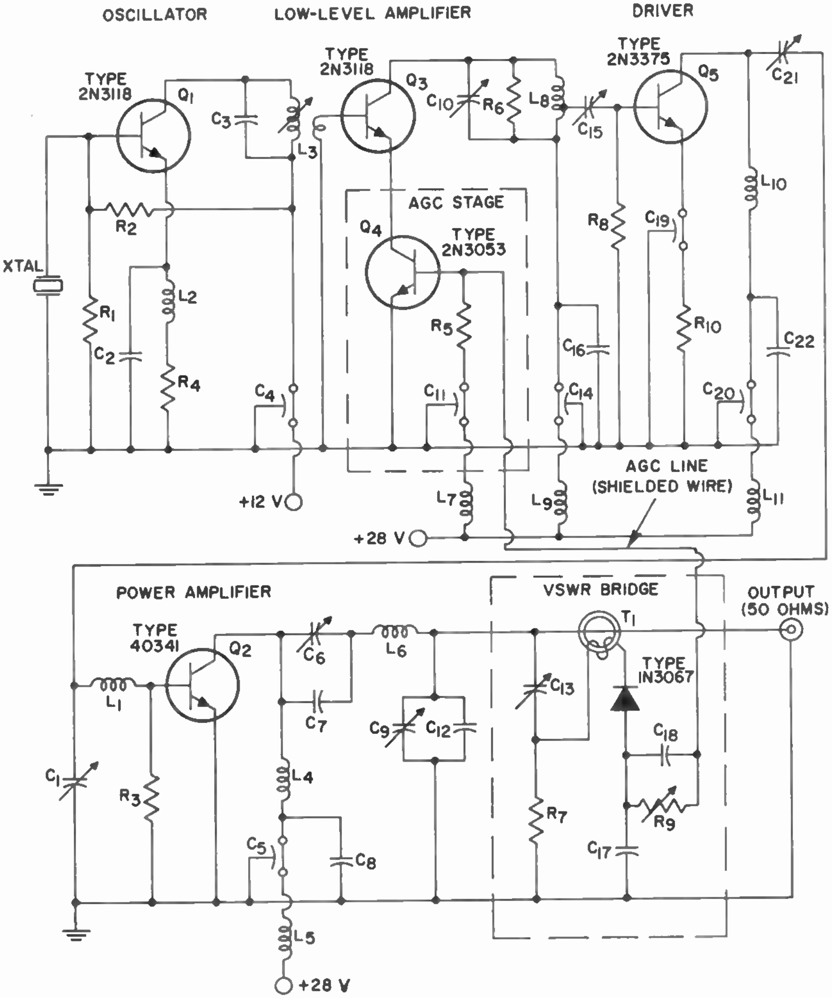
Parts List

C_1 = 75 pF, ceramic
C_2 = 30 pF, ceramic
C_3, C_4, C_7 = 0.01 μF, ceramic
C_5 = 47 pF, ceramic
C_6 = 51 pF, mica
C_8 = 24 pF, mica
C_9 = 0.01 μF, ceramic
C_{10} = variable capacitor, 90 to 400 pF (ARCO 429, or equiv.)
C_{11} = 100 pF, ceramic
C_{12} = 220 pF, ceramic
C_{13} = 5 μF, ceramic
C_{14}, C_{17} = 50 μF, electrolytic, 25 V
C_{15} = 10 μF, electrolytic, 15 V
C_{16}, C_{18} = 10 μF, ceramic
C_{19}, C_{20} = 0.2 μF, ceramic
C_{21} = 0.1 μF, ceramic
C_{22} = 500 μF, electrolytic, 15 V
L_1, L_2 = rf choke, 15 μF (Miller 4624, or equiv.)
L_3 = variable inductor (0.75 to 1.2 μH); 11 turns No. 22 wire wound on ¼-inch CTC coil form having a "green dot" core; Q = 120
L_4 = variable inductor (0.5 to 0.9 μH); 7 turns No. 22 wire wound on ¼-inch CTC coil form having a "green dot" core; Q = 140
R_1 = 510 ohms, 0.5 watt
R_2, R_{12} = 5100 ohms, 0.5 watt
R_3 = 51 ohms, 0.5 watt
R_4 = 120 ohms, 0.5 watt
R_5 = 47 ohms, 0.5 watt
R_6 = 0.1 megohm, 0.5 watt
R_7 = 10000 ohms, 0.5 watt
R_8 = 2000 ohms, 0.5 watt
R_9 = potentiometer, 10000 ohms
R_{10} = 3600 ohms, 0.5 watt
R_{11} = 15000 ohms, 0.5 watt
R_{13} = 1000 ohms, 0.5 watt
R_{14} = 1200 ohms, 0.5 watt
R_{15} = 240 ohms, 0.5 watt
R_{16}, R_{17} = 2700 ohms, 0.5 watt
R_{18}, R_{19} = 1.5 ohms, 0.5 watt
T_1 = rf transformer; primary 14 turns, secondary 3 turns of No. 22 wire wound on ¼-inch CTC coil form having a "green dot" core; slug-tuned (0.75 to 1.2 μH); Q = 100
T_2 = rf transformer; primary 14 turns, secondary 2-¾ turns of No. 22 wire wound on ¼-inch CTC coil form having a "green dot" core; slug-tuned (0.75 to 1.2 μH); Q = 100
T_3 = transformer; primary: 2500 ohms; secondary 200 ohms center-tapped; Microtran SMT 17-SB or equiv.
T_4 = transformer; primary: 100 ohms center-tapped; secondary: 30 ohms

NOTE: See general considerations for construction of high-frequency and broadband circuits on page 391.

12-21 50-Mc/s 40-WATT CW TRANSMITTER

With Load-Mismatch Protection



Circuit Description

This cw transmitter uses a VSWR bridge circuit to maintain a steady-state dissipation in the output stage under all conditions of antenna mismatch. This technique makes it possible to realize the full power potential of the 40341 overlay transistor used in the output stage.

The 50-Mc/s crystal-controlled 2N3118 oscillator stage develops the low-level excitation signal for the transmitter. The 50-Mc/s output signal from the collector of the oscillator transistor is coupled by L_3 to the base of a second 2N3118 used in a predriver stage (low-level am-

12-21 50-Mc/s 40-WATT CW TRANSMITTER (cont'd)

Circuit Description (cont'd)

plifier). This step-down transformer matches the collector impedance of the oscillator transistor to the low-impedance base circuit of the predriver transistor. The collector circuit of the predriver is tuned to provide maximum signal output at 50 Mc/s. This signal is coupled from a tap on inductor L_8 to the input (base) circuit of the driver stage, which uses a 2N3375 silicon power transistor to develop the power required to drive the output stage.

The 40341 overlay transistor used in the output stage develops 40 watts of power output at the transmitting frequency of 50 Mc/s. The driving power for the output stage is coupled from the collector of the driver transistor through a bandpass filter to the base of the output transistor. The filter networks in the collector circuit of the 40341 provide the required harmonic and spurious-frequency rejection. The 50-Mc/s output from these filter sections is coupled through a length of 50-ohm coaxial line to the antenna. Capacitors C_6, C_9, and C_{13} are adjusted to provide optimum impedance match between the transmitter and the antenna.

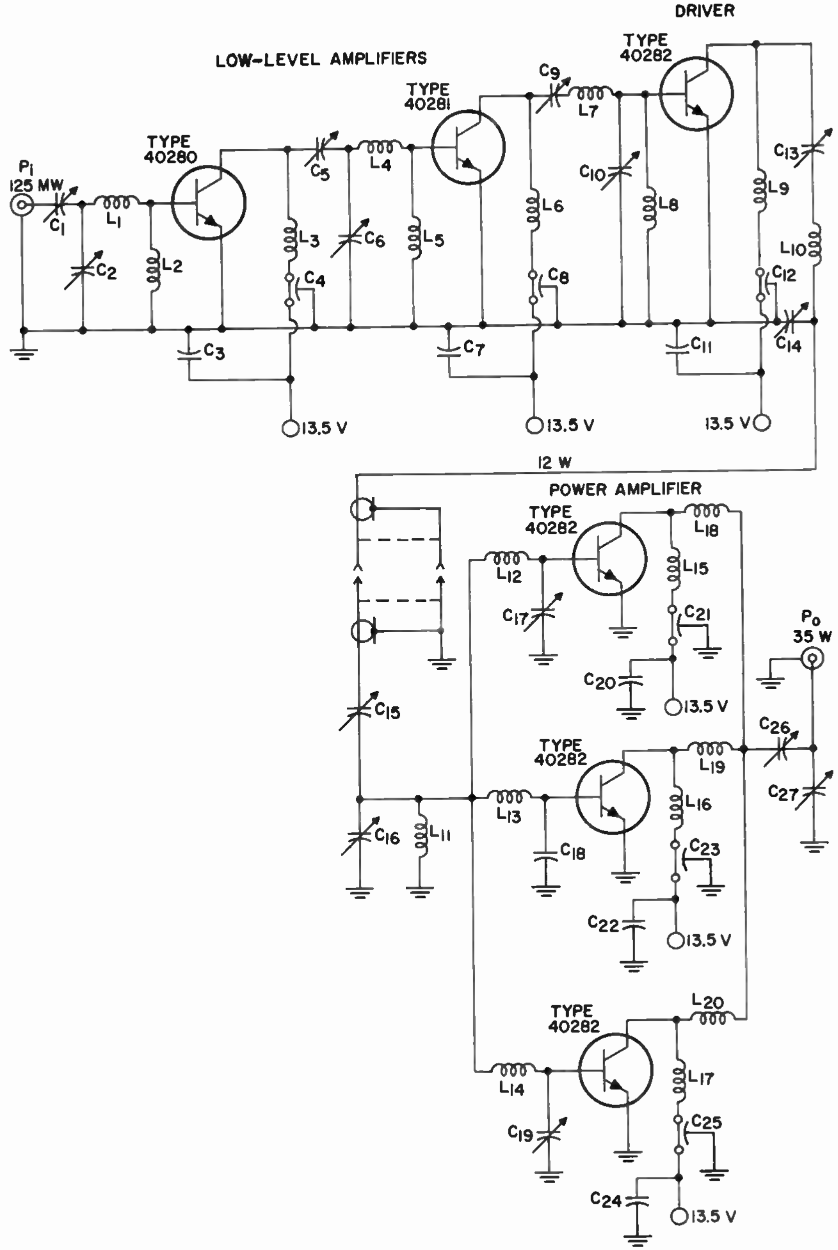
The output of the transmitter is sampled by a current transformer (toroid) T_1 loosely coupled about the output transmission line. This transformer is the sensor for a VSWR bridge detector used to prevent excessive dissipation in the output stage under conditions of antenna mismatch. If the antenna is disconnected or poorly matched to the transmitter, large standing waves of voltage and current occur on the output transmission line. A portion of this standing-wave energy is applied by T_1 to the 1N3067 diode in the bridge circuit. The rectified current from this diode charges capacitor C_{18} to a dc voltage proportional to the amplitude of the standing waves. This voltage, which is essentially an agc bias, is applied to the base of the 2N3053 agc amplifier stage. The output of the agc stage biases the 2N3118 predriver stage so that its gain changes in inverse proportion to the amplitude of the standing wave on the output transmission line. Therefore, as the amplitude of the standing waves increases (tending to cause higher heat dissipation in the output transistor), the input drive to the output stage is reduced. This compensating effect maintains a steady-state dissipation in the output transistor regardless of mismatch conditions between the transmitter output circuit and the antenna.

Parts List

C_1 = variable capacitor, 90 to 400 pF, Arco No. 429 or equiv.
C_2 = 51 pF, mica
C_3 = 30 pF, ceramic
C_4, C_5, C_{11}, C_{14}, C_{19}, C_{20} = feedthrough capacitor, 1000 pF
C_6 = variable capacitor, 1.5 to 20 pF, Arco No. 402 or equiv.
C_7 = 36 pF, mica
C_8, C_{16}, C_{22} = 0.02 μF, ceramic
C_9, C_{10} = variable capacitor, 8 to 60 pF, Arco No. 404 or equiv.
C_{12} = 91 pF, mica
C_{13} = variable capacitor, 0.9 to 7 pF, Vitramon No. 400 or equiv.
C_{15} = variable capacitor, 14 to 150 pF, Arco No. 426 or equiv.
C_{17} = 1000 pF, ceramic
C_{18} = 0.01 μF, ceramic
C_{21} = variable capacitor, 32 to 250 pF, Vitramon No. 464 or equiv.
L_1 = 1 turn of No. 16 wire; inner diameter, 5/16 inch; length, 1/8 inch
L_2 = rf choke, 1 μH
L_3 = oscillator coil; primary, 7 turns; secondary, 1-3/4 turns; wound from No. 22 wire on CTC coil form having "white dot" core
L_4 = 5 turns of No. 16 wire; inner diameter, 5/16 inch; length, 1/2 inch
L_5, L_7, L_9, L_{10}, L_{11} = rf choke, 7 μH
L_6 = 4 turns of B & W No. 3006 coil stock
L_8 = 6 turns of No. 16 wire; inner diameter, 3/8 inch; length, 3/4 inch
R_1, R_6 = 510 ohms, 0.5 watt
R_2 = 3900 ohms, 0.5 watt
R_3, R_8 = 2.2 ohms, wirewound, 0.5 watt
R_4 = 51 ohms, 0.5 watt
R_5 = 24000 ohms, 0.5 watt
R_7 = 240 ohms, 0.5 watt
R_9 = agc control, potentiometer, 50000 ohms
R_{10} = 5.6 ohms, 1 watt
T_1 = current transformer (toroid), Arnold No. A4-437-125-SF, or equiv.

NOTE: See general considerations for construction of high-frequency and broadband circuits on page 391.

12-22 175-Mc/s 35-WATT AMPLIFIER



12-22 175-Mc/s 35-WATT POWER AMPLIFIER (cont'd)

Circuit Description

This four-stage rf power amplifier operates from a dc supply of 13.5 volts and delivers 35 watts of power output at 175 Mc/s for an input of 125 milliwatts. The silicon overlay transistors used in the amplifier supply maximum output power at this level of dc voltage for use in mobile systems.

The low-level portion of the amplifier consists of three unneutralized, class C, common-emitter rf amplifier stages interconnected by band-pass filters tuned to provide maximum transfer of energy at 175 Mc/s. The 40280 input stage develops 1 watt of power output when a 125-milliwatt 175-Mc/s signal is applied to the amplifier input terminal. This output is increased to 4 watts by the 40281 transistor used in the second stage. The 40282 driver transistor then develops 12 watts of driving power for the output stage.

When the low-level stages and the output stage are mounted on separate chassis, the output from the driver stage is coupled to the output stage through a low-loss coaxial line. The line is terminated by variable capacitors C_{15} and C_{16} and inductor L_{11}. The capacitors are adjusted to assure a good impedance match between the output of the driver and the input of the output stage at 175 Mc/s. The driving signal developed across inductor L_{11} is applied to the tuned input networks of three parallel-connected 40282 transistors in the single-ended output stage. For an input of 12 watts, the three 40282 transistors deliver 35 watts of 175-Mc/s power to the output terminal of the amplifier. Capacitors C_{26} and C_{27} are adjusted to match the amplifier output to the load impedance at the operating frequency.

Parts List

C_1 = variable capacitor, 3 to 35 pF, Arco No. 403, or equiv.

C_2, C_6, C_{16}, C_{17}, C_{18}, C_{19}, C_{27} = variable capacitor, 8 to 60 pF, Arco No. 404, or equiv.

C_3, C_7, C_{11} = 0.1 μF, ceramic disc

C_4, C_8, C_{12}, C_{21}, C_{23}, C_{25} = feedthrough capacitor, 1500 pF

C_5, C_{10}, C_{13}, C_{14}, C_{26} = variable capacitor, 7 to 100 pF, Arco No. 423, or equiv.

C_9 = variable capacitor, 14 to 150 pF, Arco No. 424 or equiv.

C_{15} = variable capacitor, 1.5 to 20 pF, Arco No. 402 or equiv.

C_{20}, C_{22}, C_{24} = 0.2 μF, ceramic disc

L_1 = 2 turns of No. 16 wire; inner diameter, 3/16 inch; length, 1/4 inch

L_2, L_5, L_8 = 450-ohm ferrite rf choke

L_3, L_6, L_{11} = rf choke, 1.0 μH

L_4, L_7 = 3 turns of No. 16 wire; inner diameter, 3/16 inch; length, 1/4 inch

L_9 = 1-1/2 turns of No. 16 wire; inner diameter, 1/4 inch; length, 3/8 inch

L_{10} = 2 turns of No. 16 wire; inner diameter, 1/4 inch; length, 5/16 inch

L_{12}, L_{13}, L_{14} = 5 turns of No. 16 wire; inner diameter, 1/4 inch; length, 1/2 inch

L_{15}, L_{16}, L_{17} = 2 turns of No. 18 wire; inner diameter, 1/8 inch; length, 1/8 inch

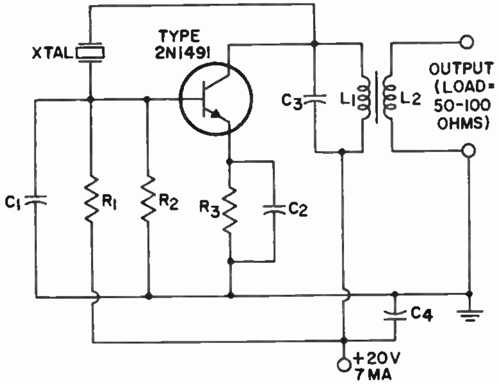
L_{18}, L_{19}, L_{20} = 2 turns of No. 16 wire; inner diameter, 1/4 inch; length, 1/4 inch

NOTE: See general considerations for construction of high-frequency and broadband circuits on page 391.

12-23

27-Mc/s CRYSTAL OSCILLATOR

Output 4 mW



Circuit Description

This crystal-controlled oscillator provides a stable 4-milliwatt output at 27 Mc/s. The circuit operates from a 20-volt, 7-milliampere dc supply.

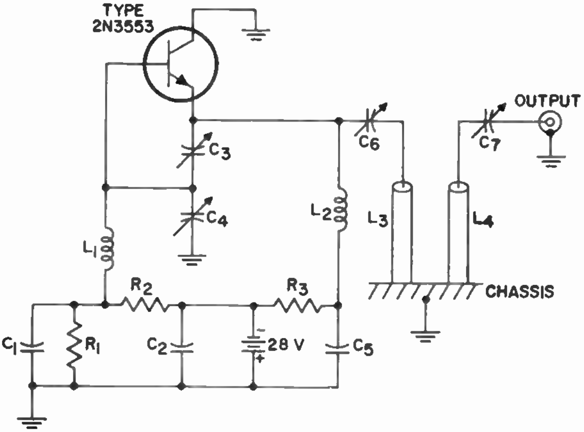
A 2N1491 common-emitter circuit amplifies the signal from the 27-Mc/s crystal to develop the rated power output. The combined effects of the base-bias network C_1 and R_1 and the emitter-bias network C_2 and R_3 bias the transistor for class C operation to prevent excessive loading of the collector resonant circuit L_1 and C_3. The use of crystal control assures excellent frequency stability for the oscillator. Positive feedback is coupled from the collector to the base of the 2N1491 across the capacitance of the crystal to sustain oscillations.

The 27-Mc/s oscillator signal developed across L_1 is inductively coupled by L_2 to the load circuit. The transformation provided by L_1 and L_2 adequately matches the collector impedance of the transistor to a load impedance of 50 to 100 ohms.

Parts List

C_1 = 20 pF, ceramic disc, 25 V
C_2, C_4 = 0.01 μF, ceramic disc, 25 V
C_3 = 22 pF, ceramic disc, 25 V
L_1 = 15 turns No. 22 enam., close-wound on CTC LS5 form (powdered-iron slug)
L_2 = 2 turns No. 18 enam., wound over cold end of L_1
R_1 = 9100 ohms, 0.5 watt
R_2 = 680 ohms, 0.5 watt
R_3 = 200 ohms, 0.5 watt
XTAL = crystal, 27 Mc/s

12-24 500-Mc/s 1-WATT POWER OSCILLATOR



Circuit Description

This power oscillator operates from a portable battery supply of 28 volts and delivers 1 watt of rf power output at 500 Mc/s. The reverse voltage to bias the 2N3553 transistor for class C operation, as required in this Colpitts-type oscillator, is developed across the emitter-to-base resistance-capacitance network C_1, C_2, C_5, R_1, R_2, and R_3. The resonant circuit consisting of inductor L_3 and tuning capacitors C_3, C_4, and C_6 forms a selective emitter-to-collector load impedance for the 2N3553, and resonates to generate a continuous 500-Mc/s signal when energy is applied to the circuit.

The capacitive voltage divider C_3 and C_4 assures that the proper amount of feedback signal is developed during each oscillator cycle. When the feedback voltage developed across capacitor C_3 is large enough and in the correct polarity to overcome the fixed bias, current flows through the 2N3553. RF chokes L_1 and L_2 and bypass capacitor C_5 prevent rf components of the transistor current from flowing into the dc circuit. The rf current is shunted through the oscillator resonant circuit and used to replenish the energy lost or coupled from the circuit during each cycle.

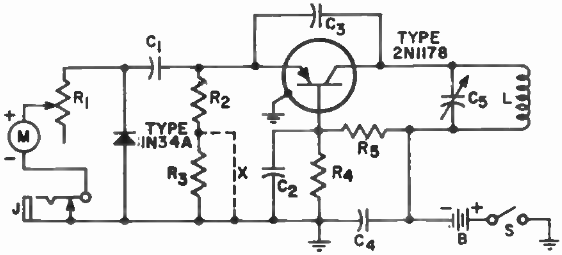
The oscillator output is inductively coupled to the load by L_3 and L_4, which consist of two parallel brass rods spaced ⅜ inch apart. Each rod is 1-¼ inches in length and $^3/_{16}$ inch in diameter. The output is delivered to the load through capacitor C_7 and a low-loss coaxial cable. The value of C_7 is selected to provide optimum match between the oscillator and the load impedance.

Parts List

C_1 = 500 pF, ceramic disc
C_2 = 0.01 μF, ceramic disc
C_3, C_6, C_7 = variable capacitor, 1.5 to 20 pF, Arco 402 or equiv.
C_4 = variable capacitor, 0.9 to 7 pF, Vitramon No. 400 or equiv.
C_5 = 50 pF, ceramic disc
L_1, L_2 = rf chokes, 0.22 μH, Nytronics No. 60Z189 or equiv.
L_3, L_4 = parallel brass rods, 1¼ inches in length, $^3/_{16}$ inch in diameter, separated by ⅜ inch
R_1 = 1800 ohms, 0.5 watt
R_2 = 75 ohms, 0.5 watt
R_3 = 2700 ohms, 0.5 watt

12-25 GRID-DIP METER

For Measuring Resonant Frequencies from 3.5 to 1000 Mc/s



Parts List

B = 13.5 volts, RCA VS304
C_1 = 33 pF, mica, 50 V
C_2 = 0.01 μF, paper, 50 V
C_3 = 5 pF, mica, 50 V
C_4 = 0.01 μF, paper, 50 V
C_5 = variable capacitor, 50 pF (Hammarlund type HF-50 or equivalent)
J = phone jack, normally closed
L = plug-in coil
M = microammeter, 0 to 50 μA (Simpson model 1227 or equivalent)
R_1 = variable resistor, 0-0.25 megohm, 0.5 watt
R_2 = 220 ohms, 0.5 watt
R_3 = 3,000 ohms, 0.5 watt
R_4 = 3,900 ohms, 0.5 watt
R_5 = 39,000 ohms, 0.5 watt
X = jumper, omit for measurements below 45 Mc

Coil-Winding Data

Coil	Freq. Range	Wire Size	No. of Turns
1	3.4-6.9 Mc/s	#28, enamel	48¼, close wound
2	6.7-13.5 Mc/s	#24, enamel	22, close wound
3	13-27 Mc/s	#24, enamel	9⅛, close wound
4	25-47 Mc/s	#24, enamel	4⅛, close wound
5	46-78 Mc/s	#24, enamel	1½, close wound
6	74-97 Mc/s	#16, tinned	hairpin formed, 1⅞ inches long including pins, and ¼ inch wide

Coil forms are Amphenol type 24-5H or equivalent.

Circuit Description

This grid-dip meter determines the frequency of resonant circuits quickly and accurately. Basically, it consists of a 2N1178 common-base rf oscillator stage that can be tuned over a wide frequency range. A 1N34A diode and a dc microammeter are used to show when rf power is being absorbed from the oscillator tuned circuit. The dc power for the oscillator is obtained from a 13.5-volt miniature battery such as the RCA VS304.

Inductor L and capacitor C_5 form the oscillator resonant circuit. Feedback to sustain oscillations in the resonant circuit is coupled by capacitor C_3 from the collector to the emitter of the 2N1178. RF voltage in the emitter-to-base circuit is coupled by C_1 to the 1N34A diode, and the rectified output appears on the dc microammeter. When power is absorbed from the oscillator resonant circuit, rf feedback is reduced and the reading on the microammeter decreases.

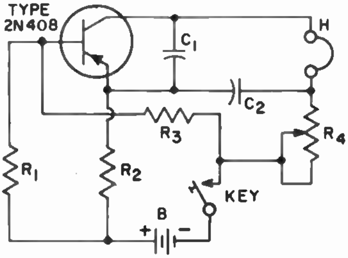
The coil used for inductor L is selected for the operating frequency desired. A frequency-tuning dial mounted on the same shaft with the variable capacitor C_5 indicates the

12-25 GRID-DIP METER (cont'd)

Circuit Description (cont'd)

operating frequency of the meter. For measurement of the frequency of a resonant circuit, a coil having a suitable frequency range is inserted in the grid-dip meter, and the meter control knob is adjusted for a reading of about half-scale. The meter is then tightly coupled to the unknown tuned circuit, and the tuning dial is rotated until a dip in the meter reading occurs. When transmitter tank circuits are measured, the transmitter plate supply must be turned off to eliminate danger of shock.

12-26 CODE-PRACTICE OSCILLATOR



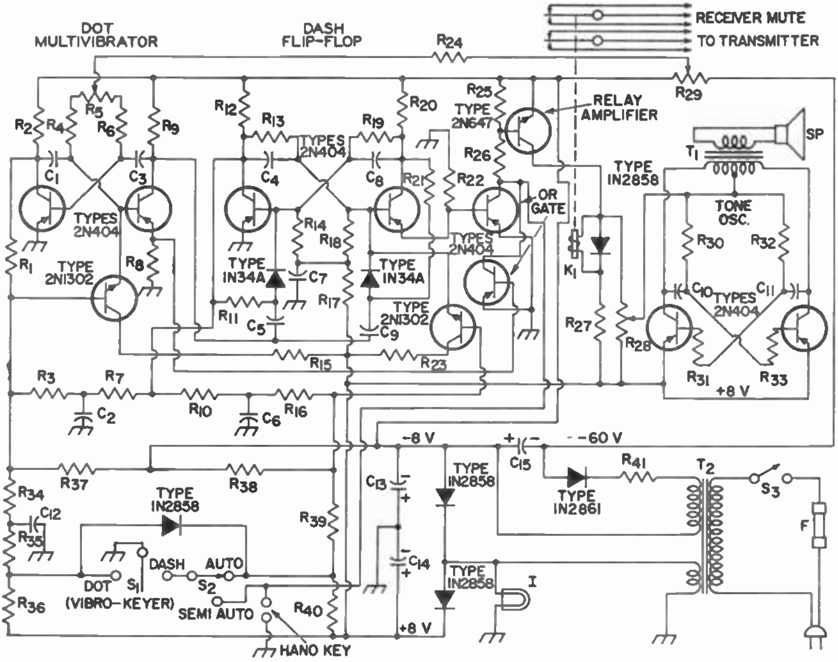
Parts List

B = 1.5-4.5 V (One to three series-connected RCA VS036 dry cells may be used, depending upon the volume level desired.)
C_1, C_2 = 0.01 μF, paper, 150 V
H = Headphone, 2000-ohm, magnetic
R_1 = 2200 ohms, 0.5 watt
R_2 = 27000 ohms, 0.5 watt
R_3 = 3000 ohms, 0.5 watt
R_4 = volume control potentiometer, 50000 ohms, 0.5 watt

Circuit Description

This simple audio oscillator operates from a dc supply of 1.5 to 4.5 volts, depending on the amount of output desired. Magnetic headphones provide an audible indication of keying. When the key is closed, the 2N408 transistor supplies energy to the resonant circuit formed by capacitors C_1 and C_2 and the inductance of the headphones, and this circuit resonates to produce an audio tone in the headphones. Positive feedback to sustain oscillation is coupled from the resonant circuit through C_1 and C_2 to the emitter of the 2N408. R_4 is adjusted to obtain the desired level of sound from the headphones.

12-27 ELECTRONIC KEYER



Parts List

C_1, C_3 = 1 μF, paper (or Mylar), 200 V
C_2 = 0.47 μF, ceramic, 25 V
C_4, C_8 = 560 pF, ceramic, 600 V
C_5, C_9 = 330 pF, ceramic, 600 V
C_6, C_7 = 0.01 μF, ceramic, 50 V
C_{10}, C_{11} = 0.02 μF, ceramic, 50 V
C_{12} = 0.1 μF, ceramic, 50 V
C_{13}, C_{14} = 2000 μF, electrolytic, 15 V
C_{15} = 16 μF, electrolytic, 150 V
F = fuse, 1 ampere
I = indicator lamp No. 47
K = dc relay; coil resistance = 2500 ohms; operating current = 4 mA
R_1 = 39000 ohms, 0.5 watt
R_2, R_9, R_{12}, R_{20} = 3900 ohms, 0.5 watt
R_3, R_{16} = 18000 ohms, 0.5 watt
R_4, R_6 = 51000 ohms, 0.5 watt
R_5, R_{29} = potentiometer, 10000 ohms
R_7, R_{10} = 22000 ohms, 0.5 watt
R_8, R_{22} = 180 ohms, 0.5 watt
R_{11}, R_{21} = 15000 ohms, 0.5 watt
R_{13}, R_{19} = 33000 ohms, 0.5 watt
R_{14}, R_{18}, R_{30}, R_{32} = 27000 ohms, 0.5 watt
R_{15}, R_{23} = 270 ohms, 0.5 watt
R_{17} = 68000 ohms, 0.5 watt
R_{24} = 100000 ohms, 0.5 watt
R_{25} = 68 ohms, 0.5 watt
R_{26} = 560 ohms, 0.5 watt
R_{27} = 1200 ohms, 0.5 watt
R_{28} = volume-control potentiometer, 50000 ohms
R_{31}, R_{33} = 10000 ohms, 0.5 watt
R_{34} = 6800 ohms, 0.5 watt
R_{35} = 8200 ohms, 0.5 watt
R_{36}, R_{39}, R_{40} = 15000 ohms, 0.5 watt
R_{37}, R_{38} = 47000 ohms, 0.5 watt
R_{41} = 10000 ohms, 1 watt
S_1 = Vibroplex keyer, or equiv.
S_2 = toggle switch, double-pole, double-throw
S_3 = toggle switch; single-pole, single-throw
T_1 = push-pull output transformer (14000 ohm to V.C.)
T_2 = power transformer, Stancor PS8415, PS8421, or equiv.

Circuit Description

This compact electronic keyer can be used for automatic keying of a cw transmitter at speeds up to 60 words per minute. Two multivibrator trigger circuits using 2N404 transistors automatically control the dot and dash transmissions. A "Vibro-Keyer", which is spring-loaded to the OFF position, selects the type of transmission desired. Unless the "Vibro-Keyer" is moved to either the DOT or the DASH po-

12-27 ELECTRONIC KEYER (cont'd)

Circuit Description (cont'd)

sition, both multivibrators are held inoperative by the biasing action of 2N1302 clamping circuits.

When the "Vibro-Keyer" S_1 is deflected to the DOT position, the first 2N1302 clamp transistor becomes inoperative, and the dot multivibrator is allowed to operate as a free-running circuit. Feedback circuits in the multivibrator assure continued operation, regardless of whether S_1 remains in the DOT position, long enough to develop the square-wave output that controls both the duration of the dot and the space that follows it. When S_1 is set to the DASH position, both clamp transistors become inoperative. The dot multivibrator and the dash flip-flop then operate simultaneously. The dash flip-flop is triggered by the positive pulses from the dot multivibrator. The 1N34A steering diodes prevent triggering of the flip-flop by negative pulses. Because two positive pulses are required to produce one complete cycle of output from the flip-flop, the frequency of this circuit is one-half that of the dot multivibrator.

The square-wave outputs from the dot multivibrator and the dash flip-flop are coupled to two more 2N404 transistors used in an OR gate circuit. During the positive half-cycle of the square-wave inputs, the OR gate conducts to remove the cutoff bias from the 2N647 relay amplifier, which controls the operation of keying relay K_1. The relay is then energized, and its contacts close for the period required to key the transmitter for the selected type of transmission. One section of K_1 may be used to mute the receiver during key-down periods. Because the OR gate circuit is keyed successively by signals from the dot multivibrator and the dash flip-flop in the formation of a dash, the duration of a dash is three times that of a dot.

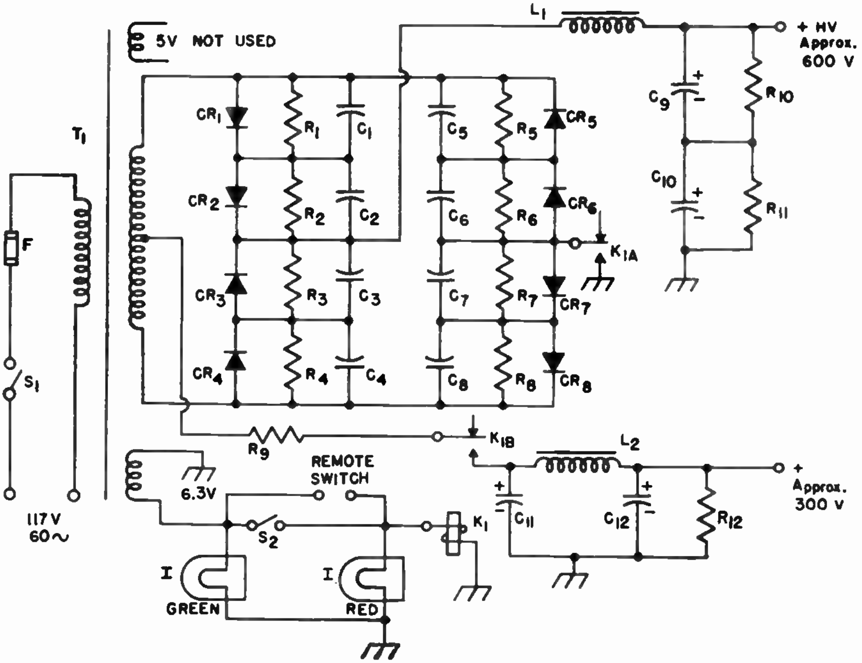
The keying speed of this electronic keyer is determined by the frequency of the dot multivibrator. This frequency is adjustable by means of potentiometer R_{29}, which varies the amplitude of the negative dc voltage. As the negative voltage at the armature of potentiometer R_5 is increased to a maximum value of 60 volts, the keying speed is increased to a maximum of 60 words per minute. Potentiometer R_5 controls the ratio of "on time" to "off time" of the dot multivibrator transistors, and thus determines the duration of both dot and dash transmissions and the minimum spacing between successive transmissions. The over-all keying speed is not affected by this adjustment.

The electronic keyer may also be operated as a semiautomatic key ("bug") when selecter switch S_2 is placed in the SEMIAUTO position. Dots are still produced automatically, but the automatic keying circuits are bypassed when S_1 is moved to the DASH position. The formation of dashes is then controlled manually. When S_2 is in the MAN position, a hand key (connected across the terminals marked HAND KEY) may be used for manual control of the keyer; the automatic keying circuits are then bypassed during the formation of both dots and dashes.

The keyer operates from a 117-volt, 60-c/s ac power input applied through a step-down power transformer T_2. The ac input voltage is converted to the negative dc voltage used to control keying speed by a 1N2861 half-wave rectifier circuit. Two other 2N2861 diodes are used in a voltage-doubler circuit that operates from the 6.3-volt secondary winding of transformer T_3 to produce the dc supply voltage for the various circuits in the keyer. A 2N404 tone oscillator, which is gated on by the relay-amplifier circuit, provides an audible indication of keying.

12-28 POWER SUPPLY FOR AMATEUR TRANSMITTER

600 Volts; 300 Volts; Total Current 330 Milliamperes (Intermittent Duty)



Parts List

C_1 C_2 C_3 C_4 C_5 C_6 C_7 C_8 = 0.001 μF, ceramic disc, 1000 V
C_9, C_{10}, C_{11}, C_{12} = 40 μF, electrolytic, 450 V
CR_1 CR_2 CR_3 CR_4 CR_5 CR_6 CR_7 CR_8 = RCA-1N2864
F = fuse, 5 amperes
I= indicator lamp
K_1 = relay; Potter and Brumfield KA11AY or equiv.
L_1 = 2.8 henries, 300 mA; Stancor C-2334 or equiv.
L_2 = 4 henries, 175 mA; Stancor C-1410 or equiv.
R_1 R_2 R_3 R_4 R_5 R_6 R_7 R_8 = 0.47 megohm, 0.5 watt
R_9 = 47 ohms, 1 watt
R_{10} R_{11} = 15000 ohms, 10 watts
R_{12} = 47000 ohms, 2 watts
S_1 S_2 = toggle switch, single-pole single-throw
T = power transformer; Stancor P-8166 or equiv.

12-28 POWER SUPPLY FOR AMATEUR TRANSMITTER (cont'd)

Circuit Description

This power supply uses eight 1N2864 silicon diodes in series-connected pairs in a bridge-rectifier circuit to supply a 600-volt dc output from a 117-volt ac input. The second set of diode pairs (CR_5 through CR_8) is also used in a conventional full-wave rectifier circuit to supply a 300-volt dc output. Series-connected pairs of diodes are used to provide the rectification in this circuit because the peak-inverse-voltage rating of such combinations is twice that of a single diode.

The operation of the power supply is controlled by two switches. When the ON-OFF switch S_1 is closed, the 117-volt 60-c/s ac input power is applied across the primary of the step-up power transformer T_1. The power supply does not become operative, however, until switch S_2 is also closed. Relay K_1 is then energized, and the closed contacts of the relay complete the ground return paths for the power-supply circuits. Switch S_2 can be used as a STANDBY switch for the transmitter, or another switch may be connected in parallel with S_2 so that the standby-to-on function can be controlled from a remote location.

During the half-cycle of ac input for which the voltage across the secondary winding of T_1 is positive at the top end and negative at the bottom end, current flows from the bottom of the secondary through diodes CR_7 and CR_8 (which are oriented in the proper direction), out the K_{1A} section of the relay contacts to ground, and then up through bleeder resistors R_{10} and R_{11} and the external load connected in shunt with the resistors to develop the 600-volt output. The return flow is completed through filter choke L_1, diodes CR_1 and CR_2, and the entire secondary winding. During the next half-cycle of the ac input, the polarity of the voltage across the secondary reverses, and the current flows through diodes CR_5 and CR_6, through the bleeder resistors and the external load circuit in the same direction as before, and then through diodes CR_3 and CR_4. Capacitors C_9 and C_{10} and choke L_1 provide the filtering to smooth out the pulsations in the 600-volt dc output.

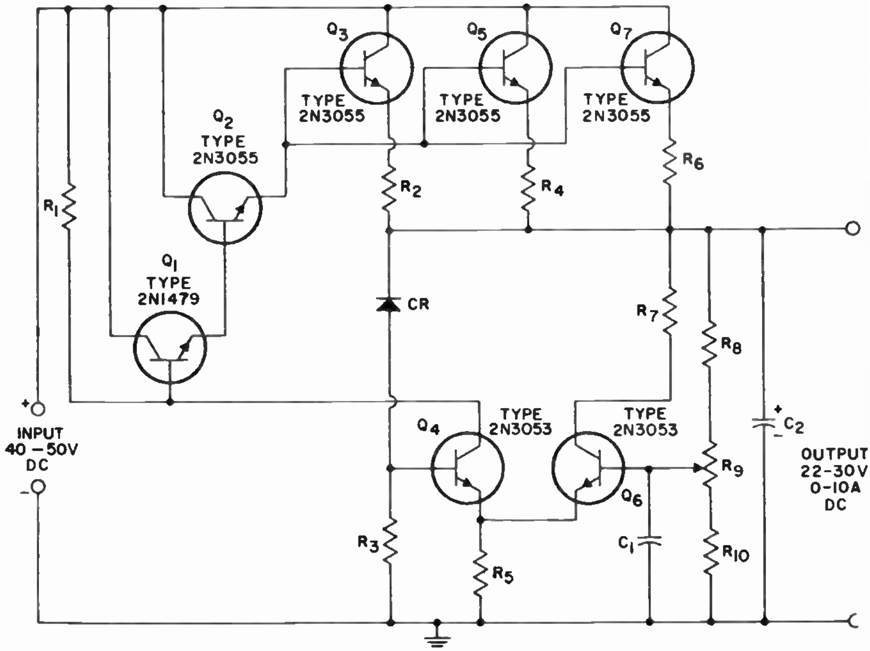
For the 300-volt dc output, only one-half the voltage across the secondary winding of T_1 is required. The CR_5-CR_6 and CR_7-CR_8 diode pairs are operated in a full-wave rectifier configuration to provide this output (diodes CR_1 through CR_4 are not included in the 300-volt circuit.) The current flow through the diode pairs is the same as described before, but the current is directed from the relay contacts up through bleeder resistor R_{12} and the external load circuit to develop the 300-volt output. The return flow is through choke L_2 and the transformer center tap. Capacitors C_{11} and C_{12} and choke L_2 provide the filtering for the 300-volt dc output.

12-29

VOLTAGE REGULATOR, SERIES TYPE

With Adjustable Output

Line Regulation within 1.0% Load Regulation within 0.5%



Parts List

C_1 = 1 μF, paper, 25 V
C_2 = 100 μF, electrolytic, 50 V
CR = reference diode, 12 V

R_1 = 1200 ohms, 0.5 watt
R_2 R_4 R_6 = 0.1 ohm, 0.5 watt
R_3 = 2000 ohms, 0.5 watt
R_5 = 570 ohms, 0.5 watt

R_7 = 270 ohms, 0.5 watt
R_8 R_{10} = 1000 ohms, 0.5 watt
R_9 = potentiometer, 1000 ohms, 0.5 watt

12-29 VOLTAGE REGULATOR, SERIES TYPE

Circuit Description

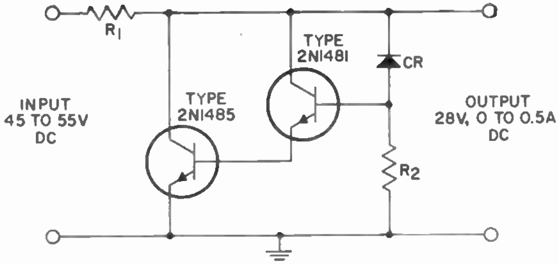
In this series-type voltage regulator, regulation is accomplished by varying the current through three paralleled 2N3055 transistors connected in series with the load circuit. A reverse-bias-connected Zener diode provides the reference voltage for the circuit. The voltage drop across this diode remains constant at the reference potential of 12 volts over a wide range of current through the diode.

If the output voltage tends to rise for any reason, the total increase in voltage is distributed across bleeder resistors R_8, R_9, and R_{10}. If potentiometer R_9, the output-voltage adjustment, is set to the mid-point of its range, one-half the increase in output voltage is applied to the base of the 2N3053 transistor Q_6. This increased voltage is coupled to the base of the 2N3053 transistor Q_4 by R_2, the common emitter resistor for the two transistors. The reference diode CR and its series resistor R_3 are connected in parallel with the bleeder resistors, and the increase in output voltage is also reflected across the diode-resistor network. However, because the voltage drop across CR remains constant, the full increase in voltage is developed across R_3 and thus is applied directly to the base of Q_4. Because the increase in voltage at the base is higher than that at the emitter, the collector current of the transistor increases.

As the 2N3053 collector current of Q_4 increases, the base voltage of the 2N1479 transistor Q_1 decreases by the amount of the increased drop across R_1. The resultant decrease in current through the 2N1479 causes a decrease in the emitter voltage of this transistor and thus in the base voltage of the 2N3055 transistor Q_2. Similar action by Q_2 results in a negative-going voltage at the base of each of the three 2N3055 transistors Q_3, Q_5, and Q_7. As a result, the current through these transistors, and through the load impedance in series with them, decreases. The decrease in load current tends to reduce the voltage developed across the load circuit to cancel the original tendency for an increase in the output voltage. Similarly, if the output voltage tends to decrease, the current through the three paralleled 2N3055 transistors and through the load circuit increases, so that the output voltage remains constant.

12-30 VOLTAGE REGULATOR, SHUNT TYPE

Regulation 0.5%



CR = reference diode, 27 V
R_1 = 28 ohms, 10 watts (includes source resistance of transformers, rectifiers, etc.)
R_2 = 1000 ohms, 0.5 watt

Circuit Description

This simple two-transistor shunt-type voltage regulator can provide a constant (within 0.5 per cent) dc output of 28 volts for load currents up to 0.5 ampere and dc inputs from 45 to 55 volts. The two transistors operate as variable resistors to provide the output regulation. A 27-volt Zener reference diode is used as the control, or sensing, element for the circuit.

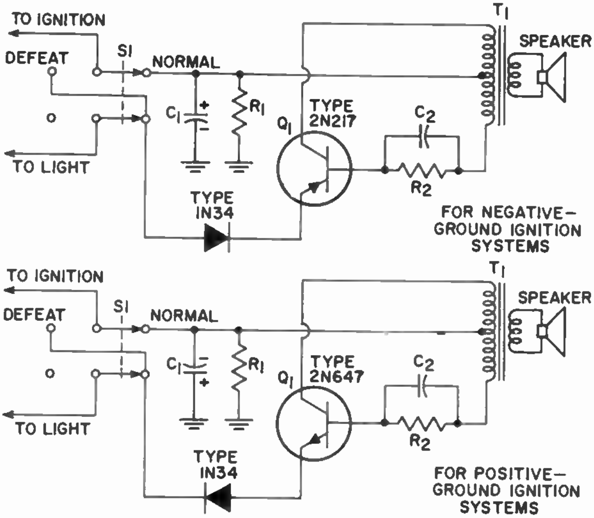
With a 28-volt output, the reverse-bias-connected reference diode, CR, operates in the breakdown-voltage region. In this region, the voltage drop across the diode remains constant (at the reference potential of 27 volts) over a wide range of reverse currents through the diode.

The output voltage tends to rise with an increase in either the applied voltage or the load-circuit impedance. The current through resistor R_2 and reference diode CR then increases. However, the voltage drop across CR remains constant at 27 volts, and the full increase in the output voltage is developed across R_2. This increased voltage across R_2 is directly coupled to the base of the 2N1481 transistor and increases the forward bias so that the 2N1481 conducts more heavily. The rise in the emitter current of the 2N1481 increases the forward bias on the 2N1485, and the current through this transistor also increases

As the increased currents of the transistors flow through resistor R_1, which is in series with the load impedance, the voltage drop across R_1 becomes a larger proportion of the total applied voltage. In this way, any tendency for an increase in the output voltage is immediately reflected as an increased voltage drop across R_1 so that the output voltage delivered to the load circuit remains constant.

If the output voltage tends to decrease slightly, the voltage drop across reference diode CR still remains constant, and the full decrease occurs across R_2. As a result, the forward bias of both transistors decreases so that less current flows through R_1. The resultant decrease in the proportional amount of the applied voltage dropped across this resistor immediately cancels any tendency for a decrease in the output voltage, and the voltage applied to the load circuit again remains constant.

12-31 LIGHT MINDER FOR AUTOMOBILES



Parts List

C_1 = 0.22 μF, electrolytic, 25 volts
C_2 = 30 μF, 15 volts
R_1 = 15000 ohms, 0.5 watt
R_2 = 680 ohms, 0.5 watt
S_1 = switch, double-pole, double-throw
Speaker = 1½-inch permanent-magnet type; voice-coil impedance, 11 ohms; Lafayette No. 99R6035 or equiv.
T_1 = audio-output transformer; 400-ohm primary, 11-ohm secondary; Lafayette No. 99R6209 or equiv.

Circuit Description

This light-minder circuit sounds an alarm if the lights of a car are left on when the ignition is turned off. The alarm stops when the lights are turned off. When the lights are intentionally left on for a period of time, the alarm can be defeated so that no warning sounds. The alarm then sounds when the ignition switch is turned on as a reminder that the system has been defeated and the switch should be returned to its "normal" position.

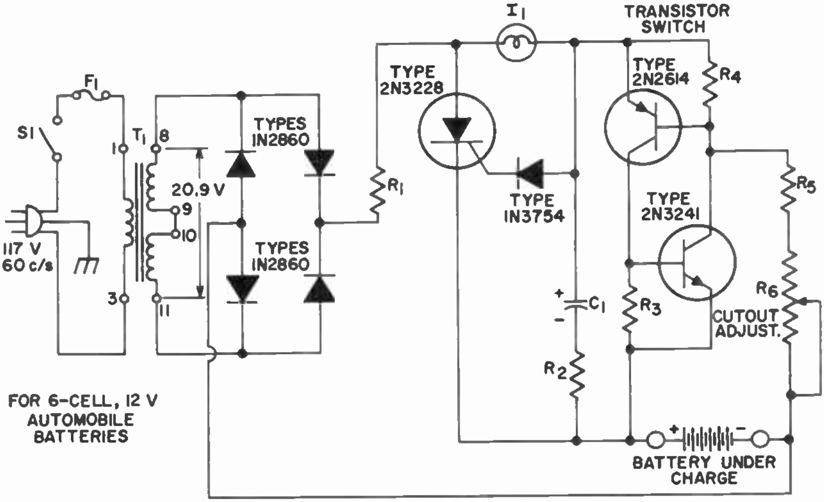
The circuit is essentially an oscillator that obtains its supply voltage from two possible sources, the ignition system or the light system of the car. In the "normal" mode of operation, the ignition system is connected to the collector circuit of the 2N217 (or 2N647) transistor, and the light system is connected through the 1N34 diode to the 2N217 (or 2N647) emitter. When the ignition switch is on, the collector of the transistor is at the supply voltage. If, at the same time, the lights are on, the emitter of the transistor is also at the supply voltage. Because both the emitter and the collector are at the same voltage, the circuit does not oscillate and no alarm sounds. When the ignition is turned off, the collector is returned to ground through R2 and C2, but the emitter remains at the supply voltage and provides the necessary bias for the circuit to oscillate. Turning the lights out removes the supply voltage and stops the oscillation.

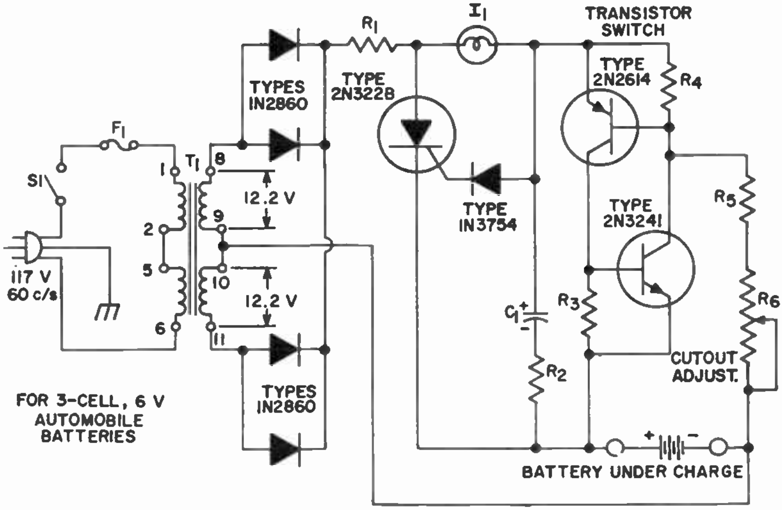
In the "defeat" mode of operation, the ignition system is connected through the 1N34 diode to the emitter of the transistor, and the light system is completely disconnected. The lights can then be turned on without the alarm sounding. When the ignition is turned on, it supplies the necessary voltage to the emitter of the transistor to cause the alarm to sound.

12-32

BATTERY CHARGERS

For 6- and 12-Volt Automobile Batteries





Parts List

C_1 = 50 μF, electrolytic, 15 V
F_1 = fuse, 1-ampere, 3 AG
I_1 = pilot lamp, No. 1488 (12 V, 150 mA) for 12-volt system or No. 47 (6 V, 150 mA) for 6-volt system
R_1 = 5 ohms, 20 watts for 12-volt system or 2 ohms, 25 watts for 6-volt system
R_2 = 33 ohms, 0.5 watt
R_3 = 470 ohms, 0.5 watt
R_4 = 150 ohms, 0.5 watt
R_5 = 1800 ohms, 0.5 watt
R_6 = potentiometer, cutoff adjustment, 10000 ohms, 2 watts
S_1 = toggle switch, single-pole, single-throw, 3-ampere, 125-volt
T_1 = power transformer, Stancor No. RT-202, or equiv.

12-32 BATTERY CHARGERS (cont'd)

Circuit Description

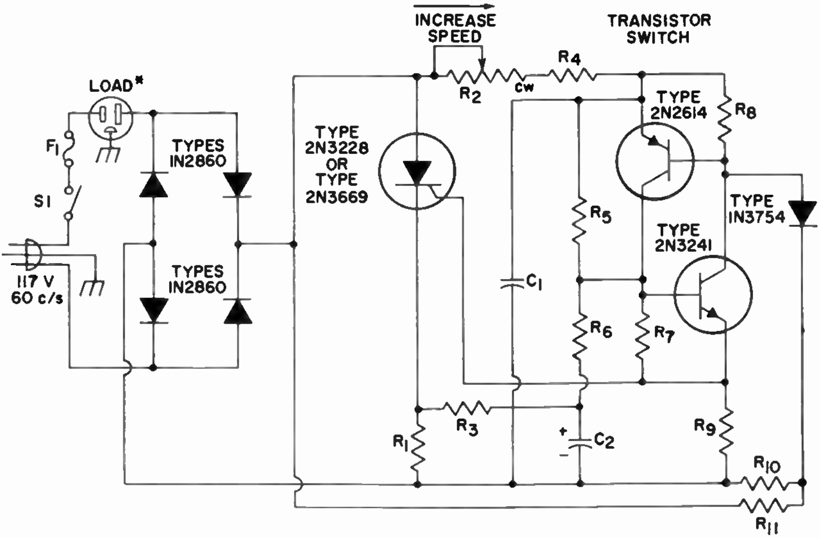
These battery chargers can be used to recharge run-down batteries in automobiles and other vehicles without removing them from their original mounting and without the need for constant attention. When the battery is fully charged, the charger circuits automatically switch from charging current to "trickle" charge, and an indicator lamp lights to provide a visual indication of this condition.

12-Volt Battery Charger—This circuit can be used to charge 6-cell, 12-volt lead storage batteries at a maximum charging rate of 2 amperes. When switch S_1 is closed, the rectified current produced by the four 1N2860 silicon diodes in the full-wave bridge rectifier charges capacitor C_1 through resistors R_1 and R_2 and the No. 1488 indicator lamp, I_1. As C_1 charges, the anode of the 1N3754 diode is rapidly raised to a positive voltage high enough so that the diode is allowed to conduct. Gate current is then supplied to the 2N3228 SCR to trigger it into conduction. The SCR and the battery under charge then form essentially the full load on the bridge rectifier, and a charging current flows through the battery that is proportional to the difference in potential between the battery voltage and the rectifier output. Resistor R_1 limits the current to a safe value to protect the 1N2860 rectifier diodes in the event that the load is a "dead" battery. The energy stored in C_1 assures that the SCR conducts and, thereby, that the charging current flows for practically the full 180 degrees of each successive half-cycle of input until the battery is fully charged. (The SCR is actually cut off near the end of each half-cycle but is retriggered shortly after the beginning of each succeeding half-cycle by the gate current applied through the 1N3754 diode as a result of the steady potential on C_1.)

When the battery is fully charged, the two-transistor regenerative switch is triggered into conduction (the triggering point is preset by means of potentiometer R_6). As a result of the regenerative action, the 2N2614 and 2N3241 transistors in the switch are rapidly driven to saturation and thus provide a low-impedance discharge path for C_1. The capacitor then discharges through these transistors and resistor R_2 to about 1 volt (the voltage drop across the transistors). This value is too low to sustain conduction of the 1N3754 diode, and the 2N3228 SCR is not triggered on the succeeding half-cycle of the input. The saturated transistor switch also provides a low-resistance path for the current to the No. 1488 indicator lamp, which glows brightly to signal the fully charged condition of the battery. The current in the lamp circuit (R_1, lamp, and transistor switch) provides a "trickle" charge of approximately 150 milliamperes to the battery.

6-Volt Battery Charger—This circuit can be used to charge 3-cell, 6-volt lead storage batteries at a maximum charging rate of 3.2 amperes. It is very similar to the 12-volt battery charger except for the rectifier configuration. In the 6-volt circuit, the four 1N2860 diodes are connected in a full-wave center-tapped rectifier circuit that provides the higher charging current of 3.2 amperes to the 6-volt battery. With the exception of the rectifier circuit, the indicator lamp, and the value used for R_1, the 6-volt charger is identical to the 12-volt charger and operates in the same way.

12-33 UNIVERSAL MOTOR SPEED CONTROL OR LIGHT DIMMER



* Maximum load is 2 amperes when 2N3228 SCR is used or 12.5 amperes when 2N3669 SCR is used.

Parts List

C_1 = 1.0 μF, paper, 200 V
C_2 = 50 μF, electrolytic, 15 V
F_1 = fuse, 3-ampere (with 2N3228 SCR) or 15-ampere (with 2N3669 SCR)
R_1 = 2 volts divided by rated value of the load current (as given on motor faceplate). The load current squared times the calculated value of resistance plus a 50-per-cent safety margin is the recommended wattage rating for the resistor.
R_2 = potentiometer, speed adjustment, 0.1 megohm, 2 watts, linear taper
R_3 = 100 ohms, 0.5 watt
R_4, R_{10} = 1000 ohms, 0.5 watt
R_5 = 5600 ohms, 0.5 watt
R_6 = 4700 ohms, 0.5 watt
R_7 = 470 ohms, 0.5 watt
R_8 = 150 ohms, 0.5 watt
R_9 = 15 ohms, 0.5 watt
R_{11} = 15000 ohms, 1 watt
S_1 = toggle switch, single-pole, single-throw

Circuit Description

This circuit can be used to provide both speed control and speed regulation (constant speed under conditions of changing loads) for ac/dc universal motors which have nameplate current ratings up to two amperes with a 2N3228 SCR or up to 12.5 amperes with a 2N3669 SCR. Motor speed can be adjusted from complete cutoff to essentially the full rated value. The circuit also provides smooth anti-skip operation at reduced speeds. This control circuit is useful for adjusting and regulating the speed of small power tools (e.g., drills, buffers, and jigsaws) as required for special jobs.

The speed of the power-tool motor is determined by the time during each half-cycle of the ac input signal that

12-33 UNIVERSAL MOTOR SPEED CONTROL OR LAMP DIMMER (cont'd)

Circuit Description (cont'd)

the SCR conducts. This time, in turn, is controlled by manual adjustment of potentiometer R_2. When R_2 is set for minimum resistance, the rectifier current from the four 1N2860 rectifiers charges capacitor C_1 rapidly to the triggering potential of the two-transistor regenerative switch (preset to six volts for this circuit), and the switch is triggered into conduction early in each input half-cycle. When the 2N2614 and 2N3241 transistors used in the switch circuit conduct, C_1 discharges through the series circuit of the transistors and the gate electrode of the SCR. This discharge current triggers the SCR into conduction, and load current then flows until the end of the input half-cycle. This operation is repeated for each succeeding half-cycle of the ac input signal, and the motor is maintained at maximum speed.

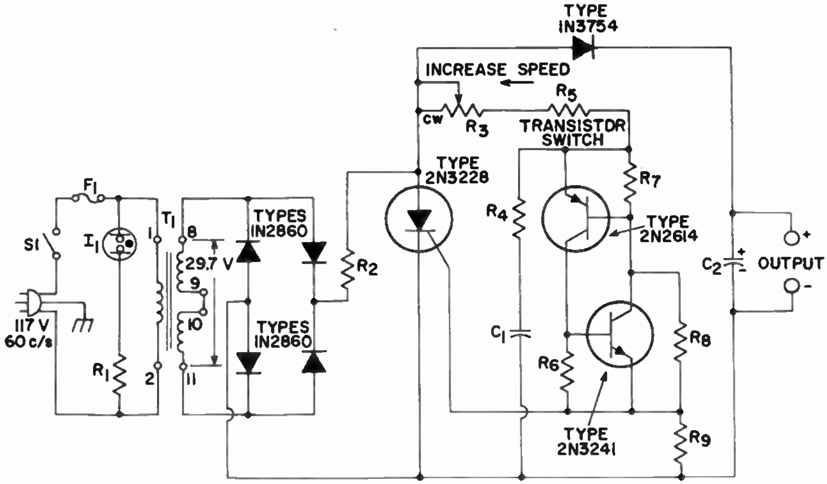
When the resistance of R_2 is increased, C_1 charges more slowly and the SCR is triggered later in the input half-cycle, or not at all if the charge on C_1 fails to reach six volts. Thus, the speed of the motor is reduced, or is cut off completely in the maximum-resistance position.

The feedback circuit (R_1, R_3, R_6, and C_2) maintains essentially constant speed of the motor under changing load conditions. As the load is applied to the motor, the speed momentarily decreases and the current through the motor and the SCR increases. Resistor R_1, in series with the SCR, develops an increased voltage drop, and the charge on capacitor C_3 is increased. This increased charge produces a current increase through resistor R_6; less current is then required through resistor R_5 and the regenerative transistor switch. As a result, the SCR is triggered earlier in the next half-cycle of the input ac voltage. The increased conduction time results in a corresponding increase in motor speed approaching that set by means of the potentiometer R_2. Resistor R_9 performs an additional function of this circuit, i.e., it shunts out commutator "hash" and thereby eliminates the possibility of premature triggering of the SCR.

The circuit can also be used to provide continuous and smooth control of the brightness of incandescent lamps. Lamps having a total power rating of 240 watts (with the 2N3228 SCR) or of 1500 watts (with the 2N3669 SCR) can be adjusted from complete cutoff to essentially full rated brightness. As a lamp dimmer, the circuit is useful for providing the exact amount of light required at different times in various locations, i.e., the desired level for any mood or occasion.

When the circuit is used as a lamp dimmer, speed regulation is not required, and capacitor C_2 and resistors R_3 and R_6 in the feedback network may be omitted. Lamp brightness is controlled in essentially the same way that the speed of a universal motor is controlled. The brightness of the incandescent lamp load is determined by the time during each half-cycle of the ac input that the SCR conducts. This time, in turn, is controlled by manual adjustment of potentiometer R_2.

12-34 MODEL TRAIN AND RACE-CAR SPEED CONTROL



Parts List

C_1 = 1 μF, paper, 200 V
C_2 = 1000 μF, electrolytic, 25 V
F_1 = fuse, 1-ampere, 3 AG
I_1 = neon lamp, NE-83 or NE-2
R_1 = 47000 ohms, 0.5 watt
R_2 = 15 ohms, 60 watts (use three 5-ohm, 20-watt resistors)
R_3 = potentiometer, speed adjustment, 1000 ohms, 2 watts, linear taper
R_4 = 15 ohms, 0.5 watt
R_5, R_9 = 100 ohms, 0.5 watt
R_6 = 470 ohms, 0.5 watt
R_7 = 150 ohms, 0.5 watt
R_8 = 1000 ohms, 0.5 watt
S_1 = toggle switch, single-pole, single-throw, 3-ampere, 125 volt
T_1 = power transformer, Stancor No. RT-202 or equiv.

Circuit Description

This circuit can be used to provide continuous and smooth control of the speed of model vehicles which are designed to operate at dc voltages up to 12 volts. The speed of such vehicles can be adusted over the complete range from zero to the full rated value. This control circuit is useful for starting, stopping, and adusting the speed of most model railroad trains, race cars, and similar "hobby type" vehicles.

The operating speed of the model railroad train or race car is determined by the delay involved in triggering the 2N3228 SCR into conduction after the start of each half-cycle of ac input voltage. This delay time, in turn, is controlled by adustment of the potentiometer R_3. Be-

12-34 MODEL TRAIN AND RACE-CAR SPEED CONTROL (cont'd)

Circuit Description (cont'd)

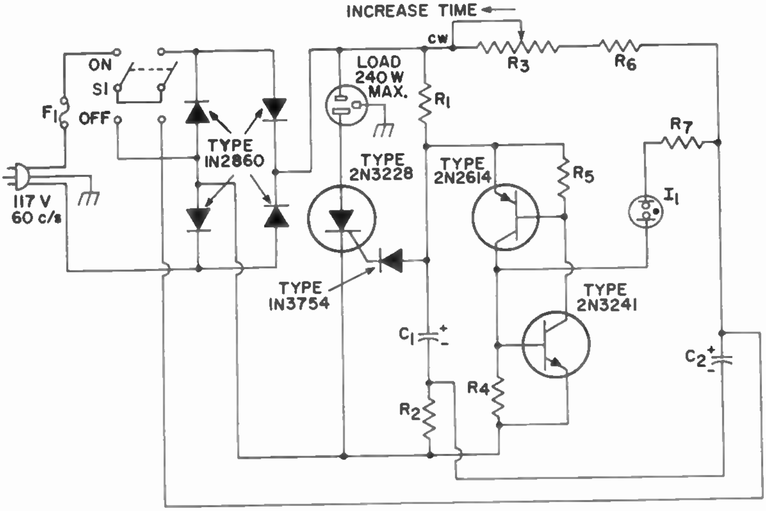
cause the load and the SCR are in parallel (rather than in series as in the Universal Motor Speed Control, Circuit 12-33), output voltage is available at the load only when the SCR is not conducting. When R_3 is set for maximum resistance (maximum clockwise position), maximum delay in triggering the SCR is obtained, and maximum speed is attained in the model vehicle.

When switch S_1 is closed, the pulsating direct current from the 1N2860 bridge rectifiers charges capacitor C_2 through the resistor R_2 and the 1N3754 silicon diode, and a voltage appears across the output terminals. Under conditions of minimum conduction of the SCR (approximately 100 degrees of each input half-cycle of voltage), a maximum voltage of approximately 13 volts is present at the output terminals. As the resistance of potentiometer R_3 is decreased, the current through R_3, R_4, and R_5 charges capacitor C_1 more quickly to the triggering potential of the two-transistor regenerative switch. The 2N2614 and 2N3241 transistors in the switch then supply the gate current to trigger the 2N3228 SCR into conduction, and the voltage across the output terminals drops to slightly less than one volt when potentiometer R_3 is set for minimum resistance.

The output voltage is filtered by capacitor C_2 and therefore approaches a steady dc level determined by the relative duration of the "on" and "off" periods of the SCR. The 1N3754 diode isolates the anode of the SCR from the potential on capacitor C_2 so that the SCR, when it is triggered into conduction, does not provide a discharge path for the capacitor and so that the anode voltage falls to zero and turns off the SCR at the end of each input half-cycle. Resistor R_9 helps to stabilize operation of the SCR and also provides a parallel path for discharge of C_1 after the SCR is triggered into conduction. Resistor R_2 limits the current through the bridge rectifier circuit to the maximum allowable value of 2 amperes in the event of a short circuit across the output terminals.

The parallel arrangement of the load and the SCR in this circuit provides superior control and speed regulation at the operating voltages of model vehicles. The circuit is inherently self-regulating, i.e., it maintains essentially constant speed under varying load conditions. When the mechanical load increases (e.g., when the vehicle travels on an inclined portion of track), the vehicle motor tends to slow down. The motor current then increases, and the voltage across the capacitor C_2 decreases. However, because this voltage is also the potential for the timing circuit (R_3, R_4, R_5, and C_1), the capacitor C_1 charges more slowly and the delay in triggering the SCR is increased. As a result, the output voltage is also increased and the speed is maintained essentially constant.

12-35 ELECTRONIC TIMER



Parts List

C_1 = 50 μF, electrolytic, 15 V
C_2 = 50 μF, electrolytic, 150 V
F_1 = fuse, 3-ampere, 3 AG
I_1 = neon lamp, NE-83
R_1 = 3000 ohms, 5 watts
R_2 = 33 ohms, 0.5 watt
R_3 = potentiometer, 1 megohm, 2 watts, linear taper
R_4 = 470 ohms, 0.5 watt
R_5 = 150 ohms, 0.5 watt
R_6 = 47000 ohms, 0.5 watt
R_7 = 10000 ohms, 0.5 watt
S_1 = toggle switch, double-pole, double-throw

Circuit Description

This circuit can be used to control the time interval between the application and interruption of power to ac/dc devices which do not use the frame as a ground and which have total power ratings up to 240 watts (nameplate current ratings up to two amperes). The interval between turn-on and turn-off can be adjusted from five seconds to approximately two minutes. The timer is useful for providing controlled "ON" times for such equipment as photo-enlargers, developers, small heaters, incandescent lamps, and universal motors.

The "ON" time of the equipment with which this circuit is used is determined by the length of time required for the timing capacitor C_2 to charge to the value required to turn on the NE-83 neon lamp and trigger the two-transistor switch. This time, in turn, is controlled by adjustment of potentiometer R_3. When ON-OFF switch S_1 is turned to the ON position, the full-wave rectified current from the 1N2860 silicon rectifiers charges capacitor C_1 through resistor R_1. When the charge on C_1 increases to a sufficient value, current flows through the 1N3754 diode and triggers the 2N3228 SCR into conduction to complete the load circuit.

At the same time, capacitor C_2 charges, at a rate determined by its capacitance and the resistance of the series combination of R_3 and R_6, to about 80 volts. At this point, the NE-83 neon lamp fires, and the current through the lamp activates the two-transistor regenerative switch. The 2N2614 and 2N3241 transistors used in this switch quickly saturate and provide a low-impedance dis-

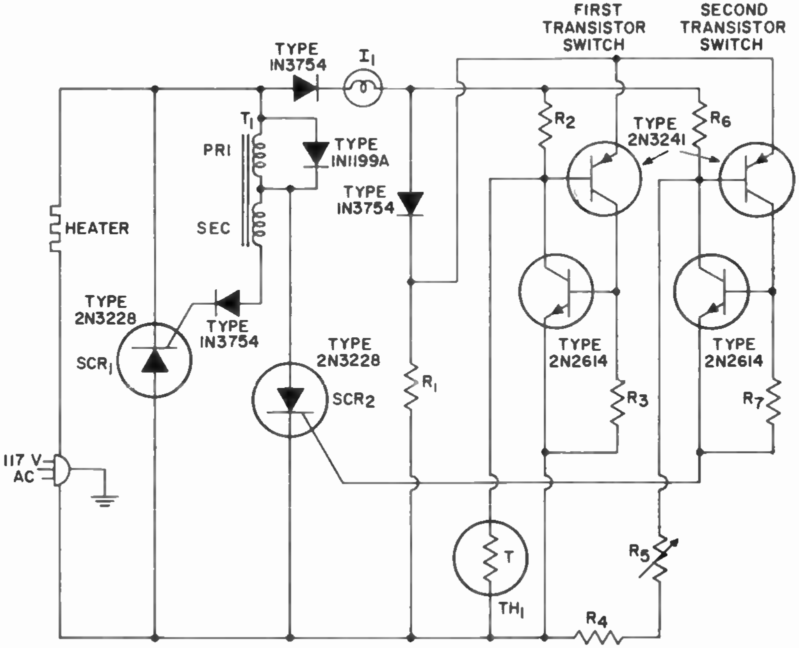
12-35 ELECTRONIC TIMER (cont'd)

Circuit Description (cont'd)

charge path for capacitor C_1. The capacitor discharges through resistor R_2 and the two transistors to approximately one volt (the drop across the transistors). Current then ceases to flow in the gate circuit of the SCR, and it is not triggered on the next half-cycle of input ac voltage. As a result, the load circuit is not completed and no power is delivered to the load until the circuit is reset. The 1N3754 diode increases the threshold voltage of the SCR gate circuit from 0.6 volt (the drop across the gate-cathode junction of the SCR) to 1.2 volts. In this way, the diode prevents accidental triggering of the SCR and improves the stability of the circuit.

12-36 ELECTRONIC HEAT CONTROL WITH READY LIGHT

Turns Off with Increase in Heat



Parts List

I_1 = incandescent lamp, 6-watt, 117-volt
R_1 = 10000 ohms, 2 watts
R_2, R_6 = 150 ohms, 0.5 watt
R_3, R_7 = 470 ohms, 0.5 watt
R_4 = 4300 ohms, 0.5 watt
R_5 = sensitivity control, potentiometer, 2500 ohms, linear taper
T_1 = transformer (primary not used), tapped secondary used as autotransformer to provide step-up in voltage, Stancor No. P-6465 or equiv.
TH_1 = thermistor; negative temperature coefficient; resistance (cold), 5500 ohms; Keystone No. RL25J1 or equiv.

12-36 ELECTRONIC HEAT CONTROL WITH READY LIGHT (cont'd)

Circuit Description

This circuit can be used to regulate the temperature of electric frypans, electric coffee makers, electric waffle irons, and similar types of electric appliances having a maximum power rating of 240 watts. Two 2N3228 SCR's are used in the circuit to provide full-wave power control. The temperature at which the circuit interrupts power to the appliance heater is determined by the setting of the sensitivity-control potentiometer, R_5. The thermistor TH_1 is the sensing element used to initiate the control function. The lamp I_1 lights when the desired operating temperature is reached to indicate that the appliance is ready for use.

When the 117-volt ac power is initially applied to the circuit, the resistance of the cold thermistor is high enough so that the current through resistor R_1 is insufficient to trigger the first two-transistor regenerative switch. Potentiometer, R_5, however, is adjusted so that the current through resistor R_7 will be large enough to trigger the 2N2614 and 2N3241 transistors in the second regenerative switch into conduction. The regenerative action of the switch circuit quickly drives these transistors into saturation. The saturated switch current flows through the gate electrode of SCR_2 and triggers it into conduction.

Once the SCR starts to conduct, the gate electrode loses its control, and the flow of current continues for almost the full 180 degrees of the input half-cycle for which the anode of SCR_2 is positive with respect to its cathode. During this period, current flows through the primary of transformer T_1 and through the appliance heater. The 1N1199A diode restricts the voltage drop across the primary of T_1 to about 0.3 volts. When SCR_2 is conducting, the voltage drop across it is about 0.5 volt. The ready lamp I_1 is connected in parallel with the transformer primary and the SCR. The total voltage drop of 0.8 volt is not enough to light the lamp.

During the input half-cycle that SCR_2 does not conduct, the flux about the step-up transformer T_1 collapses and induces sufficient voltage across the secondary winding to cause current to flow through the 1N3754 diode to the gate electrode of SCR_1. This SCR is now triggered into conduction and supplies the current to the appliance heater. In this way, full-wave power control is provided.

The flow of current through the appliance causes the ambient temperature to rise. The thermistor TH_1 has a negative temperature coefficient, and its resistance decreases. When the temperature of the appliance heater reaches the desired level, the resistance of the thermistor is reduced to a value less than the combined resistance of R_4 and R_5. The current through R_7 is then sufficient to trigger the 2N2614 and 2N3241 transistors in the first regenerative switch. These transistors are quickly driven into saturation, and the voltage across the switch decreases to about 1 volt. The bias resistors (R_4, R_5, and R_6) for the second two-transistor regenerative switch are in parallel with the first switch, and the 1 volt that appears across these resistors is not high enough to maintain the conduction of the second switch. No gate current then flows to trigger SCR_2 into conduction on the next half-cycle of the input ac power. When SCR_2 is not conducting, the current supplied to ready lamp I_1, through the first transistor switch, resistor R_2, and the 1N3754 diode, is sufficient to light the lamp.

12-37 INTEGRAL-CYCLE RATIO POWER CONTROL

For Electric Appliances

Circuit Description

This circuit can be used as a heat control for electric hot plates, and in other applications in which control of the average power level is desired. The average level of the power delivered to an electric appliance is controlled, without the use of a thermistor sensing element, by allowing current to flow in the load circuit for only controlled periods. The current delivered to the load circuit is gated on and off by a free-running (approximately 1 c/s) multivibrator; the ratio of on time to off time during each cycle determines the average amount of ac power applied. Two SCR's are used to deliver the load current so that full-wave power control can be obtained. Depending upon the maximum power rating of the appliance, either 2N3228 (up to 800 watts) or 2N3669 (up to 2000 watts) SCR's are used.

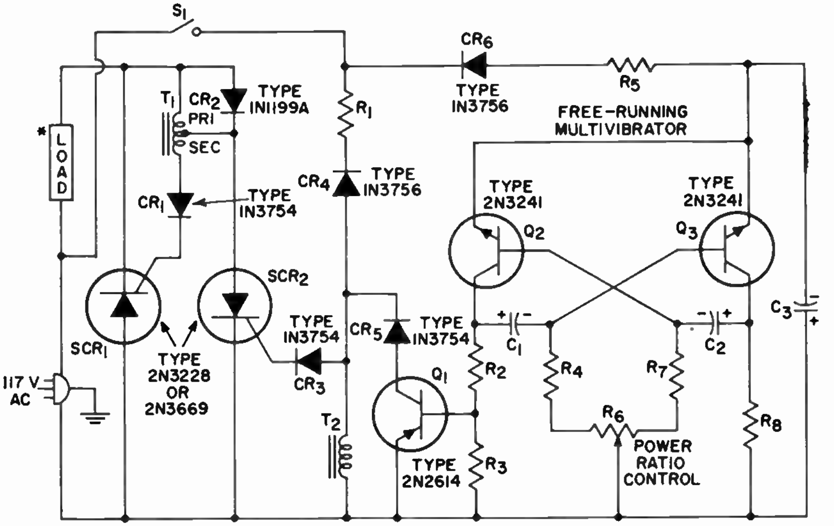
The 117-volt ac power applied to the circuit is rectified by the 1N3756 diode CR_6. The dc voltage developed across C_3 by the rectified current from CR_6 is the dc supply voltage for the 2N2614 transistors, Q_2 and Q_3, in the free-running multivibrator. The rectangular-wave output from the multivibrator is applied to the base of the 2N2614 p-n-p transistor Q_1. The multivibrator output gates the operation of Q_1. During the positive half-cycle, the transistor is held cut off; during the negative half-cycle, the transistor is driven into saturation. The setting of potentiometer R_6 determines the relative durations of the positive and negative half-cycles of the multivibrator output and, in this way, establishes the power on-time-to-off-time ratio.

During the negative half-cycle of the input ac power, current is allowed to flow through the 1N3756 diode CR_4. If Q_1 is gated on by the multivibrator during this period, most of the current from the diode is shunted through this transistor and the 1N3754 diode CR_5 in series with it, and very little current is allowed to flow through T_2. As a result, the amount of energy stored in T_2 is negligible, and when the polarity of the ac input reverses so that no current flows through CR_4, the collapsing field about this winding does not supply sufficient current to the gate electrode of SCR_2 to trigger the SCR into conduction. For this condition, no current is delivered to the load circuit.

If Q_1 is not gated on during the negative half-cycle of the ac input, all the current from CR_4 flows through T_2, and a strong magnetic field is set up around this winding. When the polarity of the ac input reverses, the collapsing field about T_2 causes sufficient current to flow through the 1N3754 diode CR_3 to the gate electrode of SCR_2 to trigger this SCR into conduction. Current then flows through the primary of autotransformer T_1 and the load circuit. The 1N1199A diode CR_2 limits the voltage drop across the primary of T_1 to about 0.3 volt.

When the polarity of the ac input again reverses so that SCR_2 no longer conducts, the collapsing field about T_1 supplies sufficient gate current to SCR_1 through the 1N3754 diode CR_1 so that this SCR is triggered into conduction. The load current is then delivered through SCR_1.

12-37 INTEGRAL-CYCLE RATIO POWER CONTROL (cont'd)



*** Maximum load is 800 watts when 2N3228 SCR is used or 2000 watts when 2N3669 SCR is used.**

Parts List

C_1, C_2 = 15 µF, electrolytic, 50 V
C_3 = 500 µF, electrolytic, 15 V
R_1 = 3000 ohms, 5 watts
R_2, R_8 = 1000 ohms, 0.5 watt
R_3 = 180 ohms, 0.5 watt
R_4, R_7 = 6800 ohms, 0.5 watt
R_5 = 2000 ohms, 5 watts
R_6 = power-ratio control, potentiometer, 0.1 megohm, linear taper
S_1 = ON-OFF switch, single-pole, single-throw
T_1 = transformer (primary not used); tapped secondary used as autotransformer to provide 1-to-5 step-up in voltage; Stancor No. P-6465 or equiv.
T_2 = transformer (secondary not used); Stancor No. P-6465 or equiv.

12-38 SERVO AMPLIFIER

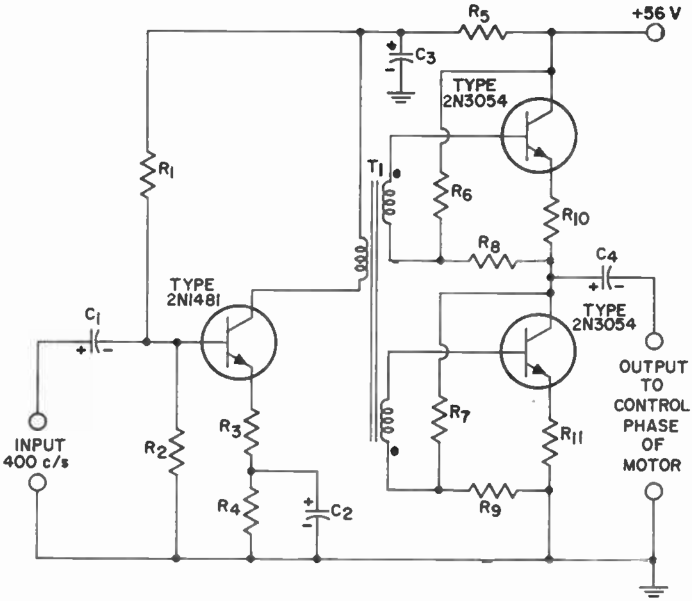
Output, 6 W

Circuit Description

This servo amplifier can supply up to 6 watts of power to the drive motor of a servo system. The amplifier is driven by a 400-c/s ac signal and is operated from a dc supply voltage of 56 volts. A pair of 2N3054 silicon power transistors are used in a class AB, push-pull, single-ended output stage to develop the required output power. This output stage is very similar to the one used in the High-Quality 10-Watt Audio Power Amplifier, circuit 12-11.

A 2N1481 common-emitter input stage amplifies the 400-c/s input to the level required to drive the 2N3054 output transistors. The amplified 400-c/s signal at the collector of the 2N1481 transistor is coupled to the base of each 2N3054 output transistor by the transformer T_1. The secondary of T_1 is split to

12-38 SERVO AMPLIFIER (cont'd)



Parts List

C_1 = 10 μF, electrolytic, 15 V
C_2 = 47 μF, electrolytic, 15 V
C_3 = 20 μF, electrolytic, 50 V
C_4 = 500 μF, electrolytic, 50 V

R_1 = 68000 ohms, 0.5 watt
R_2 = 5600 ohms, 0.5 watt
R_3 = 56 ohms, 0.5 watt
R_4 = 560 ohms, 0.5 watt
R_5 = 3300 ohms, 0.5 watt
R_6, R_7 = 18000 ohms, 0.5 watt
R_8, R_9 = 400 ohms, 0.5 watt
R_{10} R_{11} = 4 ohms, 1 watt

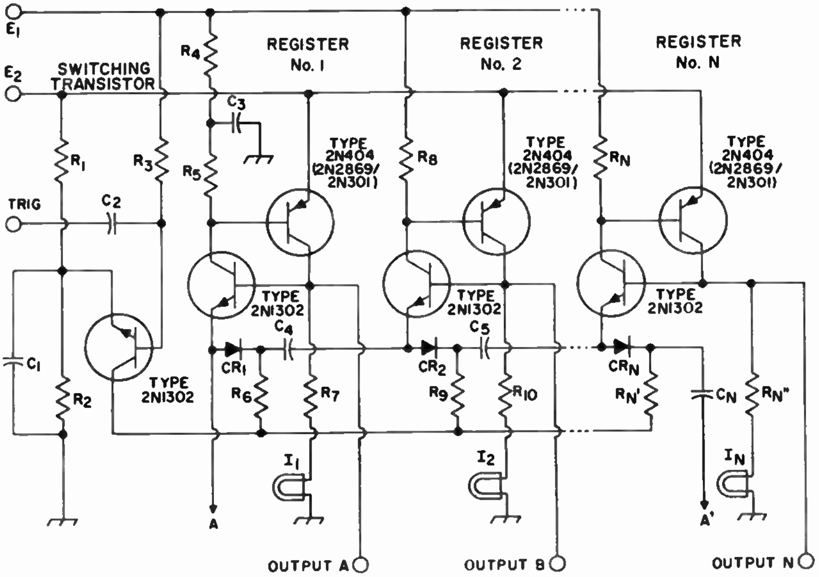
T= driver transformer; core material 0.014-inch Magnetic Metals Corp. "Crystalligned" or equiv.; primary 1500 turns; secondary 450 turns, bifilar wound (each section 225 turns)

Circuit Description (cont'd)

form two identical windings which are oriented so that the inputs to the output transistors are equal in amplitude and 180 degrees out of phase, as required for push-pull drive.

If the input to the upper output transistor were applied between the base and ground, this transistor would be operated as an emitter follower and could not provide voltage gain. The input, however, is applied between the base and the emitter so that, in effect, the upper transistor is operated as a common-emitter amplifier except that there is no phase reversal between input and output. Its gain, therefore, is equal to that of the lower output transistor, which is operated in a conventional common-emitter amplifier configuration. The positive half-cycle of the output signal developed by the upper transistor and the negative half-cycle developed by the lower transistor then have equal voltage swings. This output is coupled to the control-phase winding of the drive motor by the series output capacitor C_4.

12-39 SHIFT REGISTER OR RING COUNTER



Parts List

C_1 = 100 µF, electrolytic, 6 V
C_2, C_4, C_5, C_N = 0.05 µF (or 0.1 µF), ceramic, 50 V
C_3 = 1 µF, (or 25 µF), electrolytic, 25 V
CR_1, CR_2, CR_N = crystal diode 1N34A or equiv.
I_1, I_2, I_N = indicator lamp No. 49; 2-volt, 60-mA (or No. 1488; 14-volt, 150-mA)
R_1 = 1000 ohms, 0.5 watt (or 680 ohms, 1 watt)
R_2 = 27 ohms, 0.5 watt (or 12 ohms, 1 watt)
R_3 = 1000 ohms, 0.5 watt
R_4 = 1000 ohms, 0.5 watt (or 330 ohms, 0.5 watt)
R_5, R_8, R_N = 2200 ohms, 0.5 watt (or 680 ohms, 0.5 watt)
R_6, R_9, R_N' = 560 ohms, 0.5 watt (or 180 ohms, 1 watt)
R_7, R_{10}, R_N'' = 150 ohms, 1 watt (or 82 ohms, 2 watts)

NOTES:
The shift register may use as many stages as desired and may be made regenerative by connecting points A and A'. In addition, the basic circuit can be adapted for operation at many different output-current levels.

The circuit as shown is designed for an output-current level of 40 mA (E_1 = 12 V; E_2 = 9 V). Transistor types and component values shown in parentheses indicate the changes necessary for operation at an output-current level of 3 amperes (E_1 = 27 V; E_2 = 24 V).

Circuit Description

In this basic shift register, the successive outputs from the various stages are delayed (or shifted) from those of the preceding stages by a controlled time interval (i.e., the duration between input trigger pulses). These outputs are coupled through OR gates (not shown on circuit schematic) and may be used to program the timing sequence for various digital switching operations. If point A on the circuit is connected to point A, the register becomes regenerative and may be used as a ring counter.

The dc supply voltages E_1 and E_2 are obtained from separate taps on a resistive voltage divider. With these voltages applied, the 2N1302 switching transistor is immediately triggered into conduction by the positive voltage applied to its base

12-39 SHIFT REGISTER OR RING COUNTER (cont'd)

Circuit Description (cont'd)

through R_3. One of the register stages must be triggered simultaneously to provide a complete path for the current through the switching transistor.

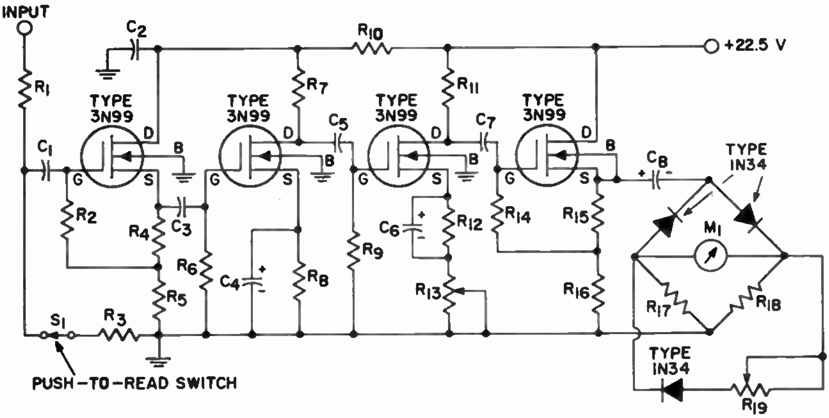
Each register stage is basically a two-transistor regenerative switch that employs an n-p-n triggering transistor and a p-n-p output transistor. For the E_1 and E_2 voltages used (see notes below circuit schematic), the n-p-n transistor is a 2N1302, and the p-n-p transistor is a 2N404 or a 2N2869/2N301 depending upon the level of output current desired. If either of the transistors in a register stage starts to conduct, both of them are quickly driven into saturation by the regenerative action of the stage. The relatively high current from the p-n-p transistor in the stage flows through the resistance that exists between the E_1 and E_2 taps on the power-supply voltage divider. The increased voltage drop across this resistance reduces the E_2 voltage to a value less than that required to trigger the other register stages, and these stages are held inoperative.

When power is initially applied to the circuit, C_3 and R_4 assure that the first register stage is triggered into conduction before current flows through any of the other register stages. When the power is first applied, the initial surge of current through C_3 and R_4 immediately triggers the 2N1302 transistor in the first stage into conduction. This transistor and the p-n-p output transistor are then quickly driven into saturation by the regenerative action of the stage. No other register stage is then allowed to conduct, and the lamp I_1 in the collector of the p-n-p transistor in the first stage lights to indicate that the output is being supplied by this stage. This condition is maintained until an input trigger pulse is applied. During this period, C_4 charges through diode CR_1, the 2N1302 transistor, and resistors R_4 and R_5 to the E_1 voltage less the sum of the voltages dropped across the other components in the charging path.

A negative trigger pulse is applied to the base of the 2N1302 switching transistor to initiate a register shift. A sufficiently large negative pulse will drive the switching transistor to cut off. All the register stages are then held inoperative for the duration of the trigger pulse. When the trigger pulse is removed, the switching transistor again conducts through one of the register stages. This time, however, no quick surge of current can flow through C_3 and R_4 to trigger the first register stage, because C_3 has fully charged to the E_1 voltage. Moreover, the charge on C_4 tends to reverse-bias diode CR_1, and thus impedes the flow of current through the first register stage. The charge on C_4, however, is series-aiding with the dc supply voltage in the second register stage. This series-aiding effect causes the second stage to be triggered into conduction before current can flow through any of the other stages. The biasing action of this stage then holds the other stages inoperative. The lamp I_2 then lights to indicate that the output is being supplied by the second stage.

When the next register shift is initiated by a negative trigger pulse, the charge on C_5 assures that the third register stage will be triggered to supply the output. In this way, the operation of the register is shifted from one stage to the next each time a negative trigger pulse is applied. The register can be reset so that the operation starts with the first stage at any time by discharging capacitor C_3.

12-40 AC VOLTMETER



Parts List

C_1 = 0.01 µF, paper, 600 V.
C_2 = 25 µF, ceramic disc, 25 V.
C_3, C_5, C_7 = 0.33 µF
C_4, C_6 = 100 µF, electrolytic, 6 V.
C_8 = 50 µF, electrolytic, 25 V.
M_1 = dc milliameter
R_1 = 1000 ohms, 0.5 watt
R_2 = 10 megohms, 0.5 watt
R_3 = 100 ohms, 0.5 watt
R_4, R_8, R_{12} = 10000 ohms, 0.5 watt
R_5 = 47000 ohms, 0.5 watt
R_6, R_9, R_{14} = 0.39 megohm, 0.5 watt
R_7, R_{11} = 33000 ohms, 0.5 watt
R_{10} = 5000 ohms, 0.5 watt
R_{13} = gain-control potentiometer, 1000 ohms, 0.5 watt, linear
R_{15} = 2000 ohms, 0.5 watt
R_{16}, R_{17}, R_{18} = 5100 ohms, 0.5 watt
R_{19} = zero-adjustment potentiometer, 10000 ohms, 0.5 watt, linear taper
S_1 = push-to-read switch; single-pole, single-throw; Microswitch No. BZ2RQ1 or equiv.

Circuit Description

This circuit illustrates the application of RCA-3N99 MOS transistors in an ac voltmeter. The circuit has an input impedance of 1 megohm, a full-scale sensitivity of 10 millivolts on the lowest range, a flat frequency response over the audio range of 20 to 20,000 c/s, and a low current drain which permits fully portable operation. The amplifier portion of the voltmeter circuit consists of four 3N99 stages. The first stage is operated as a source-follower and presents a very low input capacitance to the conventional one-megohm input-signal voltage divider. With this stage operating at a drain current of only 230 microamperes and a drain-to-source voltage of 0.5 volts, the effective input capacitance is only 0.5 picofarad. The source of the first stage is coupled to the insulated gate of the second stage by a 0.33-microfarad ceramic capacitor.

The second stage is operated as a common-source amplifier. As in the first stage, the 10,000-ohm source resistor establishes a quiescent drain current of approximately 230 microamperes. The source resistor is bypassed with a 100-microfarad capacitor. This stage provides a voltage gain of between 16 and 20.

The third stage is similar to the second stage except that an unbypassed 1000-ohm potentiometer is added in series with the bypassed 10,000-ohm source resistance. This potentiometer can be used to vary

12-40 AC VOLTMETER CIRCUIT (cont'd)

Circuit Description (cont'd)

the voltage gain of the stage between 10 and 20 by varying the amount of negative feedback voltage. With a 10-millivolt signal at the input of the first stage, the maximum output-signal voltage at the drain of the third stage is about 2.8 volts rms.

The fourth stage is operated as a source-follower and provides the necessary impedance transformation between the high output impedance (approximately 300,000 ohms) of the third stage and the low impedance of the meter rectifier circuit.

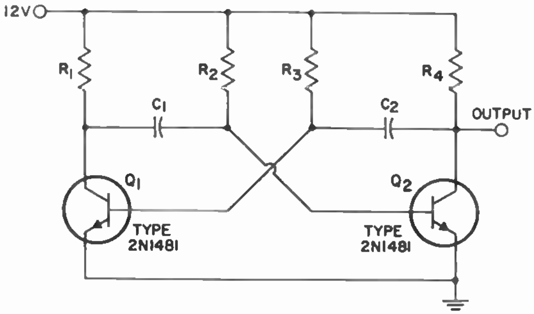
The meter rectifier uses two 1N34 diodes in a conventional meter-circuit bridge configuration. A third 1N34 diode is used in conjunction with a 10,000-ohm potentiometer to compensate for the nonlinear rectification characteristic of the rectifier diodes at the low end of the meter scale.

A 100-to-1 voltage divider is placed ahead of the input-coupling capacitor of the first stage to protect the gate of the 3N99 in this stage from overload in the event that an excessively large signal is accidentally applied to the input terminals when the range switch is in the 10-millivolt position. A "push-to-read" switch removes this 100-to-1 attenuation network from the circuit.

The total consumption from the battery for the complete meter amplifier is only 2.5 milliamperes.

12-41 ASTABLE MULTIVIBRATOR

(Frequency = 7000 c/s)



$$f = \frac{1}{(0.7C_1R_2)\,(0.7C_2R_3)}$$

C_1, C_2 = 0.1 μF, paper, 25 V
R_1 R_4 = 60 ohms, 5 watts
R_2 R_3 = 1000 ohms, 0.5 watt

12-41 ASTABLE MULTIVIBRATOR (cont'd)

Circuit Description

This astable (free-running) multivibrator develops a square-wave output that has a peak value equal to the dc supply voltage (V_{CC} = 12 volts) and a minimum value equal to the collector saturation voltage of the transistors. The circuit is basically a two-stage nonsinusoidal oscillator in which one stage conducts at saturation while the other is cut off until a point is reached at which the stages reverse their conditions. The circuit employs two 2N1481 transistors operated in identical common-emitter amplifier stages with regenerative feedback resistance-capacitance coupled from the collector of each transistor to the base of the other transistor.

When power is initially applied to the circuit, the same amount of current tends to flow through each transistor. It is unlikely, however, that a perfect balance will be maintained, and if the current through transistor Q_1, for example, should increase slightly without an attendant increase in that through transistor Q_2, the multivibrator will oscillate to generate a square-wave output.

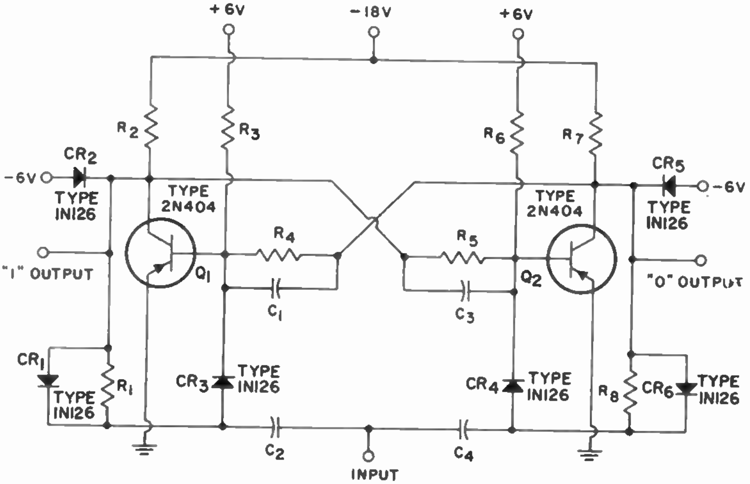
As the current through transistor Q_1 increases, the resultant decrease in collector voltage is immediately coupled to the base of transistor Q_2 by the discharge of capacitor C_1 through resistor R_2. This negative voltage at the base reduces the current through transistor Q_2, and its collector voltage rises. The charge of capacitor C_2 through resistor R_3 couples the increase in voltage at the collector of transistor Q_2 to the base of transistor Q_1, and further increases the flow of current through Q_1. The collector voltage of Q_1 decreases even more, and the base of Q_2 is driven more negative. As a result of this regenerative action, transistor Q_1 is driven to saturation almost instantaneously, and, just as quickly, transistor Q_2 is cut off. This condition is maintained as long as the discharge current of C_1 develops sufficient voltage across R_2 to hold Q_2 cut off. The time constant of C_1 and R_2, therefore, determines the time that Q_2 remains cut off (i.e., the duration of the positive half-cycle of the square-wave output). During this period, the voltage at the output terminal is the dc supply voltage (12 volts).

The discharge current from C_1 decreases exponentially, as determined by the time constant of the discharge path, and eventually becomes so small that the voltage developed across R_2 is insufficient to hold Q_2 cut off. The decrease in collector voltage that results when Q_2 conducts is coupled by C_2 and R_3 to the base of Q_1. The current through Q_1 then decreases, and the collector voltage of this transistor rises. The positive swing of the voltage at the collector of Q_1 is coupled by C_1 and R_2 to the base of Q_2 to increase further the conduction of Q_2. The regenerative action of the multivibrator then quickly drives Q_2 to saturation and Q_1 to cutoff. The length of time that this condition is maintained is determined by the time constant of C_2 and R_3. During this period, which represents the negative half-cycle of the square-wave output, the voltage at the output terminal is the collector saturation potential of Q_2.

12-42

BISTABLE MULTIVIBRATOR

1-Mc/s "Flip-Flop"



Parts List

C_1, C_3 = 180 pF, mica, 24 V
C_2, C_4 = 430 pF, mica, 24 V
R_1 R_8 = 5100 ohms, 0.5 watt
R_2 R_7 = 1200 ohms, 0.5 watt
R_3 R_6 = 11000 ohms, 0.5 watt
R_4 R_5 = 2700 ohms, 0.5 watt

Circuit Description

The bistable multivibrator is ideally suited for generating the binary ("1" and "0") type of outputs required in computer applications and also finds widespread use as an electronic switch. The circuit is in a stable state when either transistor is conducting and the other transistor is cut off. The states of the transistors are switched by the application of a properly applied trigger pulse. The 1N126 steering diodes, CR_3 and CR_4, assure that the 2N404 p-n-p transistors in the circuit are triggered to alternate states only when positive pulses are applied to the input terminal.

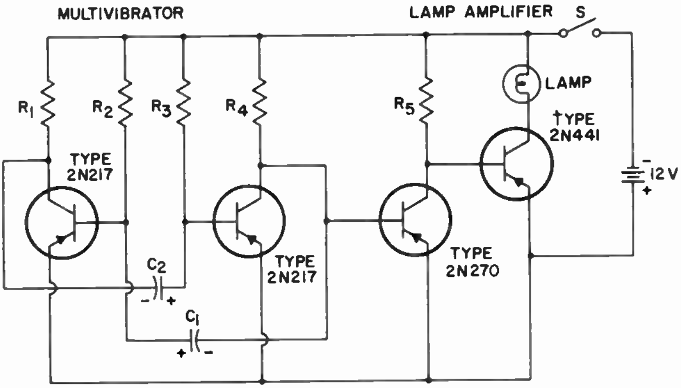
A positive trigger pulse applied to the input terminal when transistor Q_1 is conducting and Q_2 is cut off causes Q_1 to conduct less, and the collector voltage of this transistor increases to a more negative value. The increase in negative voltage at the collector of Q_1 is coupled to the base of Q_2. If this voltage is large enough to overcome the cutoff bias on Q_2, as determined by the amplitude of the trigger pulse, Q_2 conducts. The collector voltage of Q_2 then decreases to a less negative value. This positive-going voltage is coupled to the base of Q_1 to decrease further the conduction of this transistor. The regenerative action continues until Q_2 is driven to saturation and Q_1 is cut off. This condition is maintained until another positive trigger pulse is applied to switch the multivibrator from this stable state.

The output of the multivibrator, which may be taken between collector and ground of either transistor (or both) is a unit step voltage when one trigger is applied. A square-wave output is obtained by a continuous periodic pulsing of the input. A frequency division from input to output of 2 to 1 is thus obtained.

12-43

LIGHT FLASHER

60 Flashes per Minute



Parts List

C_1 = 25 µF, electrolytic, 12 V
C_2 = 100 µF, electrolytic 12 V
LAMP = bulb, 12 V 1 ampere
R_1 R_4 = 2000 ohms, 0.5 watt
R_2 R_3 = 100000 ohms, 0.5 watt
R_5 = 120 ohms, 0.5 watt
S = ON-OFF switch; single-pole, single-throw
NOTE: C_1 and C_2 may be varied to change flashing rate. Bulbs and other resistive loads handling currents up to one ampere may be used, but inductive loads should not be used.

Circuit Description

In this light-flasher circuit, a free-running multivibrator is used to gate the operation of a two-stage amplifier. An incandescent lamp is used as the collector load in the second amplifier stage, and each time the stage conducts, the lamp lights. The dc power for the circuit is supplied by a 12-volt B battery.

The multivibrator uses a pair of 2N217 transistors; the square-wave output developed at the collector of the second transistor is directly coupled to the base of a 2N270 transistor operated in a common-emitter amplifier stage.

The 2N270 transistor stage is gated on and off by the square-wave signal from the multivibrator. This stage, in turn, gates the operation of the 2N441 common-emitter amplifier stage in which the lamp is used as the collector load. Each time the 2N441 transistor is gated on, the lamp lights. The lamp, therefore, flashes at the frequency of the multivibrator. With the equation given for the astable multivibrator, circuit 12-41, the natural (unloaded) frequency of the multivibrator in the lamp dimmer is calculated to be between 6 and 7 cycles per minute. The loading effect of the low-impedance lamp circuit, however, reduces substantially the switching time constant of the multivibrator so that its frequency is increased by approximately a factor of 10. The lamp, therefore, flashes at a frequency of approximately 60 cycles per minute.

RCA Technical Publications

on Semiconductor Products, Electron Tubes, and Batteries

Copies of the publications listed below may be obtained from your RCA distributor or from Commercial Engineering, Radio Corporation of America, Harrison, N. J.

Semiconductor Products

- RCA SEMICONDUCTOR PRODUCTS HANDBOOK — HB-10. Two binders, each 7⅜" L x 5⅝" W x 2⅞" D. Contains over 1000 pages of looseleaf data and curves on RCA semiconductor devices such as transistors, silicon rectifiers, and semiconductor diodes. Available on a subscription basis. Price $10.00* including service for first year. Also available with RCA Electron Tube Handbook HB-3 at special combination price of $25.00.*

- RCA TUNNEL DIODE MANUAL—TD-30 (8⅜" x 5⅜")—160 pages. Describes the microwave and switching capabilities of tunnel diodes. Contains information on theory and characteristics, and on tunnel-diode applications in switching circuits and in microwave oscillator, converter, and amplifier circuits. Includes data for over 40 RCA germanium and gallium arsenide tunnel diodes and tunnel rectifiers. Price $1.50.*†

- RCA SEMICONDUCTOR PRODUCTS GUIDE—SPG201/1L1147B (10⅞" x 8⅜")—12 pages. Contains classification chart, index, and ratings and characteristics on RCA's line of transistors, silicon rectifiers, semiconductor diodes, and photocells. Single copy free on request.

- TECHNICAL BULLETINS—Authorized information on RCA semiconductor products. Be sure to mention type-number bulletin desired. Single copy on any type free on request.

Electron Tubes

- RCA ELECTRON TUBE HANDBOOK —HB-3 (7⅜" x 5⅝"). Five 2¼-inch-capacity binders. Contains over 5000 pages of looseleaf data and curves on RCA receiving tubes, transmitting tubes, cathode-ray tubes, picture tubes, photocells, phototubes, camera tubes, ignitrons, vacuum gas rectifiers, traveling-wave tubes, premium tubes, pencil tubes, and other miscellaneous types for special applications. Available on subscription basis. Price $20.00* including service for first year. Also available with RCA Semiconductor Products Handbook HB-10 at special combination price of $25.00.*

- RADIOTRON° DESIGNER'S HANDBOOK—4th Edition (8¾" x 5½")—1500 pages. Comprehensive reference covering the design of radio and audio circuits and equipment. Written for the design engineer, student, and experimenter. Contains 1000 illustrations, 2500 references, and cross-referenced index of 7000 entries. Edited by F. Langford-Smith. Price $7.00*†

- RCA PHOTOTUBE AND PHOTOCELL MANUAL—PT-60 (8¼" x 5⅜")—192 pages. Well-illustrated informative manual covering fundamentals and operating considerations for vacuum and gas phototubes, multiplier phototubes, and photocells. Also describes basic applications for these devices. Features easy-to-use selection chart for multiplier phototubes. Data and performance curves given for over 90 photo-sensitive devices. Price $1.50*†

- RCA RECEIVING TUBE MANUAL—RC-24 (8" x 5¼")—576 pages. Contains technical data on over 1000 receiving-type tubes for home-entertainment use and picture tubes for black-and-white and color TV. Features tube theory written for the layman, application data, selection charts, and typical circuits. Features lie-flat binding. Price $1.25*†

● RCA TRANSMITTING TUBES—TT-5 (8¼" x 5⅜")—320 pages. Gives data on over 180 power tubes having plate-input ratings up to 4 kw and on associated rectifier tubes. Provides basic information on generic types, parts and materials, installation and application, and interpretation of data. Contains circuit diagrams for transmitting and industrial applications. Features lie-flat binding. Price $1.00*†

● RCA INDUSTRIAL RECEIVING-TYPE TUBES—RIT 104P (10⅞" x 8⅜")—52 pages. Technical information on over 200 RCA "special red" tubes, premium tubes, nuvistors, computer tubes, pencil tubes, glow-discharge tubes, small thyratrons, low-microphonic amplifier tubes, mobile communications tubes, and other special types. Includes socket-connection diagrams. Price 40 cents.*†

● RCA RECEIVING TUBES AND PICTURE TUBES—1275L (10⅞" x 8⅜")—56 pages. New, enlarged, and up-to-date booklet contains classification chart, application guide, characteristics chart, and base and envelope connection diagrams on more than 1300 entertainment receiving tubes and picture tubes. Price 50 cents.*†

● RCA INTERCHANGEABILITY DIRECTORY OF INDUSTRIAL-TYPE ELECTRON TUBES—ID-1020E (10⅞" x 8¾")—12 pages. Lists more than 2100 basic type designations for 20 classes of industrial tube types; shows the RCA Direct Replacement Type or the RCA Similar Type, when available. Price 20 cents.*†

● RCA PHOTOCELLS—CSS-800 (10⅞" x 8⅜")—36 pages. Contains a selection of photocell-circuit diagrams; technical data and characteristic curves of RCA photoconductive, photojunction, and photovoltaic cells; interchangeability information. Also contains representative circuits. Price 40 cents.*†

● RCA INTERCHANGEABILITY DIRECTORY OF FOREIGN vs. U.S.A. RECEIVING-TYPE ELECTRON TUBES—1CE-197D (8⅜" x 10⅞")—8 pages. Covers approximately 800 foreign tube types used principally in AM and FM radios, TV receivers, and audio amplifiers. Indicates U.S.A. direct replacement type or similar type if available. Price 10 cents.*†

● RCA NUVISTOR TUBES FOR INDUSTRIAL AND MILITARY APPLICATIONS—1CE-280 (10⅞" x 3⅞")—16 pages. Describes unique features of nuvistors and includes tabular data, dimensional outlines, curves, terminal diagrams, and socket information. Price 25 cents.*†

○ TECHNICAL BULLETINS—Authorized information on RCA receiving tubes, transmitting tubes, and other tubes for communications and industry. Be sure to mention tube-type bulletin desired. Single copy on any type free on request.

Batteries

● RCA BATTERY MANUAL—BDG-111 (10⅞" x 8¾")—64 pages. Contains information on dry cells and batteries [carbon zinc (Leclanché), mercury, and alkaline types]. Includes battery theory and applications, detailed electrical and mechanical characteristics, a classification chart, dimensional outlines, and terminal connections on each battery type. Price 50 cents.*†

● RCA BATTERIES—BAT-134G (10⅞" x 8⅜")—24 pages. Technical data on 142 Leclanché, alkaline, and mercury-type dry batteries for radios, industrial applications, flashlights, lanterns, and photoflash service. Price 35 cents.*†

° Trade Mark Reg. U.S. Pat. Off.

* Prices shown apply in U.S.A. and are subject to change without notice.

† Suggested price.

Index to RCA Semiconductor Devices

Index

WHERE TO FIND DATA ON
RCA Semiconductor Devices

TRANSISTORS:

Active types—arranged in numerical-alphabetical-numerical sequence on pages 120 through 332

Discontinued types—charts on pages 333 and 334

SILICON RECTIFIERS:

Charts on pages 372 to 375

SILICON CONTROLLED RECTIFIERS:

Charts on pages 376 and 377

TUNNEL DIODES AND TUNNEL RECTIFIERS:

Charts on pages 378 and 379

OTHER DIODES:

Pages 378 and 379

COMPLETE INDEX TO INDIVIDUAL DEVICES ON PAGES 473 TO 476

RCA

transistor manual