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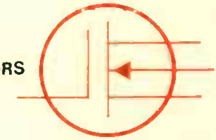
BIPOLAR TRANSISTORS

RCA Transistor Manual

MOS FIELD-EFFECT TRANSISTORS



THYRISTORS < SCR'S / TRIACS

SILICON RECTIFIERS AND OTHER DIODES

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

Dale L. Braun

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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, MOS field-effect transistors, thyristors (SCR's and triacs), silicon 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.

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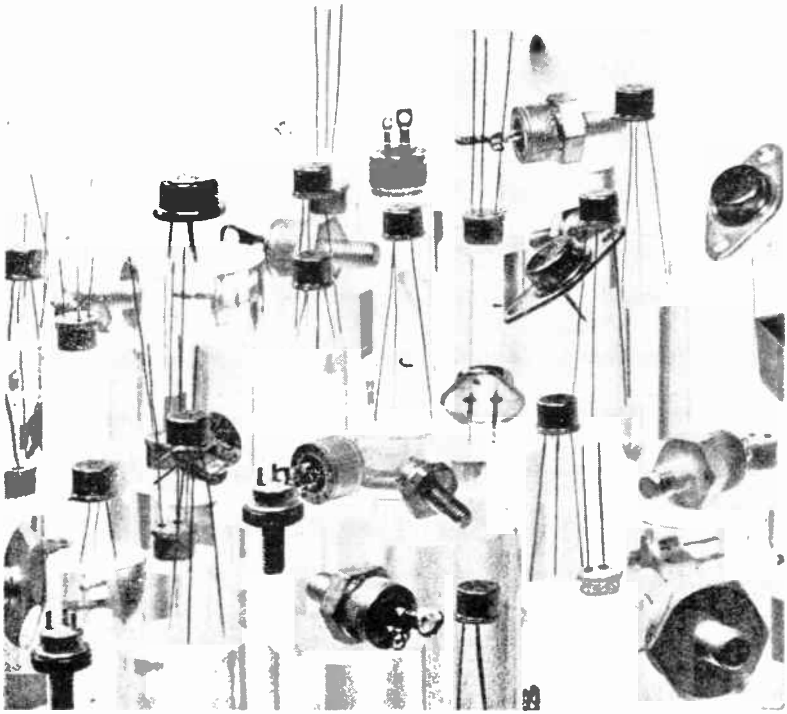
RCA Transistors, MOS Field-Effect Transistors, Thyristors (SCR's and triacs), and Semiconductor Diodes



for entertainment, industrial, and military applications

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

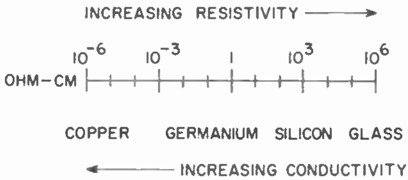


Figure 1. Resistivity of typical conductor, semiconductors, and insulator.

which reduce their resistivity to about 2 ohm-centimeters at room temperature (this resistivity decreases rapidly as the temperature rises).

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

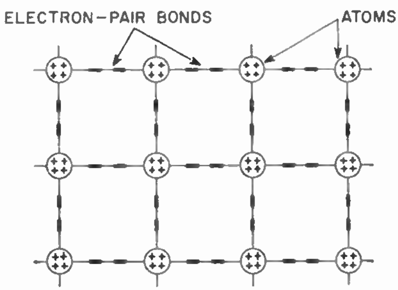


Figure 2. Crystal lattice structure.

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.

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

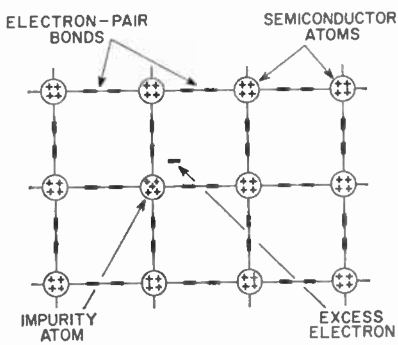


Figure 3. Lattice structure of n-type material.

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

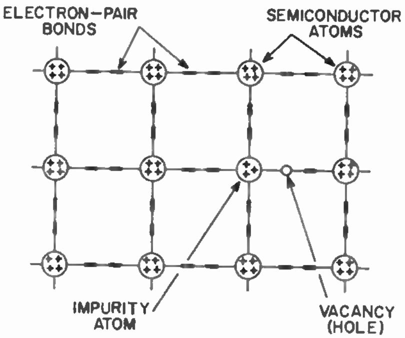


Figure 4. Lattice structure of p-type material.

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.

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

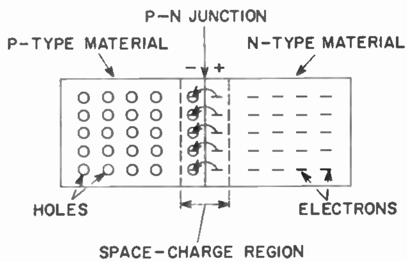


Figure 5. Interaction of holes and electrons at p-n junction.

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.

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.

Thermal energy causes charge carriers (electrons and holes) to diffuse from one side of the p-n junction to the other side; this flow of charge carriers is called **diffusion current**. As a result of the diffusion process, however, a potential gradient builds up across the space-charge region. This potential gradient can be represented, as shown in Fig. 6, by an imaginary battery connected across the p-n junction. (The battery symbol

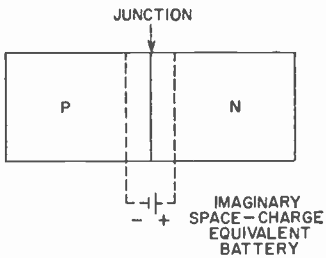


Figure 6. Potential gradient across space-charge region.

is used merely to illustrate internal effects; the potential it represents is not directly measurable.) The potential gradient causes a flow of charge carriers, referred to as **drift current**, in the opposite direction to the diffusion current. Under equilibrium conditions, the diffusion current is exactly balanced by the drift current so that the net current across the p-n junction is zero. In other words, when no external current or voltage is applied to the p-n junction, the potential gradient forms an **energy barrier** that prevents further diffusion of charge carriers across the junction. In effect, electrons from the n-type material that tend to diffuse across the junction are repelled by the slight negative charge induced in the p-type material by the potential gradient, and holes from the p-type material are repelled by the slight positive charge induced in the n-type material. The potential gradient (or energy barrier, as it is sometimes called), therefore, prevents total interaction between the two types of materials, and thus preserves the differences in their characteristics.

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

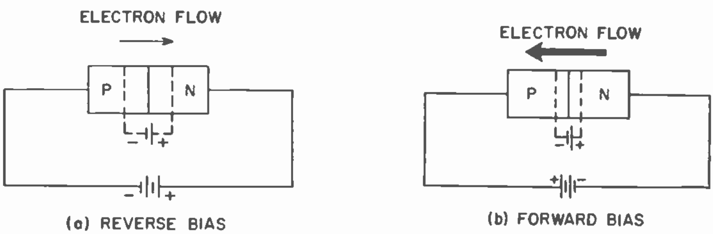


Figure 7. Electron current flow in biased p-n junctions.

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 terminal 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.

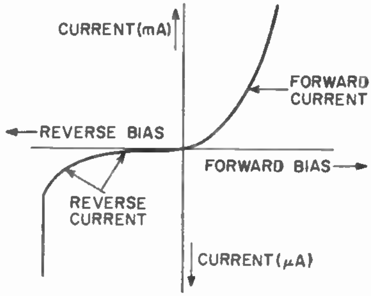


Figure 8. Voltage-current characteristic for a p-n junction.

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

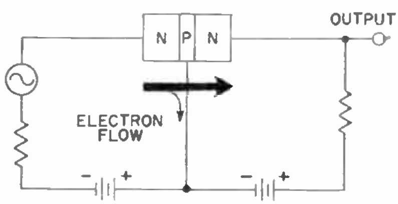


Figure 9. N-P-N structure biased for power gain.

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.

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"

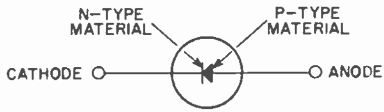


Figure 10. Schematic symbol for a semiconductor diode.

mentioned above; electron current flows in a direction opposite to the arrow.

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

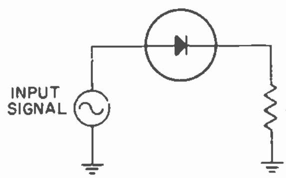


Figure 11. Simple diode rectifying circuit.

or no current flows during the negative half cycle.

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 several hundred amperes or more, and are capable of operation at voltages as high as 1000 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 two n-type semiconductor materials are arranged in a series array that consists of alternate n-type and p-type layers, 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. These devices, called **thyristors**, have control characteristics similar to those of thyratron tubes. The **silicon controlled rectifier (SCR)** and the **triac** are the most popular types of thyristors. Fig. 12 shows the schematic symbols for the SCR and triac. Characteristics

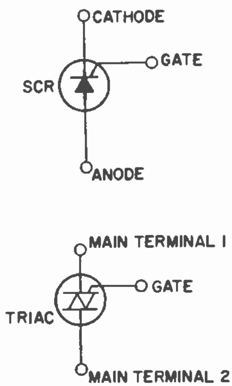


Figure 12. Schematic symbols for SCR's and triacs.

and applications of these devices are discussed in detail in the section on **Thyristors.**

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. 13a. In normal operation, the emitter-to-base junction is biased in the forward direction, and the collector-to-base junction in the reverse direction.

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.

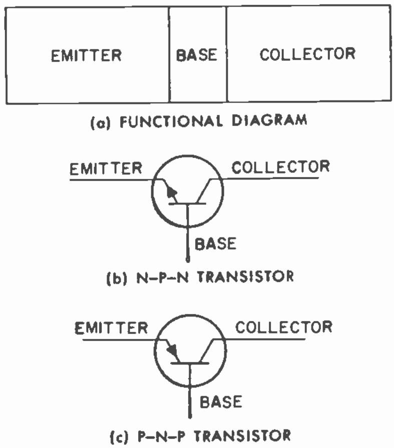


Figure 13. Functional diagram and schematic symbols for transistors.

In the n-p-n transistor shown in Fig. 13b, electrons flow from the emitter to the collector. In the p-n-p transistor shown in Fig. 13c, 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 transmitter 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 emitter and 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.**

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 various alloy, diffusion, and crystal-growth techniques.

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. Fig. 14a shows a cross-section of a grown-junction transistor.

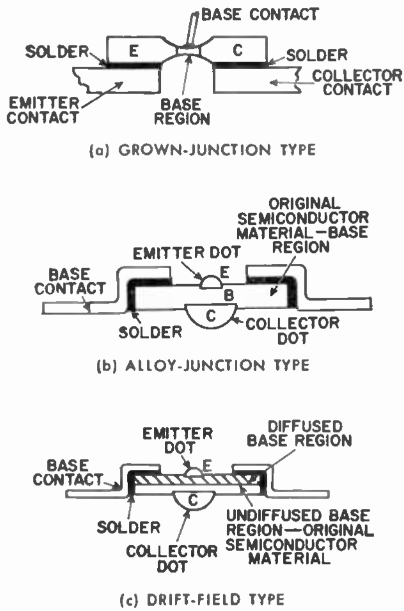


Figure 14. Cross-sections of junction transistors.

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. 14b.

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.

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. 14c. 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.

The **diffused-junction** transistor represents a major advance in transistor technology because increased control over junction spacings and impurity levels makes possible significant improvements in transistor performance capabilities. A cross-section of a **single-diffused** "hometaxial" structure is shown in Fig. 15a. Hometaxial transistors are fabricated by simultaneous diffusion of impurity from each side of a homogeneously doped base wafer. A **mesa** or flat-topped peak is etched on one side of the wafer in an intricate design to define the transistor emitter and expose the base region for connection of metal contacts. Large amounts of heat can be dissipated from a hometaxial structure through the highly conductive solder joint between the semiconductor material and the device package. This structure provides a very low collector resistance.

Double-diffused transistors have an additional degree of freedom for selection of the impurity levels and junction spacings of the base, emitter, and collector. This structure provides high voltage capability through a lightly doped collector region without compromise of the junction spacings which determine device frequency response and other important characteristics. Fig. 15b shows a typical double-diffused transistor; the emitter and base junctions are diffused into the same side of the original semiconductor wafer, which serves as the collector. A mesa is usually etched through the base region to reduce the collector area at the base-to-collector junction and to provide a stable semiconductor surface.

Double-diffused **planar** transistors

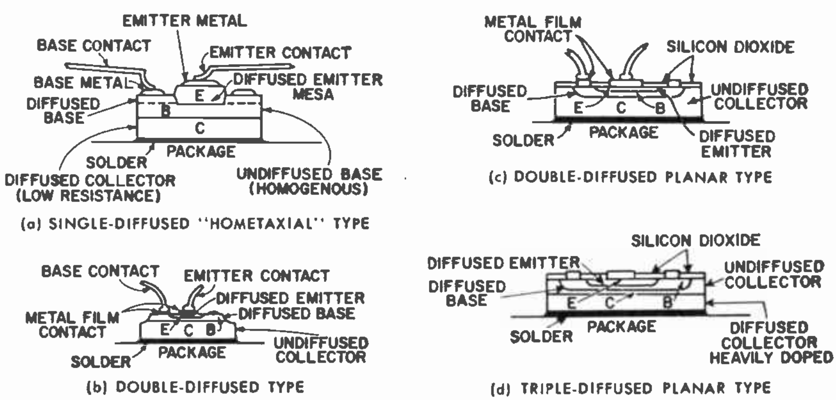


Figure 15. Cross-sections of diffused transistors.

provide the added advantage of protection or passivation of the emitter-to-base and collector-to-base junction surfaces. Fig. 15c shows a typical double-diffused planar transistor. The base and emitter regions terminate at the top surface of the semiconductor wafer under the protection of an insulating layer. Photolithographic and masking techniques are used to provide for diffusion of both base and emitter impurities in selective areas of the semiconductor wafer.

In **triple-diffused** transistors, a heavily doped region diffused from the bottom of the semiconductor wafer effectively reduces the thickness of the lightly doped collector region to a value dictated only by electric-field considerations. Thus, the thickness of the lightly doped or high-resistivity portion of the collector is minimized to obtain a low collector resistance. A section of a triple-diffused planar structure is shown in Fig. 15d.

Epitaxial transistors differ from diffused structures in the manner in which the various regions are fabricated. Epitaxial structures are grown on top of a semiconductor wafer in a high-temperature reaction chamber. The growth proceeds atom by atom, and is a perfect extension of the crystal lattice of the wafer on which it is grown. In the epitaxial-base transistor shown in Fig. 16a, a lightly doped base region is deposited by epitaxial techniques on a heavily doped collector wafer of opposite-type dopant. Photolithographic and masking techniques and a single impurity diffusion are used to define the emitter region. This structure offers the advantages of low collector resistance and easy control of impurity spacings and emitter geometry. A variation of this structure uses two epitaxial layers. A thin lightly doped epitaxial layer used for the collector is deposited over the original heavily doped semiconductor wafer prior to the epitaxial deposition of the base region. The collector epitaxial layer

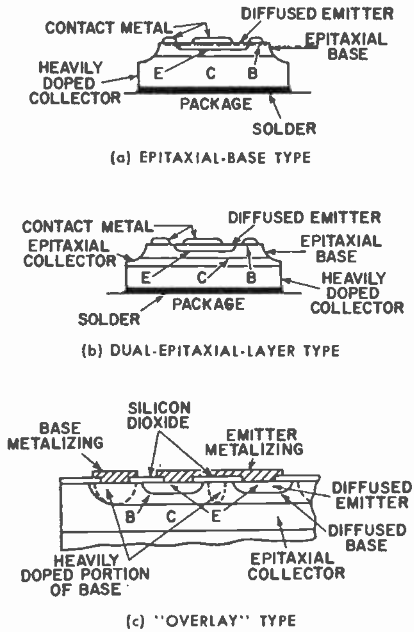


Figure 16. Cross-sections of epitaxial transistors.

is of opposite-type dopant to the epitaxial base layer. This structure, shown in Fig. 16b, has the added advantage of higher voltage ratings provided by the epitaxial collector layer.

The overlay transistor is a double-diffused epitaxial device which employs a unique emitter structure. A large number of separate emitters are tied together by diffused and metalized regions to increase the emitter edge-to-area ratio and reduce the charging-time constants of the transistor without compromise of current- and power-handling capability. Fig. 16c shows a section through a typical overlay emitter region.

After fabrication, individual transistor chips are mechanically separated and mounted on individual headers. Connector wires are then bonded to the metalized regions, and each unit is encased in plastic or a hermetically sealed enclosure. In power transistors, the wafer is usually soldered or alloyed to a solid metal header to provide for high thermal conductivity and low-resistance collector contacts, and low-resistance contacts are soldered or metal-bonded from the emitter or base metalizing contacts to the appropriate package leads. This packaging concept results in a simple structure that can be readily attached to a variety of circuit heat sinks and can safely withstand power dissipations of hundreds of watts and currents of tens of amperes.

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 input 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.

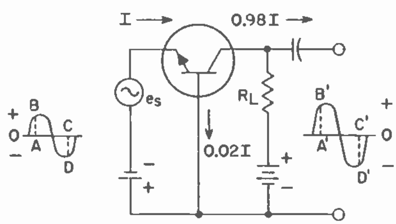


Figure 17. Common-base circuit configuration.

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-emitter) impedance is about 50 to 50,000 ohms. Power gains in the order of

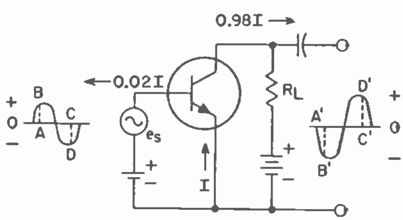


Figure 18. Common-emitter circuit configuration.

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.

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

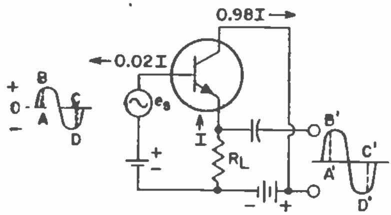


Figure 19. Common-collector circuit configuration.

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.

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

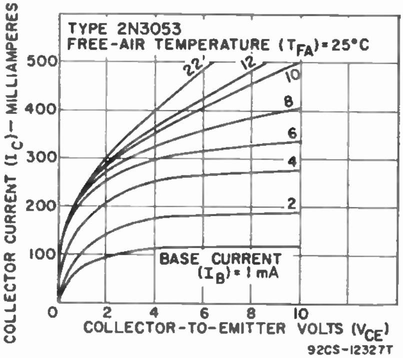


Figure 20. Collector-characteristic curves.

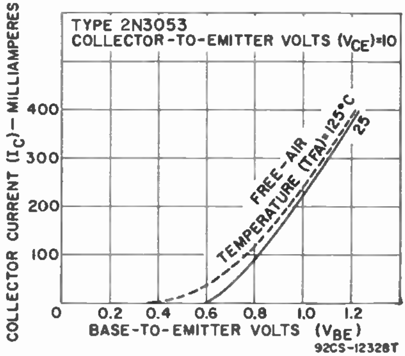


Figure 21. Transfer-characteristic curves.

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

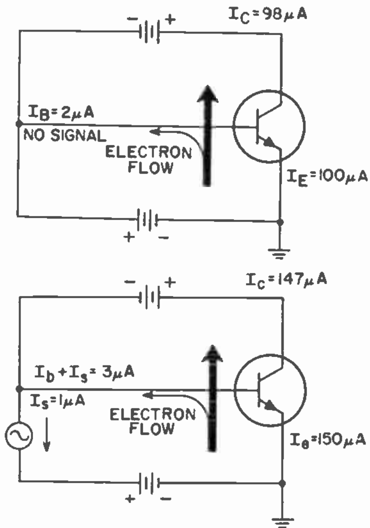


Figure 22. Electrode currents under no-signal and signal conditions.

which the value of alpha (for a common-base circuit) or beta (for a common-emitter circuit) drops to 0.707 times its one-kilohertz 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.

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

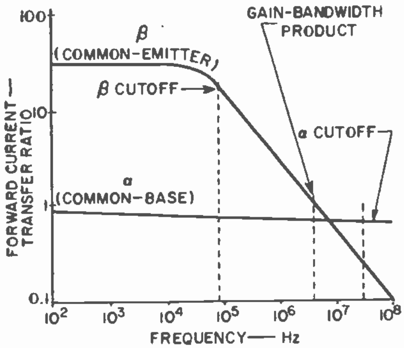


Figure 23. Forward current-transfer ratio as a function of frequency.

"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

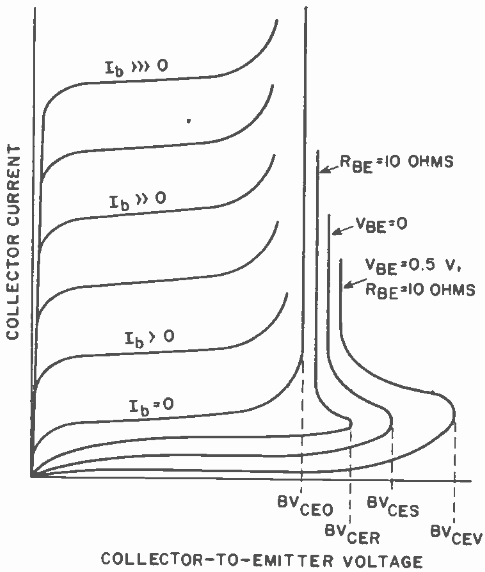


Figure 24. Typical collector-characteristic curves showing location of various breakdown voltages.

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

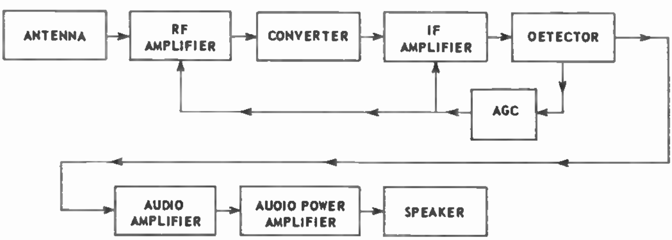


Figure 25. Simplified block diagram for a broadcast-band receiver.

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.

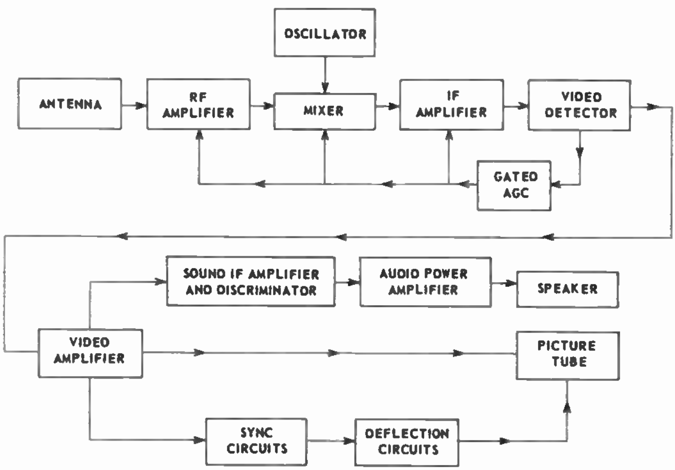


Figure 26. Simplified block diagram for a television receiver.

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 megahertz. The transmitting section of a communications system may also include frequency-multiplier circuits which raise the frequency of the developed rf signal as required.

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

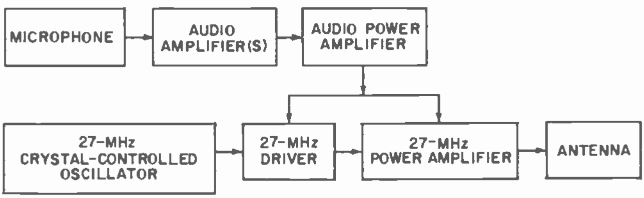


Figure 27. Simplified block diagram for the transmitter portion of a 27-MHz communications transceiver.

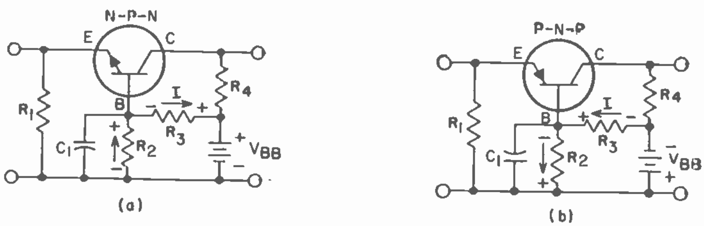


Figure 28. Biasing network for common-base circuit for (a) n-p-n and (b) p-n-p transistors.

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

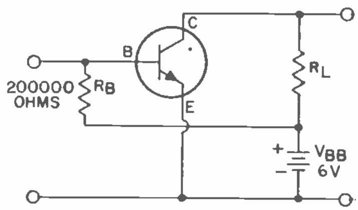


Figure 29. "Fixed-bias" arrangement for common-emitter circuit.

value of R_B was selected to provide a base current of 27 microamperes, as follows:

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

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.

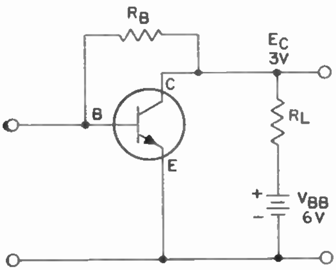


Figure 30. "Self-bias" arrangement for common-emitter circuit.

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

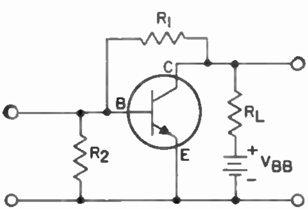


Figure 31. Bias network using voltage-divider arrangement for increased stability.

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.

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

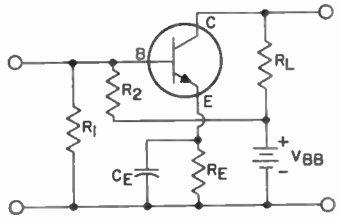


Figure 32. Bias network using emitter stabilizing resistor.

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.

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.

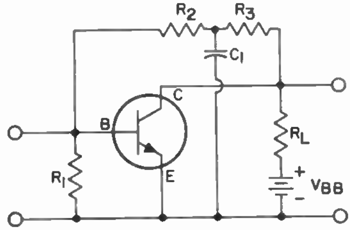


Figure 33. Bias network using split voltage-divider network.

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

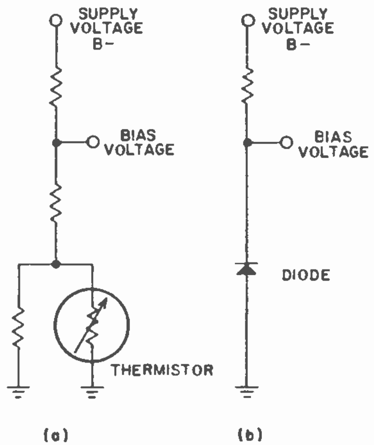


Figure 34. Bias networks including (a) a thermistor and (b) a temperature- and voltage-compensating diode.

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.

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).

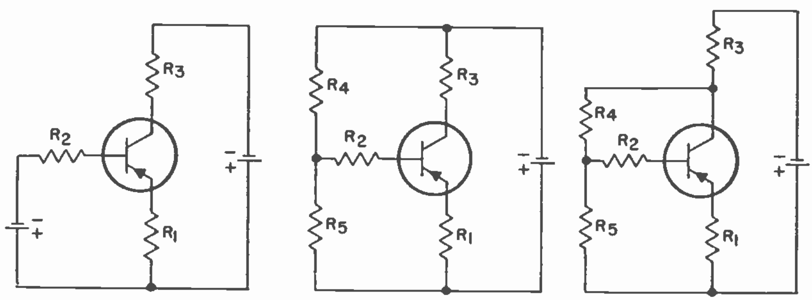
The calculated values of SF can then be used, together with the appropriate values of beta and r_b' (base-connection resistance), to determine suitable resistance values for the transistor circuit. Fig. 35 shows equations for SF in terms of resistance values for three typical circuit configurations. 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.

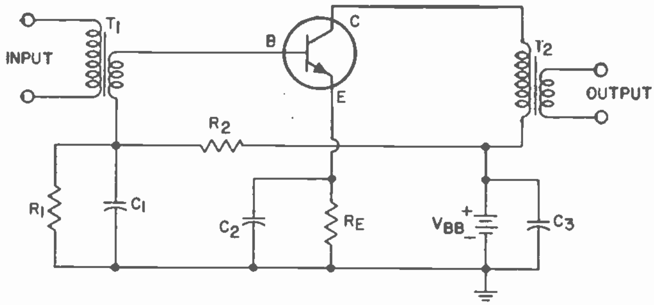


Figure 36. Transformer-coupled common-emitter stage.

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

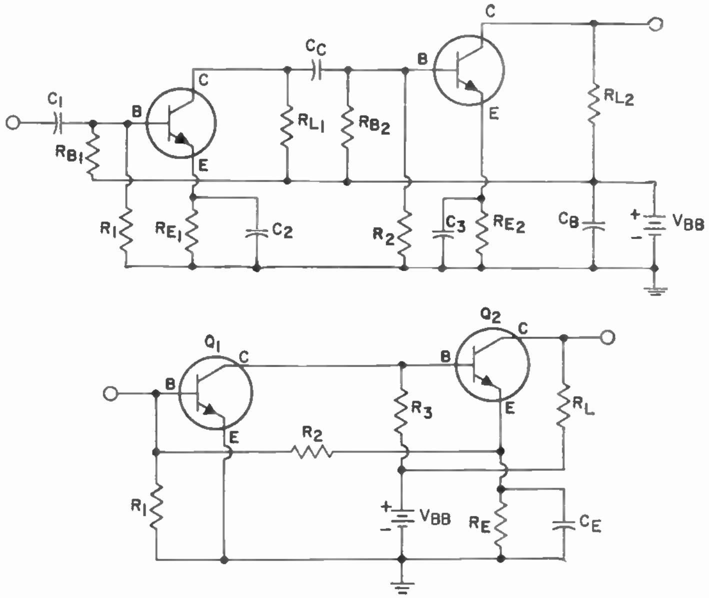


Figure 37. (a) Two-stage resistance-capacitance-coupled circuit and (b) two-stage direct-coupled circuit.

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-

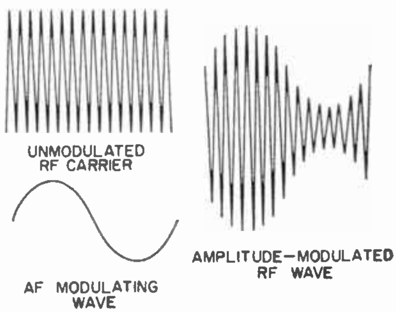


Figure 38. Waveforms showing effect of amplitude modulation on an rf wave.

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

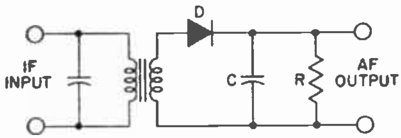


Figure 39. Basic diode detector circuit.

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.

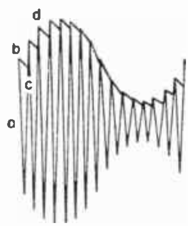


Figure 40. Waveform showing modulated rf input (light line) and output voltage (heavy line) of diode-detector circuit of Figure 39.

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-

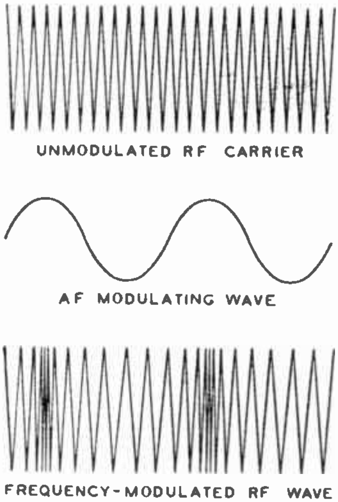


Figure 41. Waveforms showing effect of frequency modulation on an rf wave.

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

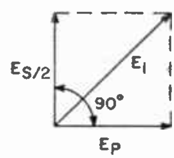


Figure 43. Diagram illustrating phase shift in double-tuned transformer at resonance.

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

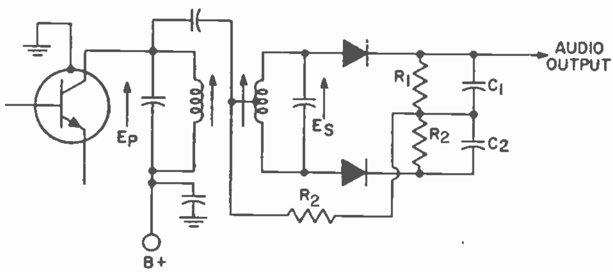


Figure 42. Balanced phase-shift discriminator circuit.

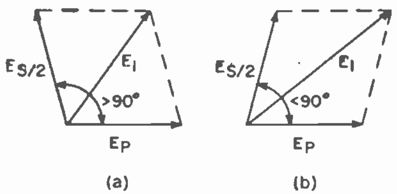


Figure 44. Diagrams illustrating phase shift in double-tuned transformer (a) below resonance and (b) above resonance.

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

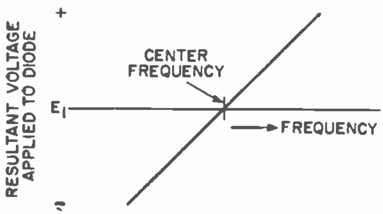


Figure 45. Diagram showing resultant voltage E_1 in Figure 43 as a function of frequency.

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

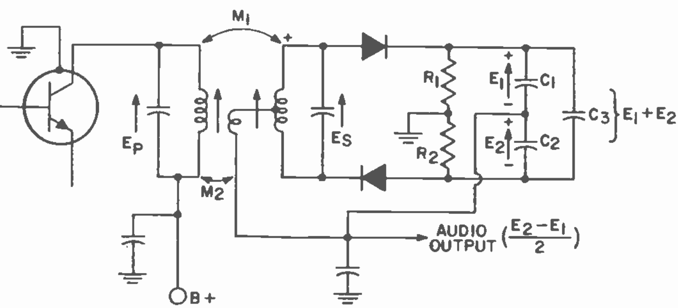


Figure 46. Ratio-detector circuit.

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 Hz. 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 kHz.

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

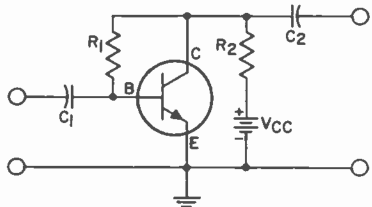


Figure 47. Simple low-level class A amplifier.

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.

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".

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.

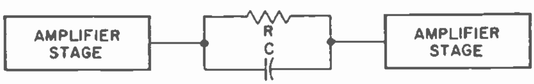


Figure 48. Simple RC frequency-compensation network.

* 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. 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.

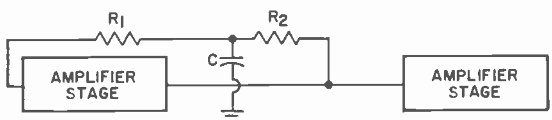


Figure 49. Negative-feedback frequency-compensation network.

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.

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

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.

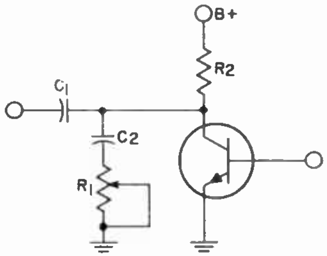


Figure 50. Simple tone-control network for fixed tone compensation or equalization.

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.

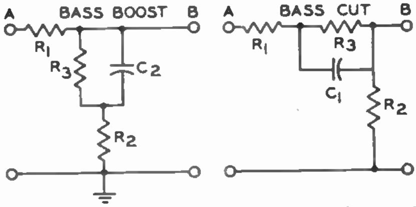


Figure 52. Simplified representations of bass-control circuit at extreme ends of potentiometer.

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,

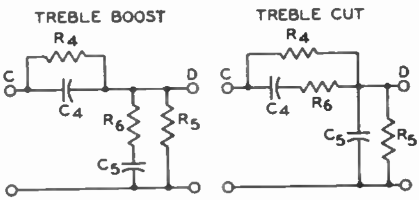


Figure 53. Simplified representations of treble-control circuit at extreme ends of potentiometer.

R_4 is bypassed by the high frequencies and the voltage-divider point D is placed closer to C. In the cut posi-

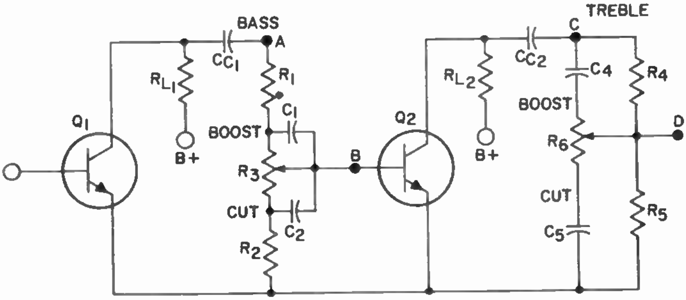


Figure 51. Two-stage tone-control circuit incorporating separate bass and treble controls.

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.

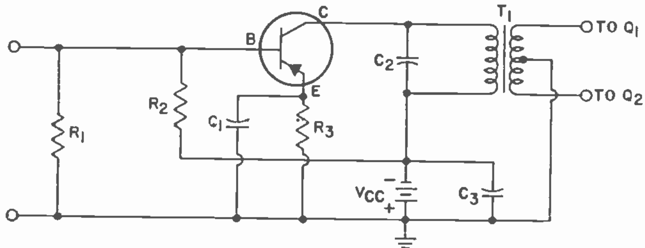


Figure 54. Driver stage for push-pull output circuit.

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-

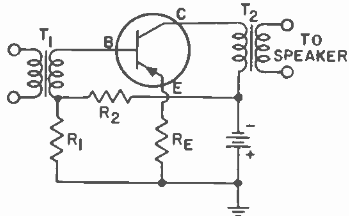


Figure 55. Class A power-amplifier circuit.

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.

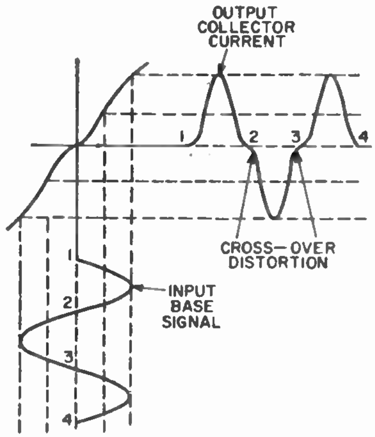


Figure 56. Waveforms showing cause of cross-over distortion.

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

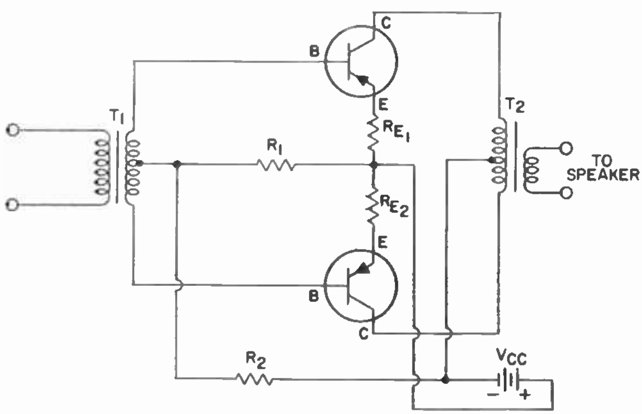


Figure 57. Class B push-pull audio-amplifier circuit.

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.

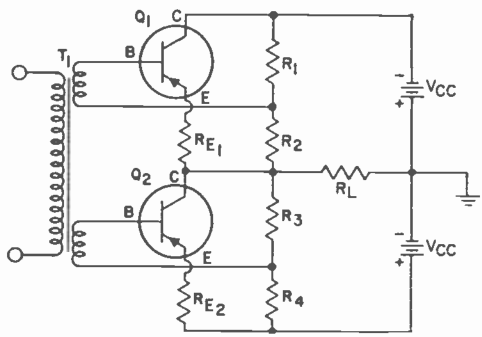


Figure 58. Single-ended class B circuit.

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.

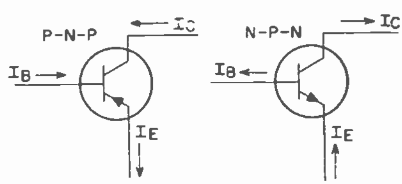


Figure 59. Electron-current flow in p-n-p and n-p-n transistors.

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

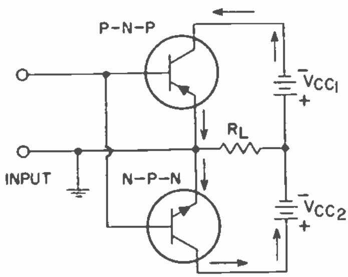


Figure 60. Basic complementary-symmetry circuit.

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 cross-over 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,

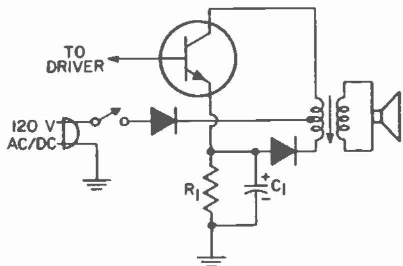


Figure 62. Alternate method for protection against transient voltages.

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

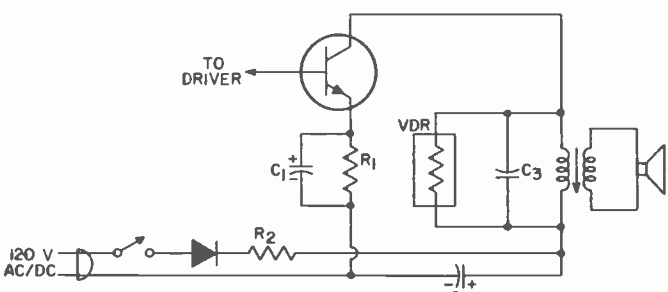


Figure 61. Basic audio output stage for line-operated equipment.

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.

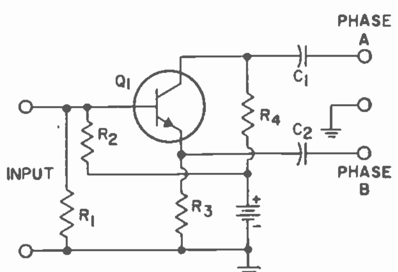


Figure 63. Split-load phase inverter stage.

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.

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

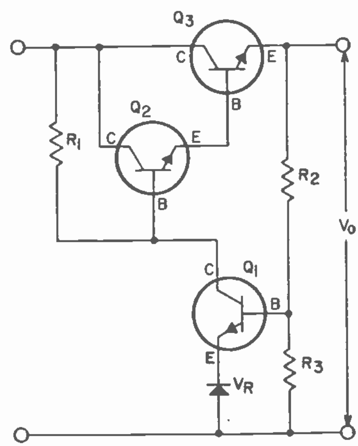


Figure 64. Typical series regulator circuit.

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 difference 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.

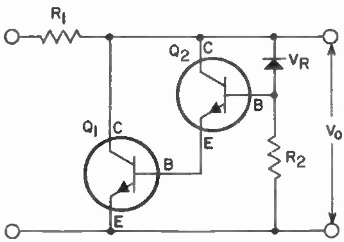


Figure 65. Typical shunt regulator circuit.

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

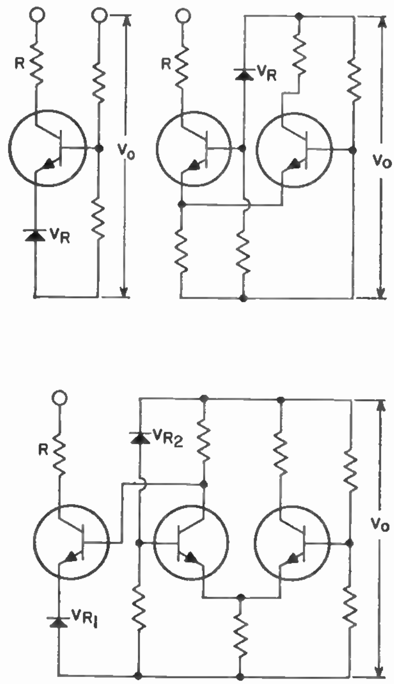


Figure 67. Typical differential amplifier circuits.

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

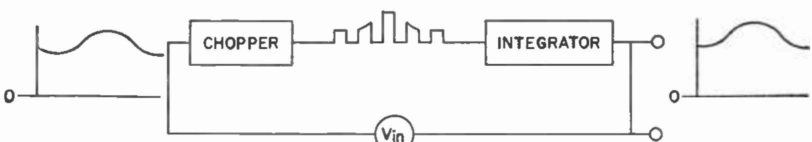


Figure 66. Block diagram showing action of "chopper" circuit.

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.

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

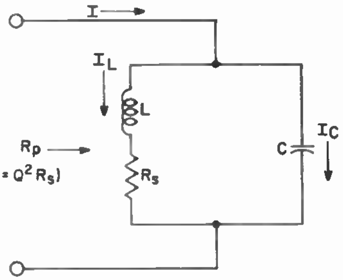


Figure 68. Simple parallel resonant circuit.

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

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

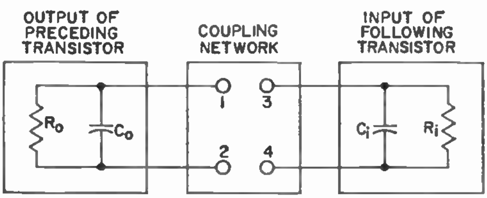


Figure 69. Equivalent output and input circuits of transistors connected by a coupling network.

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:

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

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.

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

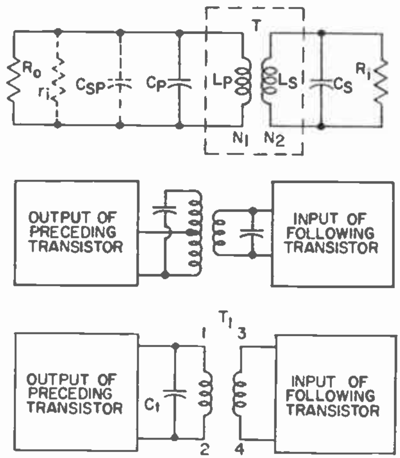


Figure 70. Equivalent circuits for transformer-coupling networks: (a) having tuned primary winding; (b) using inductive coupling; (c) using tap on primary winding.

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-

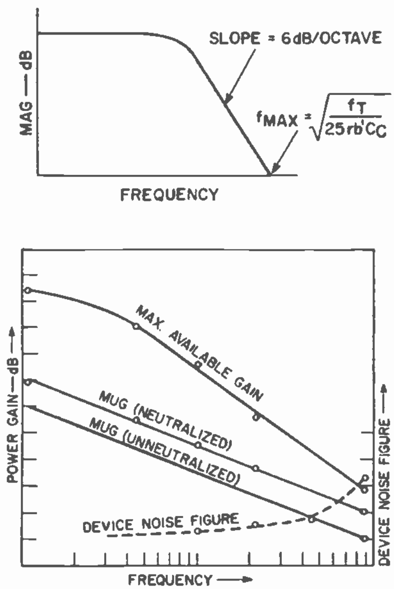


Figure 71. Maximum available gain MAG, maximum usable gain MUG, and noise figure NF as functions of frequency.

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 kHz) 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 kHz. 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-kHz signal from the input tuned circuit to the emitter. Resistor R_2, which is bypassed for 455 kHz by capacitor C_4, is the emitter dc stabilizing resistor. The amplified signal

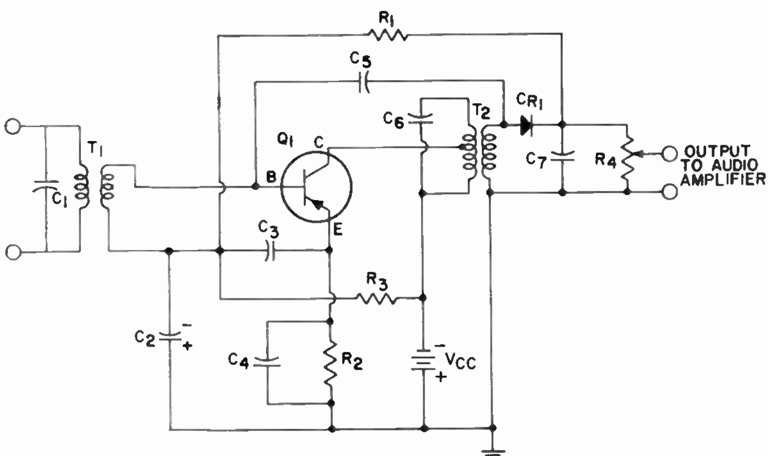


Figure 72. Neutralized if-amplifier and second-detector circuit.

from the transistor is developed across the parallel resonant circuit (tuned to 455 kHz) 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

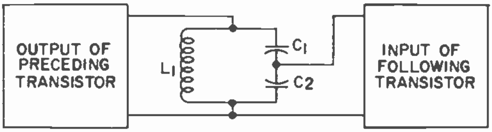


Figure 73. Single-tuned coupling network using capacitive division.

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

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.

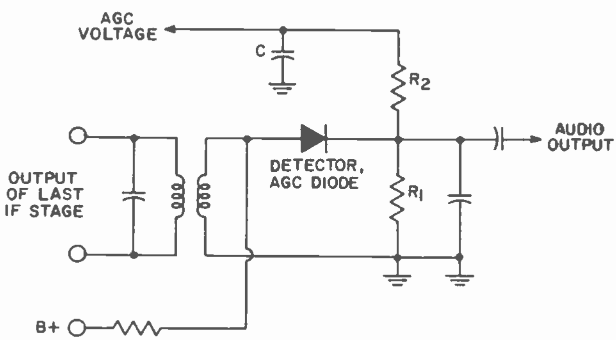


Figure 74. Simple reverse agc circuit.

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 hertz) to high frequencies (tens of megahertz) 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

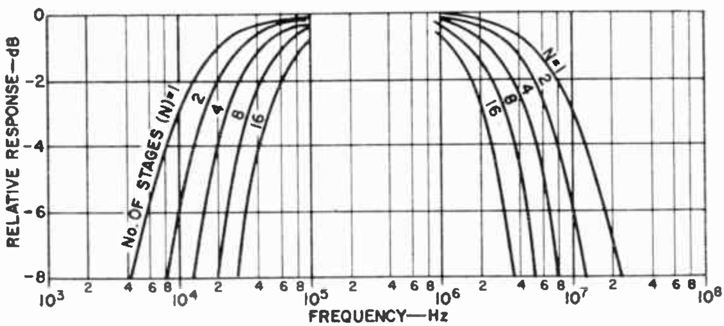


Figure 75. Amplitude response characteristics of various numbers (N) of identical uncompensated amplifiers.

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

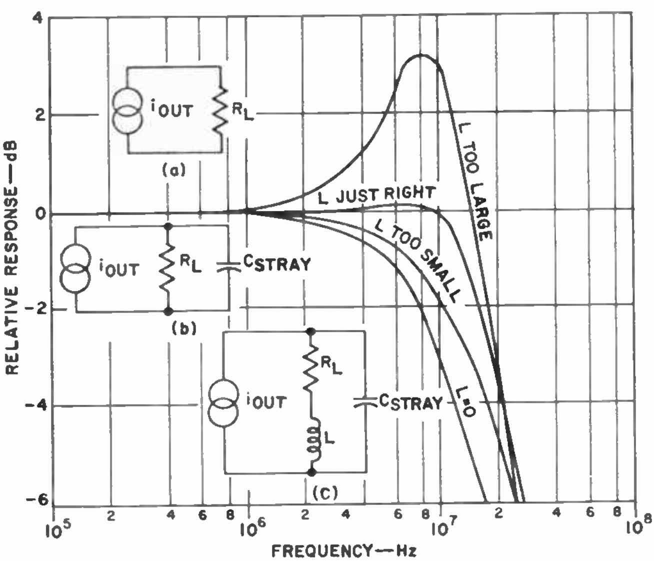


Figure 76. Equivalent circuits and frequency response of uncompensated and shunt-peaked amplifiers.

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.

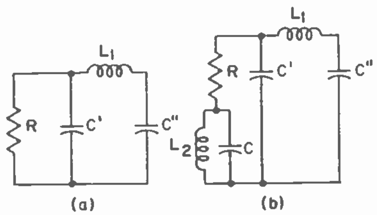


Figure 77. Circuits using (a) series peaking, and (b) both self-resonant shunt peaking and series peaking.

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 1 MHz, and if a total gain variation of plus 1 dB and minus 3 dB is allowed, the bandwidth of the amplifier is 0.5 MHz without compensation. Shunt peaking raises the bandwidth to 1.3 MHz. Self-resonant shunt peaking raises it to 1.5 MHz. An infinitely complicated Self-resonant shunt peaking raises it could raise it to 2 MHz. If the distribution of capacitance permits it, series peaking alone can provide a bandwidth of about 2 MHz, while a combination of shunt and series peaking can provide a bandwidth of approximately 2.8 MHz. 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 MHz.

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 MHz 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

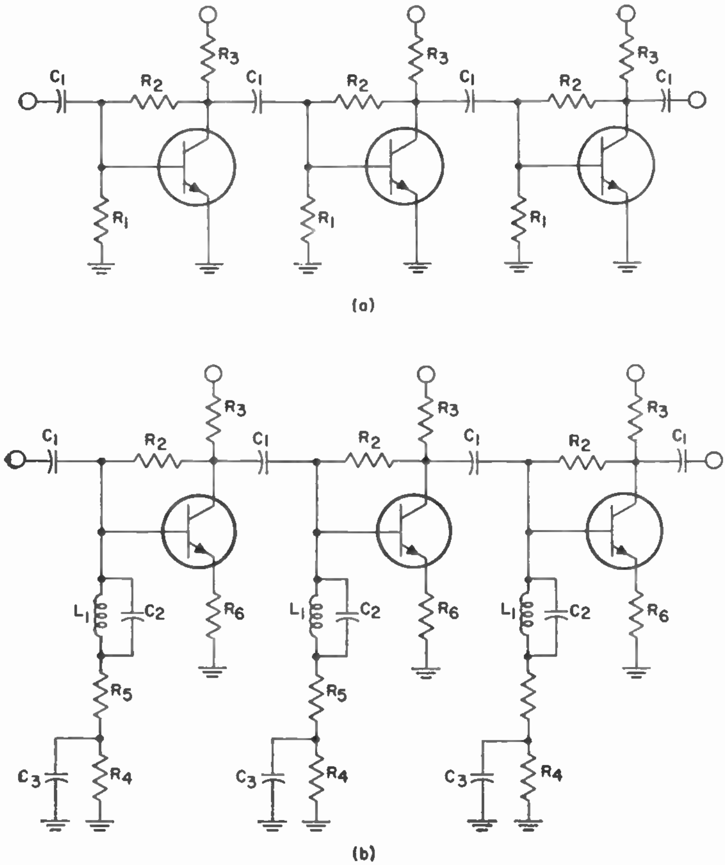


Figure 78. (a) Uncompensated and (b) compensated versions of three stages of a multistage wideband amplifier.

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_5, the low-frequency gain is increased because the resistor no longer heavily shunts the transistor input. Selection of the proper value for C_8 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

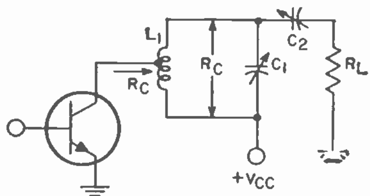


Figure 79. Output-coupling network using parallel tuned circuit.

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.

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 establshed 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

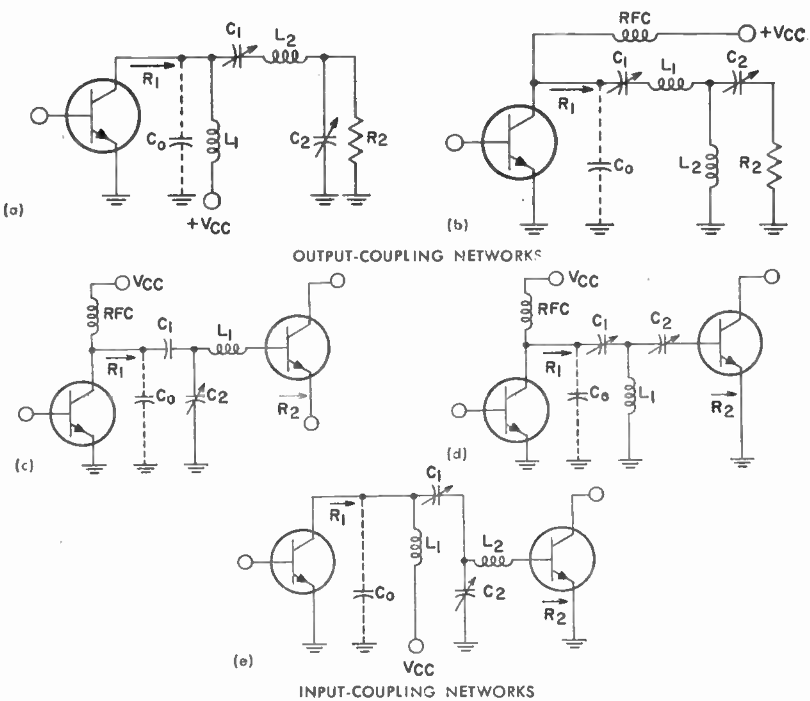


Figure 80. Coupling networks for high-frequency power amplifiers.

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. 80 also shows 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. 80c, 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 $(C_i + C_o)$. Capacitors C_1 and C_o provide the impedance matching to the collector of the driver stage.

Fig. 80d 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 combination of $(C_1 + C_o)$ and C_2.

The circuits shown in Figs. 80c and 80d require the collector of the driving transistor to be shunt fed by a high-impedance rf choke. Fig. 80e 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

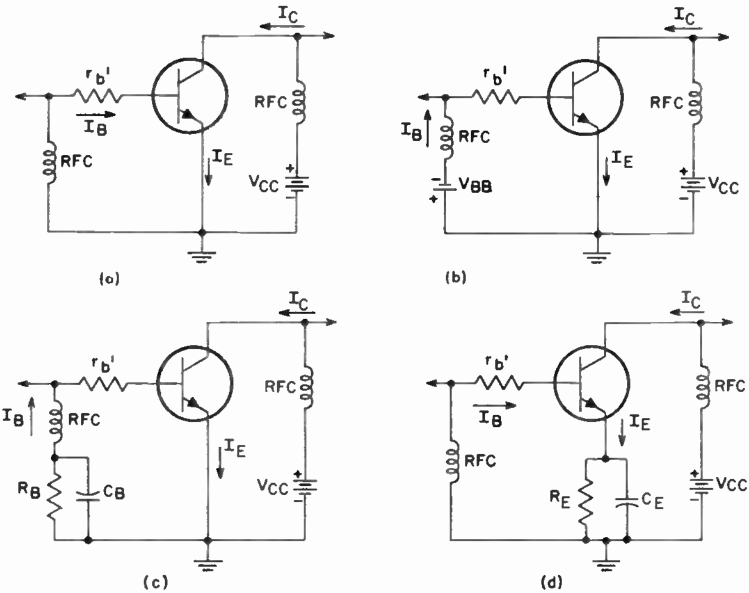


Figure 81. Biasing networks for high-frequency power amplifiers.

output transistor is series tuned.

As mentioned previously, the base-to-emitter junction of a transistor is reverse-biased for class C operation. Fig. 81 shows several ways of obtaining this reverse bias. In Fig. 81a, 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. 81b 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. 81c, 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. 81d 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 MHz. 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. 82 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. 82 operating at 28 volts

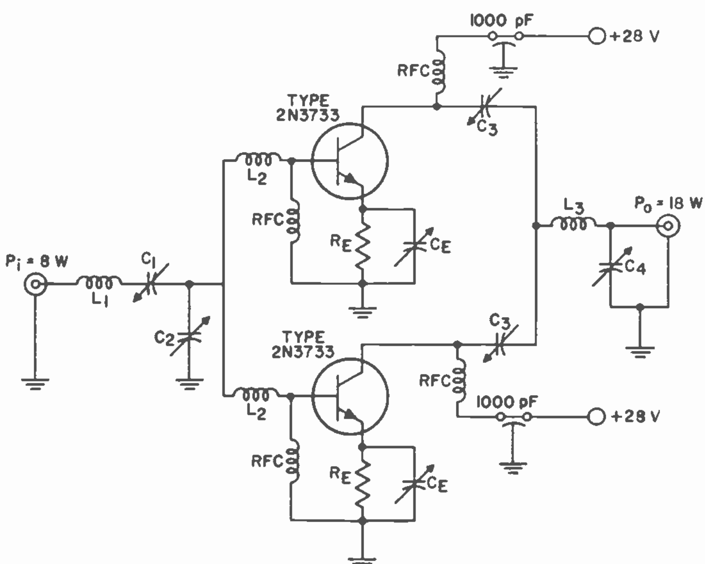


Figure 82. High-frequency power amplifier using two 2N3733 overlay transistors in a parallel arrangement.

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 $= 2 \times 0.25$). 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.

Nonlinearities in an amplifier generate intermodulation (IM) distortion. The important IM products are those close to the desired output frequency which occur within the pass band and cannot be filtered out by normal tuned circuits. If f_1 and f_2 are the two desired output signals, third-order IM products take the form $2f_1 - f_2$ and $2f_2 - f_1$. The matching third-order terms are $2f_1 + f_2$ and $2f_2 + f_1$, but these matching terms correspond to frequencies near the third-harmonic output of the amplifier and are greatly attenuated by tuned circuits. Only odd-order distortion products appear near the fundamental frequency. The frequency spectrum shown in Fig. 83a illustrates the frequency relationship of some distortion products to the test signals f_1 and f_2. All such products are either

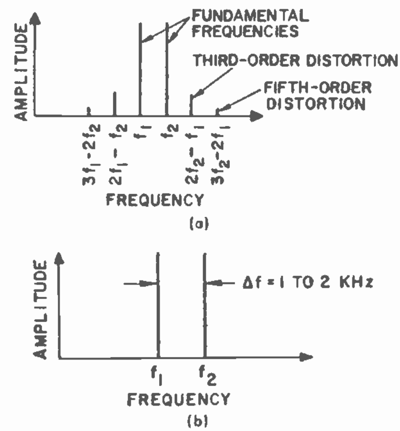


Figure 83. Frequency spectra showing (a) relationship of distortion products to test signals f_1 and f_2, and (b) typical two-tone signal without distortion.

in the difference-frequency region or in the harmonic regions of the original frequencies. Tuned circuits or filters following the nonlinear elements can effectively remove all products generated by the even-order components of curvature. Therefore, the second-order component that produces the second harmonic does not produce any distortion in an SSB linear amplifier. This factor explains why class AB and class B rf amplifiers can be used as linear amplifiers in SSB equipment even though the collector-current pulses contain large amounts of second-harmonic current. In a wideband linear application, however, it is possible for harmonics of the operating frequency to occur within the pass band of the output circuit. Biasing the output transistor further into class AB can greatly reduce the undesired harmonics. Operation of two transistors in the push-pull configuration can also result in cancellation of even harmonics in the output.

The signal-to-distortion ratio (in dB) is the ratio of the amplitude of one test frequency to the amplitude of the strongest distortion product. A signal-to-distortion specification of —30 dB means that no distortion product will exceed this value for a two-tone signal level up to the peak envelope power (PEP) rating of the amplifier.

For an amplifier to be linear, the output voltage must be directly proportional to the input voltage for all signal amplitudes. Because a single-frequency signal in a perfectly linear single-sideband system remains unchanged at all points in the signal path, the signal cannot be distinguished from a cw signal or from an unmodulated carrier of an AM transmitter. To measure the linearity of an amplifier, it is necessary to use a signal that varies in amplitude. In the method commonly used to measure nonlinear distortion, two sine-wave voltages of different frequencies are applied to the amplifier input simultaneously, and the sum, difference, and various combination frequencies that are produced by the nonlinearity of the amplifier are observed. A frequency difference of 1 to 2 kHz is used widely for this purpose. A typical two-tone signal without distortion, as displayed on a spectrum analyzer, is shown in Fig. 83b. The resultant signal envelope varies continuously between zero and maximum at an audio-frequency rate. When the signals are in phase, the peak of the two-frequency envelope is limited by the voltage and current ratings of the transistor to the same power rating as that for the single-frequency case. Because the amplitude of each two-tone frequency is equal to one-half the cw amplitude under peak power condition, the average power of one tone of a two-tone signal is one-fourth the single-frequency power. For two tones, conversely, the PEP rating of a single-sideband system is two times the average power rating.

Nonlinearity caused by the voltage-current characteristic of the base-to-emitter junction affects distortion at low power levels. Third-order distortion is improved by use of a higher bias current, as shown in Fig. 84.

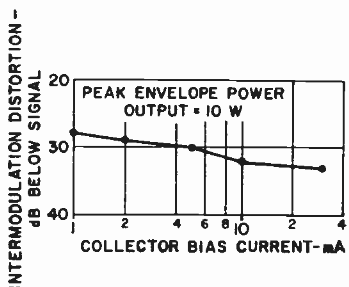


Figure 84. Intermodulation distortion as a function of collector current for a typical power transistor.

If collector bias current is set too high initially, in an attempt to improve linearity at low power-output levels, the linear region of the collector characteristic is reduced. As a result, distortion because of saturation occurs much sooner. The controlling factor in determining the proper bias-current level is usually the maximum distortion that can be tolerated at a given power output. For a given transistor type, the bias point that yields the best compromise between linear performance and good collector efficiency must be determined experimentally.

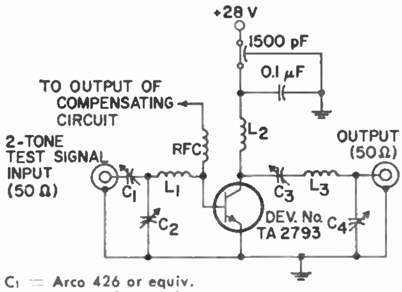
Most high-frequency power transistors are designed for class C operation. The forward biasing of such devices for class AB operation places them in a region where second breakdown may occur. The susceptibility of a transistor to second breakdown is frequency-dependent. Experimental results indicate that the higher the frequency response of a transistor, the more severe the second-breakdown limitation becomes. For an rf power transistor, the second-breakdown energy level at high voltage (greater than 20 volts) becomes a small fraction of its rated maximum power dissipation.

The 2N5070 is a power transistor designed especially for use as a linear amplifier. Together with its high-frequency response, the transistor can be forward-biased for class AB operation. The ability of the transistor to withstand second breakdown is improved by subdividing the emitter into many small sites and resistively ballasting the individual sites. Typical SSB performance of a 2N5070 for —30 dB distortion is tabulated below for 30-MHz operation with the transistor biased at a quiescent collector current of 10 milliamperes:

P_o (PEP) at 28V = 90 W
Power Gain = 13 dB
Collector Efficiency = 50%

The common-emitter configuration should be used for power amplifiers because of its stability and high power gain. Tuning is less critical, and the amplifier is less sensitive to variations in parameters among transistors. The class AB mode is used to obtain low intermodulation distortion. Neither resistive loading nor neutralization is used to improve linearity because of the resulting drastic reduction in power gain; furthermore, neutralization is diffcult for large signals because parameters such as output capacitance and output and input impedances vary nonlinearly over the limits of signal swing.

Fig. 85 shows a schematic diagram of a narrow-band, high-power, 30-MHz amplifier. The amplifier provides an output power in excess of



C1 = Arco 426 or equiv.
C2 = Arco 427 or equiv.
C3 = 80-480 pF, Arco 469 or equiv.
C4 = 140-680 pF, Arco 466 or equiv.
L1 = 3 turns No.14 wire, ¼" ID, ½" long
L2 = 3 turns No.10 wire, ½" ID, ⅜" long
L3 = 3½ turns No.10 wire, ⅝" ID, ½" long

Figure 85. Narrow-band, high-power, 30-MHz amplifier.

30 watts PEP from a 28-volt power supply.

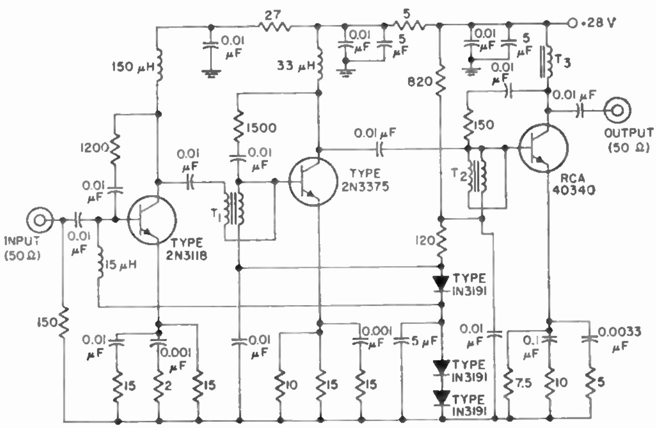
Fig. 86 shows a 2-to-30-MHz wide-band linear amplifier that uses other types of RCA rf transistors. At 5 watts (PEP) output, IM distortion products are more than 40 dB below one tone of a two-tone signal. Power gain is greater than 40 dB.

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



T1, T2 = 18 turns, twisted pair, No.28 enamel wire on Q1 CF 102 form
T3 = 50 turns No.30 enamel wire on CF102 Q1 form

L1 = 3½ turns No. 14 wire, ¼" ID, ⅜" long
L2 = 5 turns No.10 wire, ½" ID, ⅝" long
L3 = 4 turns No.10 wire, ½" ID, ½" long

Figure 86. 2-to-30-MHz linear power amplifier.

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 Hz.

The geometry of the standard odd-line interlaced scanning pattern is illustrated in Fig. 87. 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.

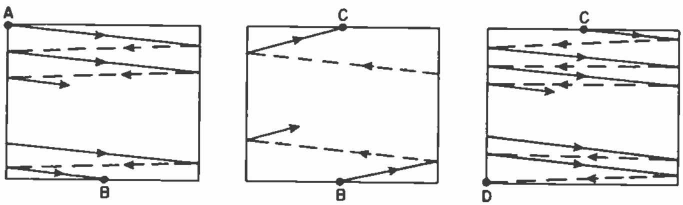


Figure 87. The odd-line interlaced scanning procedure.

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. 87 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 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. 88 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

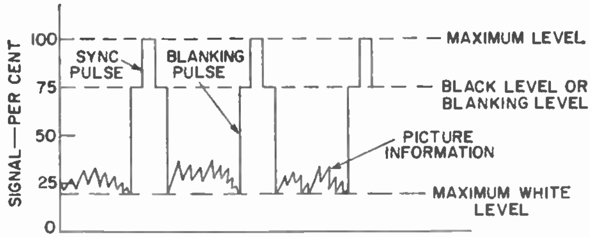


Figure 88. Detected video signal.

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. 88. 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. 89. 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. 89a, 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. 89b, the base-emitter junction of the transistor functions in the same manner as the diode in Fig. 89a, 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 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. 90. The horizontal sync pulses have a repetition rate of 15,750 per second (one for each horizontal line) and a pulse width

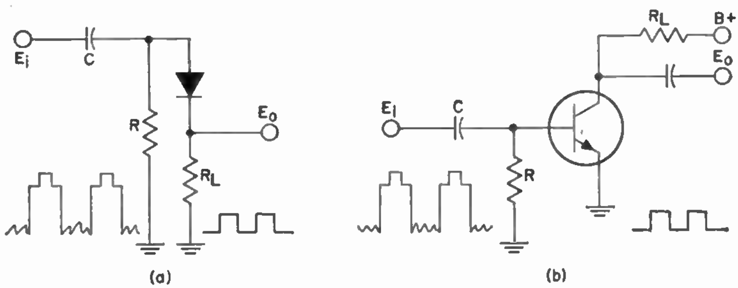


Figure 89. Sync-separator circuits using (a) diode, and (b) a transistor.

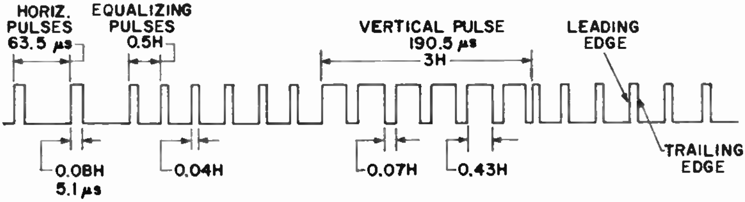


Figure 90. Waveform of TV synchronizing pulses (H = horizontal line period of 1/15,750 seconds, or 63.5 µs).

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. 91, 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 peak for the trailing edge of every pulse. One polarity is produced by the charging current for the leading

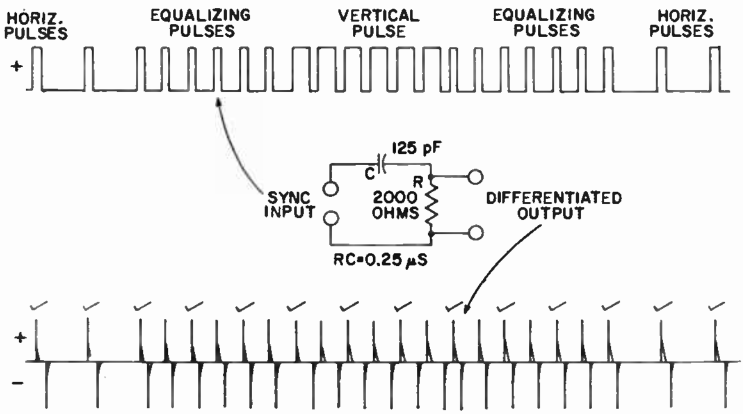


Figure 91. Separation of the horizontal sync signals from the total sync by a differentiating circuit.

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. 91 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. 91, 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. 92 shows the general circuit configuration used, together with the input and output signals for both odd and even fields. 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. 92, therefore, only vertical synchronization information appears at the output.

The vertical synchronizing pulses are repeated in the total sync signal

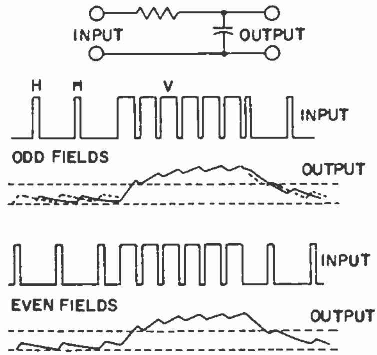


Figure 92. Separation of vertical sync signals from the total sync for odd and even fields with no equalizing pulses. (Dashed line indicates triggering level for vertical scanning generator.)

at the field frequency of 60 per second. Therefore, the integrated output voltage across the capacitor of the RC circuit of Fig. 92 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. 93a. 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.

Although the basic circuit of Fig. 93a 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.

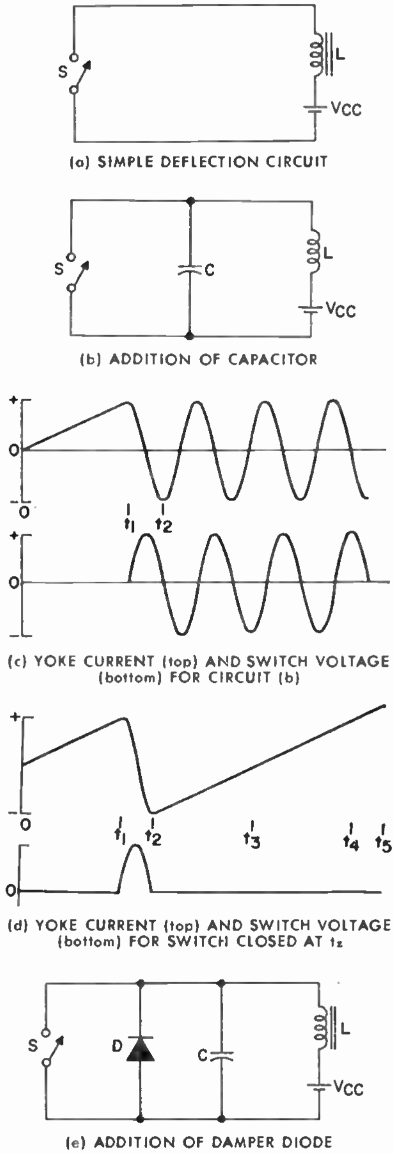


Figure 93. Development of horizontal-deflection circuit.

If a capacitor is placed across the switch, as shown in Fig. 93b, 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. 93c. 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 $1/(2\pi\sqrt{LC})$.

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. 93d shows the yoke-current and switch-voltage waveforms for this new condition.

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. 93b 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. 93e, the diode acts as a closed switch as soon as the capacitor voltage reverses slightly. 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 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

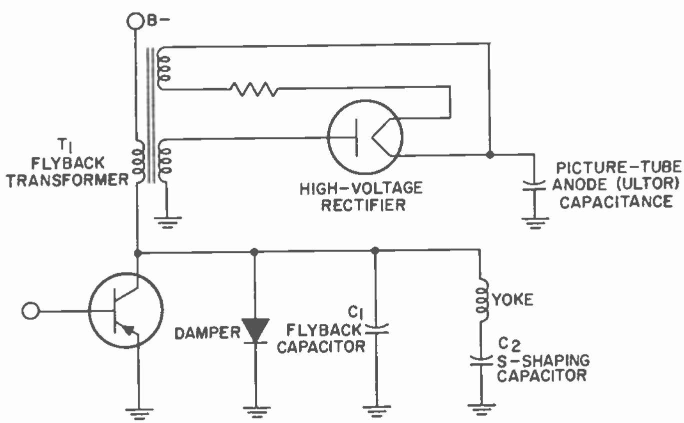


Figure 94. Simple transistor horizontal-deflection circuit.

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 kHz 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 Hz), and a need for controlled linearity. The equivalent low-frequency response for a 10-per-cent deviation from linearity is 1 Hz. 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 1 Hz. 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.

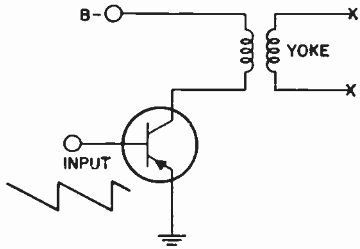


Figure 95. Simple vertical-deflection circuit.

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.

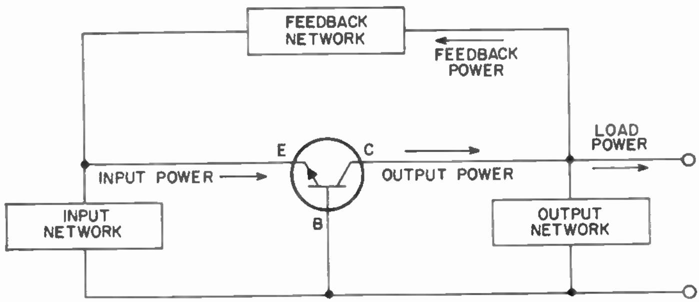


Figure. 96 Block diagram of transistor oscillator showing division of output power.

LC Resonant Feedback Oscillators

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

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 per-

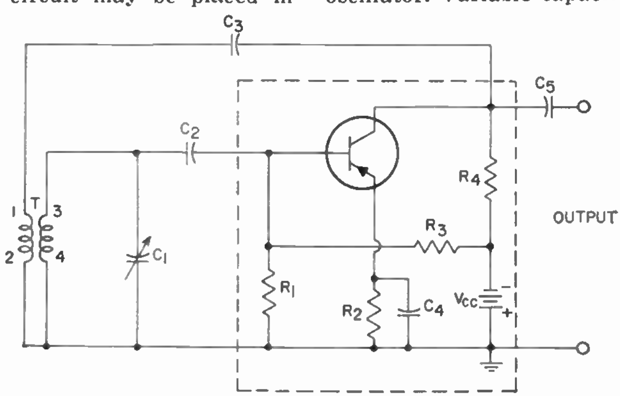


Figure 97. Tuned-base oscillator.

mits 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

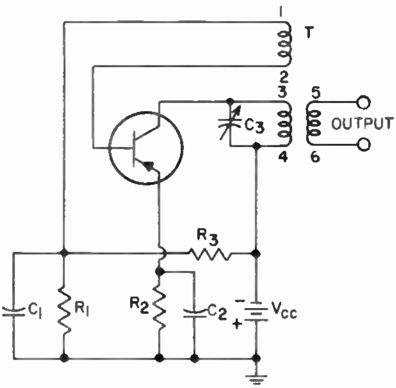


Figure 98. Tuned-collector oscillator.

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 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, 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

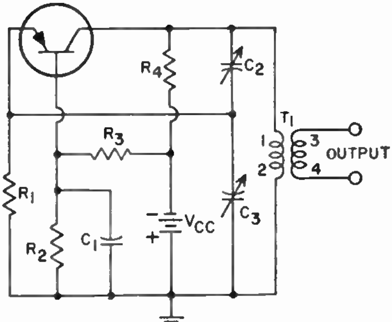


Figure 99. Transistor Colpitts oscillator.

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_2 and C_3, 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

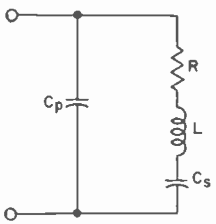


Figure 100. Equivalent circuit of quartz crystal.

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 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

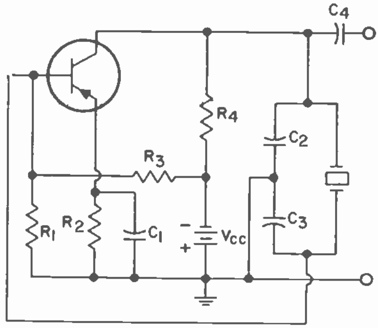


Figure 101. Pierce-type transistor crystal oscillator.

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.

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.

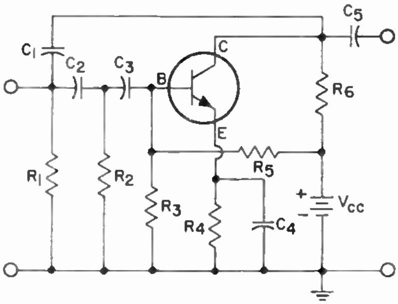


Figure 102. Transistor RC phase-shift oscillator.

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.

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

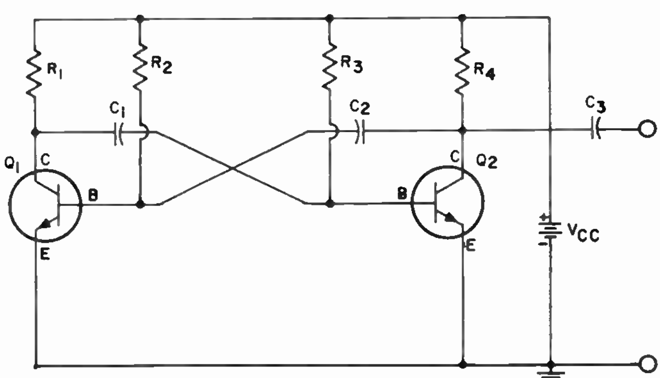


Figure 103. RC-coupled common-emitter multivibrator.

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.

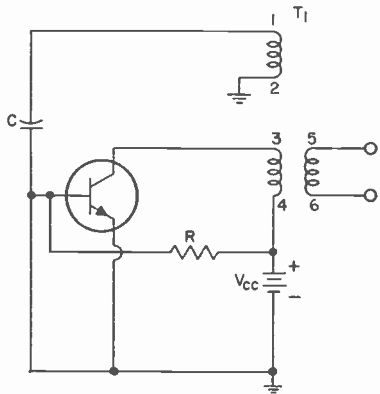


Figure 104. Basic circuit of blocking oscillator.

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 determined 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,

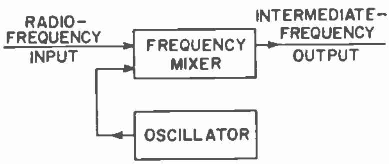


Figure 105. Block diagram of simple frequency-converter circuit.

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.

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.

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 unbalanced 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

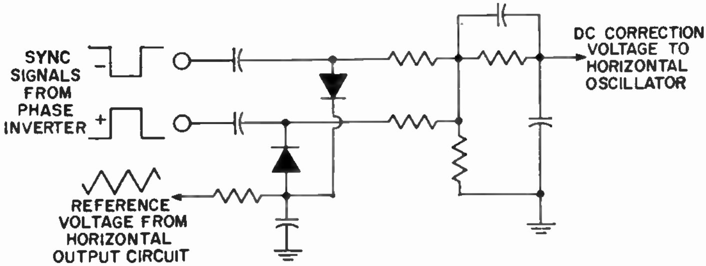


Figure 106. Balanced-phase-detector or phase-discriminator circuit for horizontal afc.

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.)

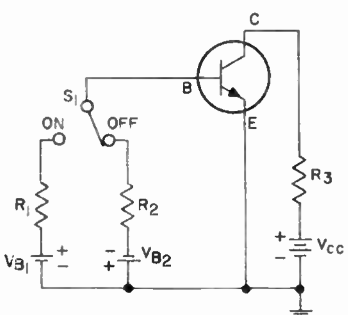


Figure 107. Simple switching circuit.

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.

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

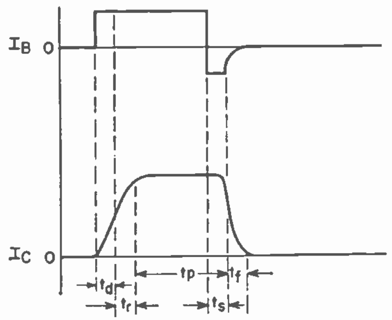


Figure 108. Current waveforms obtained in switching circuit.

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 decrease. 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

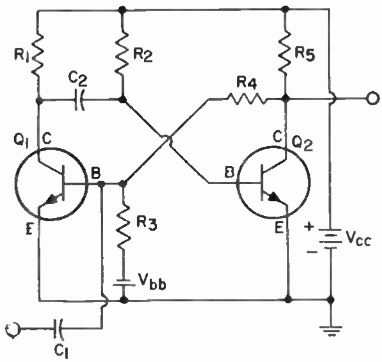


Figure 109. Monostable multivibrator.

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

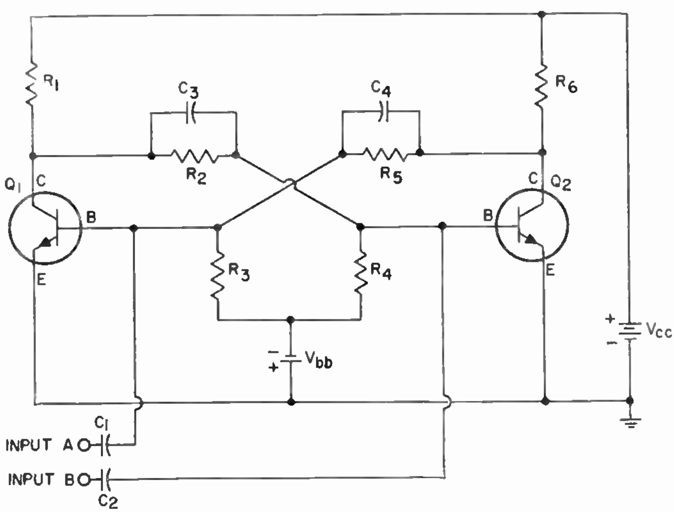


Figure 110. Eccles-Jordan-type bistable multivibrator.

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 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. 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.

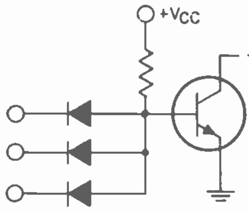


Figure 111. Simple diode NOR gate.

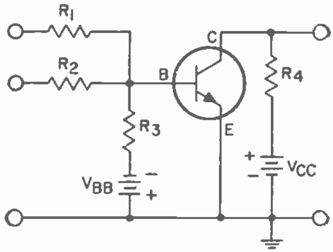


Figure 112. Simple transistor NOR gate.

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

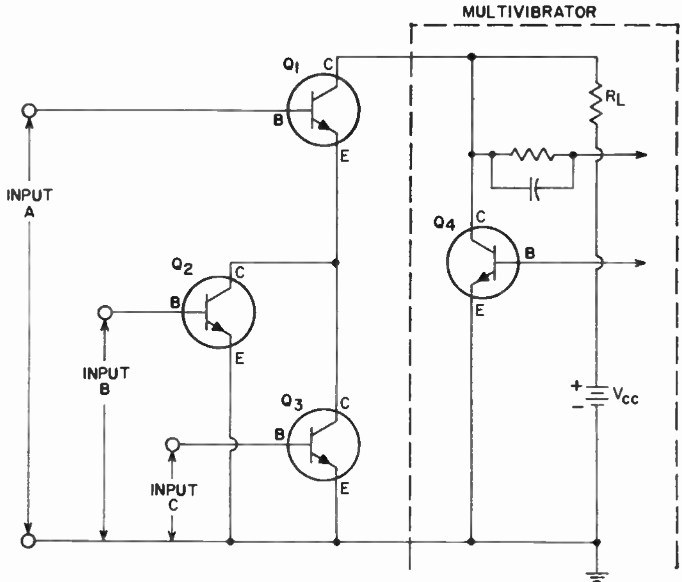


Figure 113. AND-OR gate or trigger circuit.

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 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 pro-

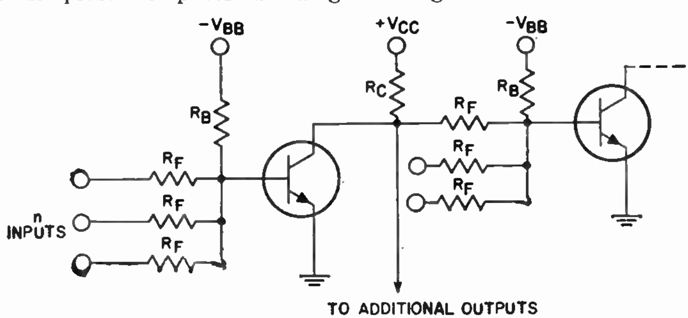


Figure 114. Simple RTL (resistance-transistor-logic) NOR circuit.

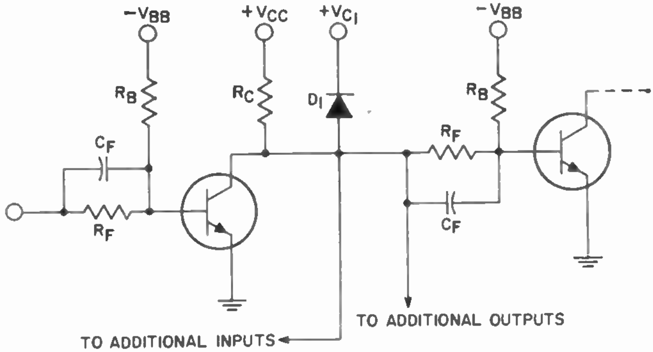


Figure 115. Generalized RCTL (resistance-capacitance-transistor-logic) NOR circuit.

vides 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 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

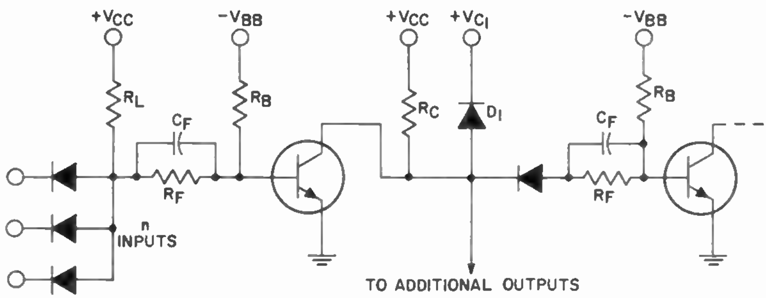


Figure 116. Generalized DTL (diode-transistor-logic) circuit.

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 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-**

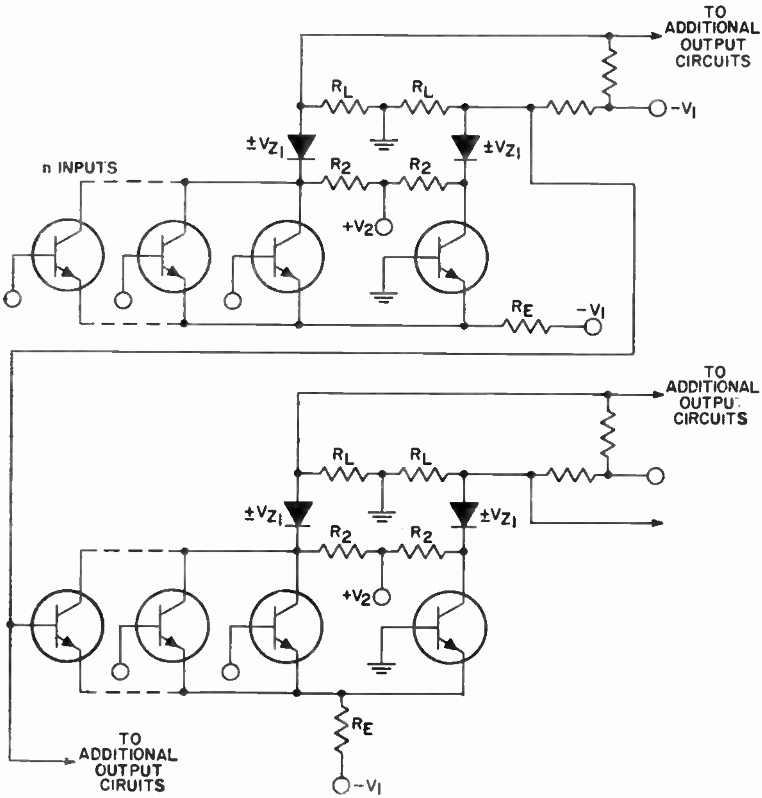


Figure 117. Generalized current-steering system using reference diodes and transistors.

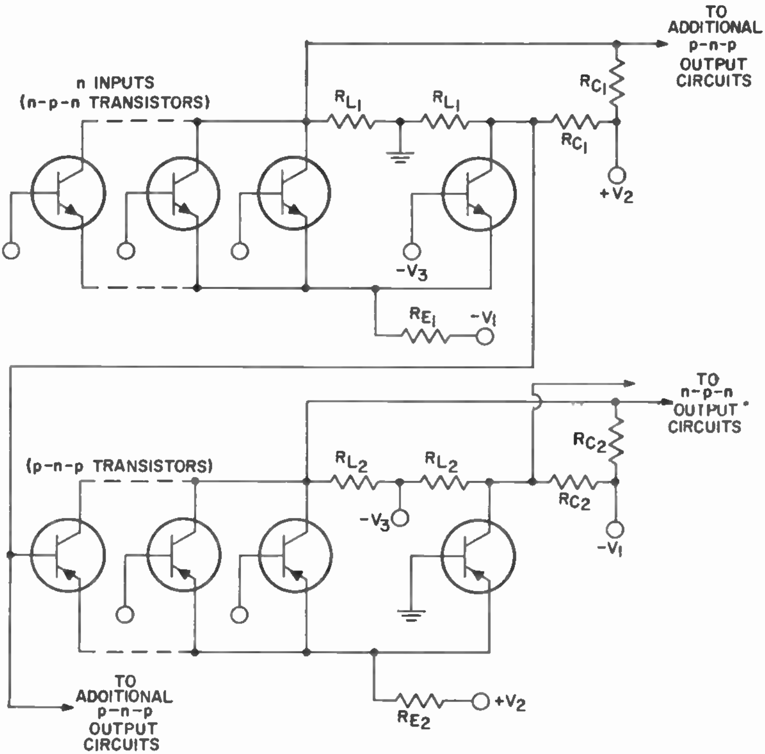


Figure 118. Generalized circuit for complementary-symmetry current-steering system using only transistors.

symmetry approach is superior to diode current steering because it is 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-

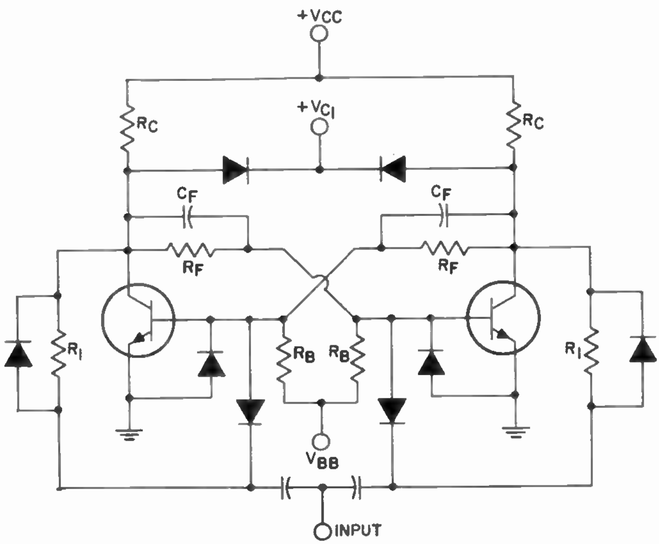


Figure 119. Binary-counter-type flip-flop circuit.

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_R 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_R + V_{BE}. For the OFF condition, therefore, the positive noise-voltage amplitude required is given by

$$V_n = (V_B + V_{BE}) \ (1 + \frac{C_1}{C_F})$$

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_S, C_F, and C_1 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

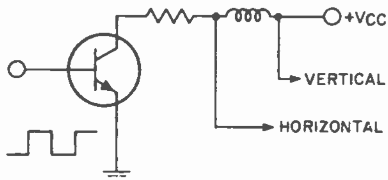


Figure 120. Simple test circuit for analysis of a load line.

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.

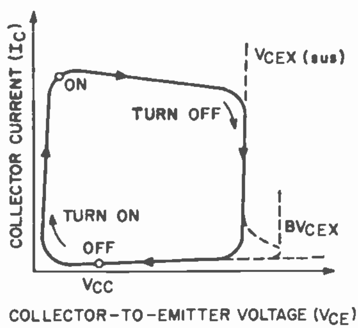


Figure 121. Typical load line for circuit shown in Figure 120.

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

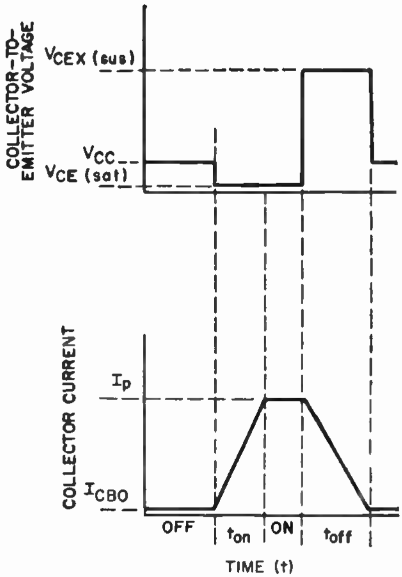


Figure 122. Typical voltage and current waveforms for switch shown in Figure 120.

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

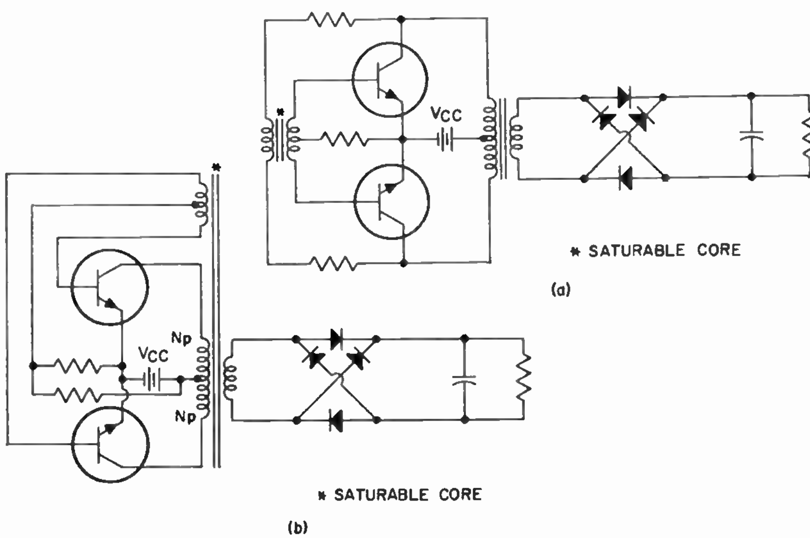


Figure 123. Simple converter circuits that can be used in place of vibrator-type converters in automobile radios.

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

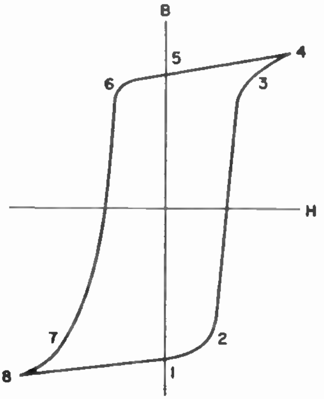


Figure 124. Characteristic hysteresis loop of auto-transformer used in circuit of Figure 123b.

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.

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

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

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.

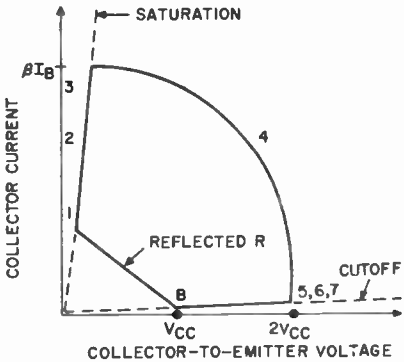


Figure 125. Approximate load line for converter circuit shown in Figure 123b.

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

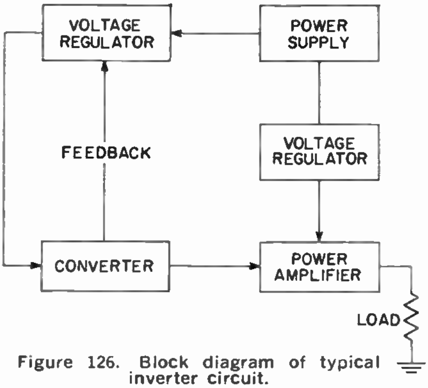


Figure 126. Block diagram of typical inverter circuit.

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.

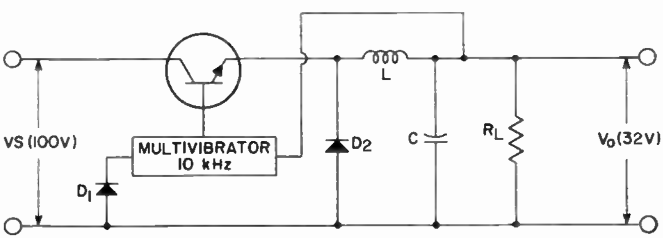


Figure 127. Typical switching regulator.

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-

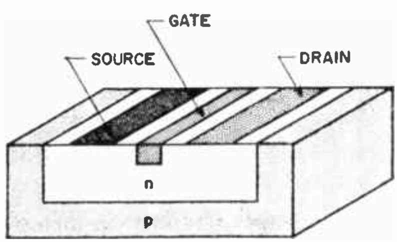


Figure 128. Structure of p-n junction field-effect transistor.

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.

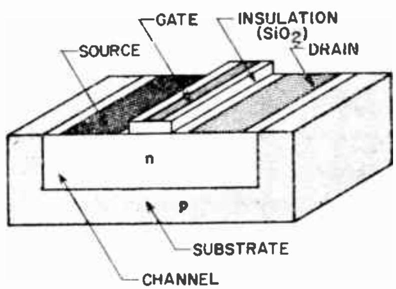


Figure 129. Structure of an MOS field-effect transistor.

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

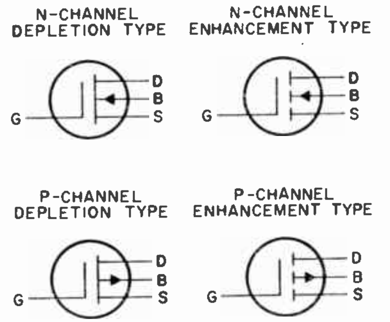


Figure 130. Schematic symbols for MOS transistors (G = gate, D = drain, B = active bulk, S = source).

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.

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

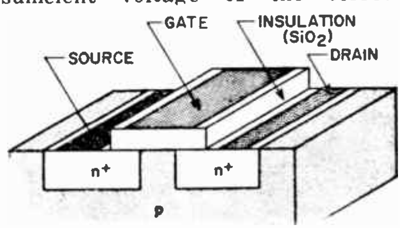


Figure 131. Structure of n-channel enhancement-type MOS transistor.

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")

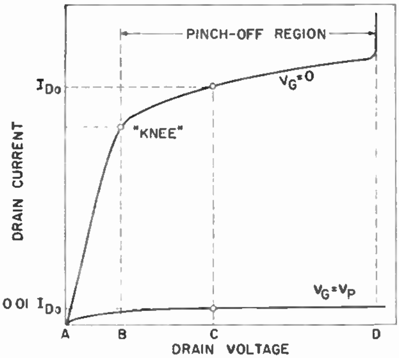


Figure 132. Basic current-voltage relationship for a depletion-type MOS transistor.

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.)

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-

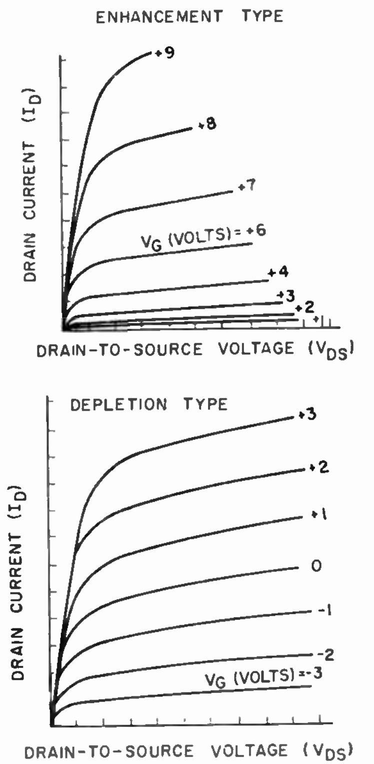


Figure 133. Typical output-characteristic curves for n-channel MOS transistors.

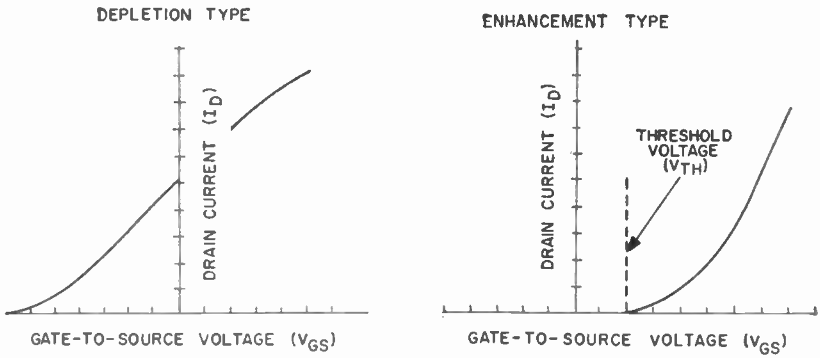


Figure 134. Typical transfer characteristics for n-channel MOS transistors.

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

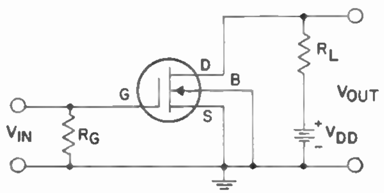


Figure 135. Basic common-source circuit for MOS field-effect transistors.

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

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

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

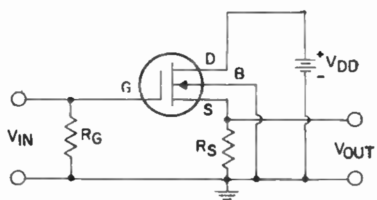


Figure 136. Basic common-drain (or source-follower) circuit for MOS transistors.

voltage feedback; its gain A′ is given by

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

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 MOS 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 unit 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

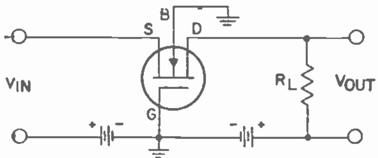


Figure 137. Basic common-gate circuit for MOS transistors.

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

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

where R_G is the resistance of the input-signal source. For a typical 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-kHz 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 1 kHz. 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 hertz. The upper frequency limit of such an amplifier may range from a few hundred hertz in general-purpose electrometer applications to several megahertz 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 MOS transistors such as the 3N128 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

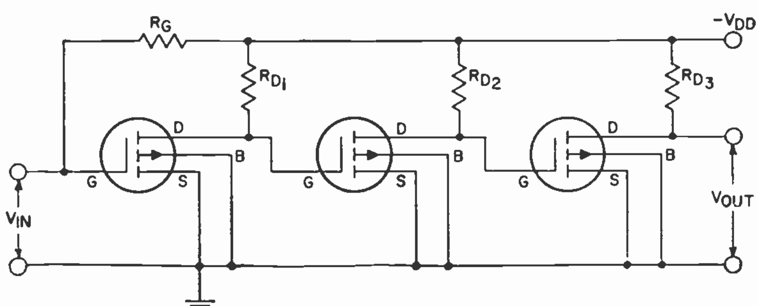


Figure 138. Typical single-ended dc amplifier using p-channel enhancement-type MOS transistors.

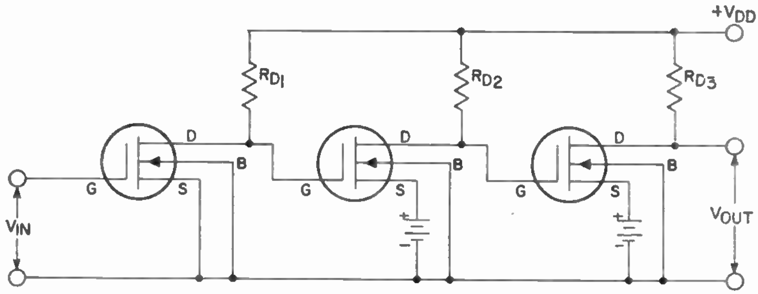


Figure 139. DC amplifier circuit in which n-channel depletion-type MOS transistors are direct-coupled by use of level shifting.

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-

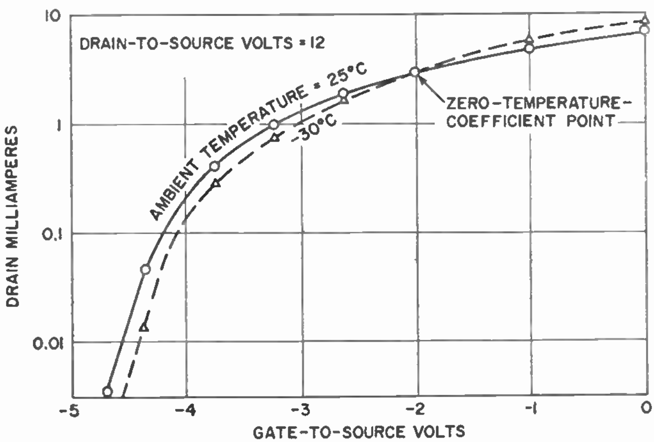


Figure 140. Forward-transfer characteristics of MOS transistor at 25°C and −30°C; intersection indicates zero-temperature-coefficient operating point.

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 3N128 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 RCA-40461 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. Transistors having higher pinch-off voltages accept correspondingly greater peak signal-voltage swings before wave-shape 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 n-channel MOS transistor produces total harmonic distortion of less than two per cent in a 100-millivolt 400-Hz sine wave. Fig. 142 shows an attenuator circuit using an MOS transistor 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

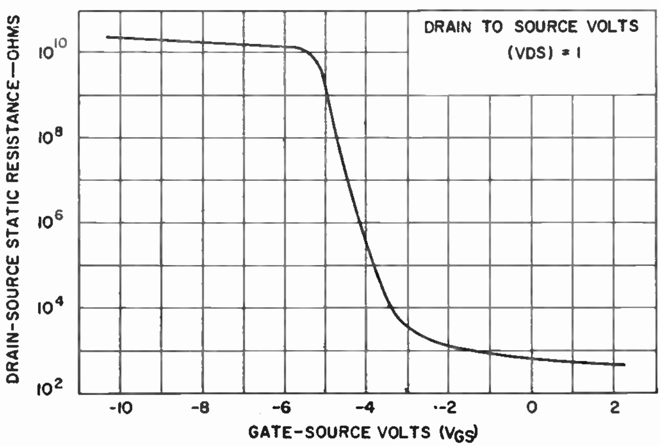


Figure 141. Drain resistance as a function of gate voltage for typical n-channel depletion-type MOS transistor.

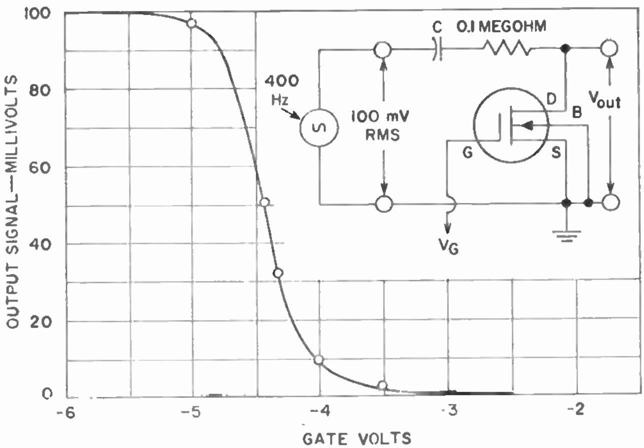


Figure 142. Output signal as a function of gate voltage for MOS transistor in circuit shown.

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

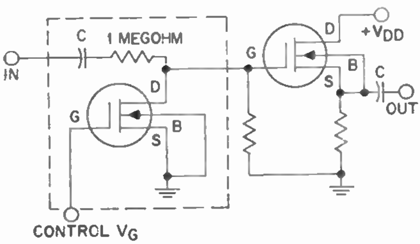


Figure 143. Attenuator circuit in which MOS transistor serves as variable-resistive element in low side.

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.

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

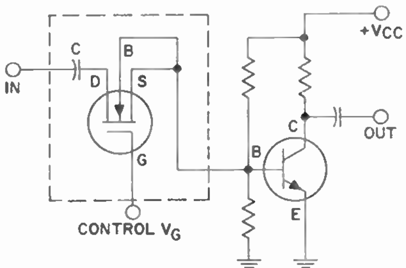


Figure 144. Attenuator circuit in which MOS transistor serves as variable-resistive element in high side.

usually followed by a low-impedance load such as a common-emitter bipolar transistor amplifier stage.

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

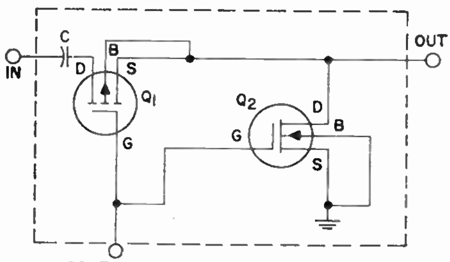


Figure 145. L-pad attenuator circuit using two MOS transistors.

circuit must work into a high-impedance load.

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

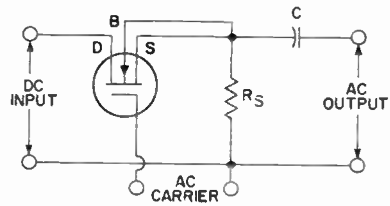


Figure 146. Basic series chopper circuit using an MOS transistor.

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 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

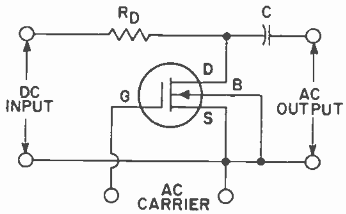


Figure 147. Basic shunt chopper circuit using an MOS transistor.

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 considerably improve the level of solid-state chopper performance.

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-

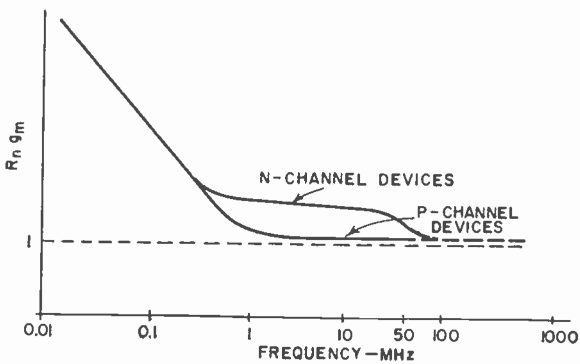


Figure 148. Input noise resistance R_N of MOS transistors as a function of frequency.

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

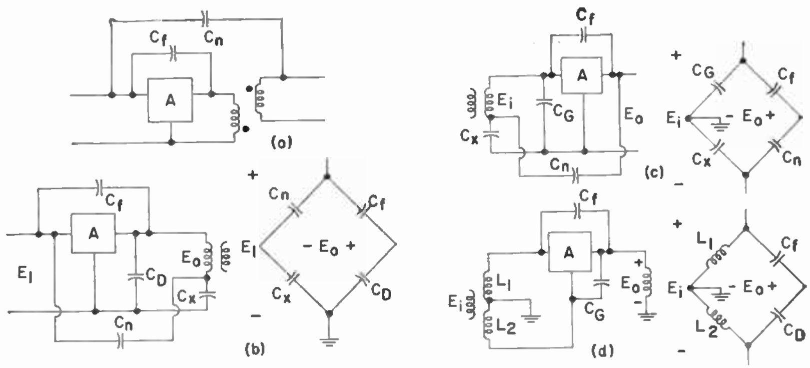


Figure 149. Some suitable neutralizing techniques for MOS rf circuits.

circuit using an n-channel MOS transistor is shown in Fig. 150. The transistor shown is intended for operation at frequencies up to 60 MHz, although it has useful response well beyond this value. Typically its forward transconductance g_{fs} does not drop 3 dB until approximately 150 MHz. The stage shown in Fig. 150 has a typical power gain of 10 to 18 dB at 60 MHz. 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

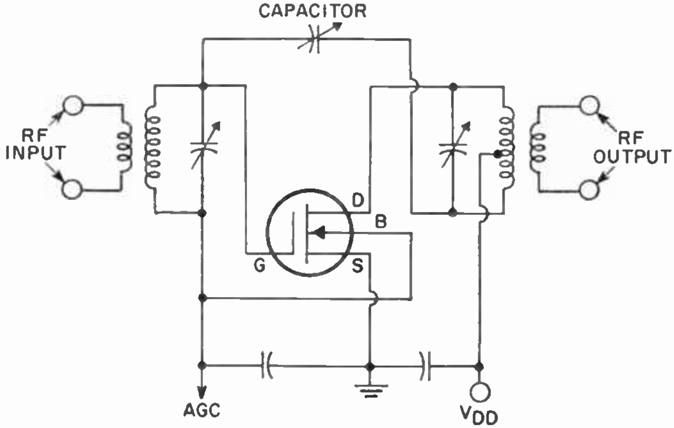


Figure 150. Typical 60-MHz rf-amplifier stage using MOS transistor.

is greater than V_{GO}. If both inputs are LOW, both MOS transistors are cut off and the output voltage is

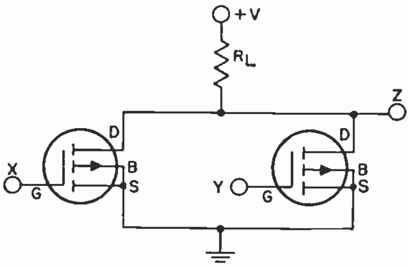


Figure 151. Simple NOR logic gate using MOS transistors.

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.

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

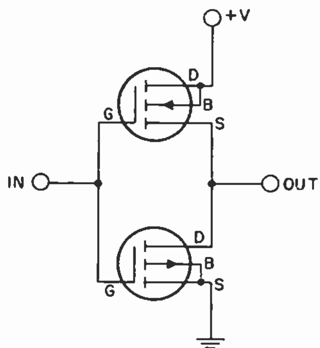


Figure 152. Complementary inverter circuit using MOS transistors.

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.

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

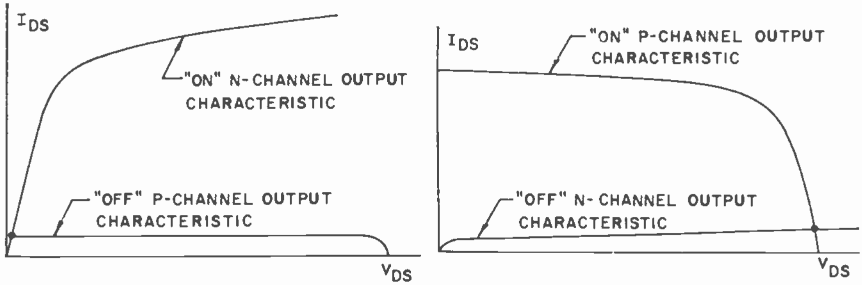


Figure 153. Characteristics of inverter circuit of Figure 152 in its two stable states.

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 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 stor-

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

age 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

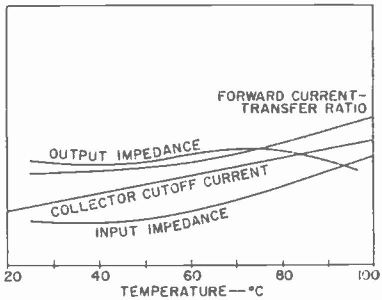


Figure 154. Variation of transistor characteristics with temperature.

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.

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. 155a 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.

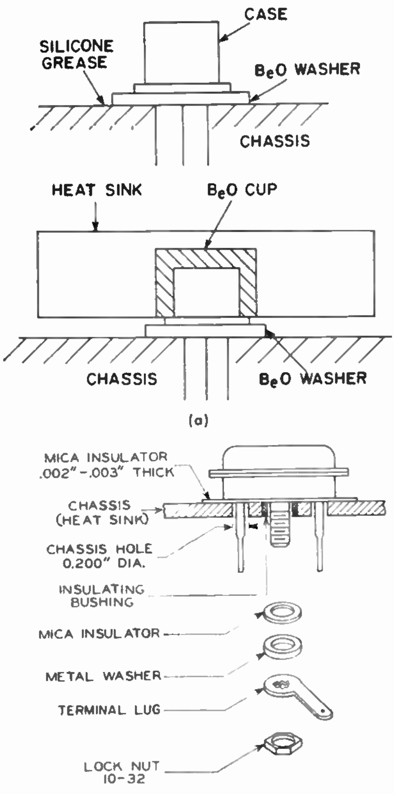


Figure 155. Suggested mounting arrangements for (a) transistors having a JEDEC TO-5 package, and (b) power transistors.

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. 155b. 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. 155b, to prevent a short circuit between them.

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.

Some high-frequency power transistors, such as the 2N5070, are supplied in a plastic package (HF-10) that features low-inductance, electrically isolated electrodes. Although both pins and pads are provided in the package for circuit flexibility, electrical connections should be made to the pads for best rf performance. Fig. 156 shows some of the possible mounting configurations for this package. Various methods of printed-circuit-board mounting are shown in Figs. 156a and 156b. Because of the elimination of pin-lead inductance in the emitter and base circuits, the configuration shown in Fig. 156b is more desirable for operation at frequencies above 300 MHz.

Fig. 156c shows a suitable mounting arrangement for stripline applications. A clearance hole is placed in the board between the two collector pins to provide access for soldering the emitter to the ground plane. When a radial strip-lead package is desired, thin copper strips may be soldered directly to the pads, as shown in Fig. 156d. The pins may be bent over the strip leads to provide support during soldering.

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

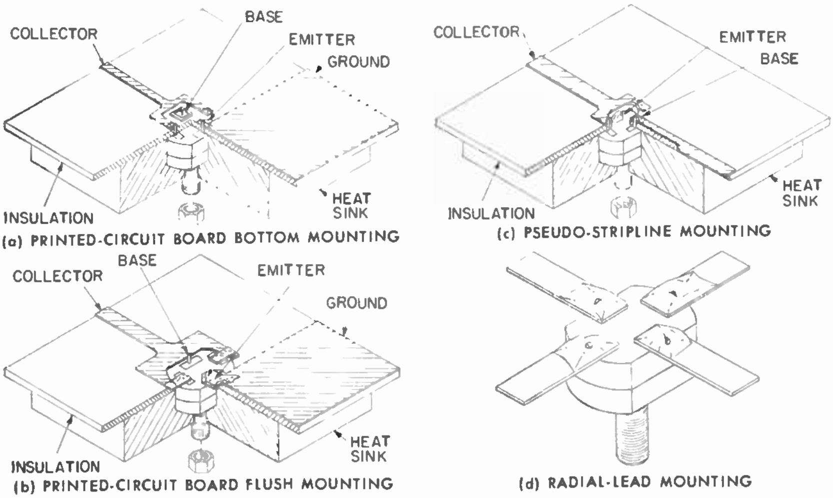


Figure 156. Mounting configurations for high-frequency plastic transistor package.

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, 150, 175, and 200 degrees centigrade. If the maximum operating temperature of a transistor is some other value, a new curve can be drawn from point A in the figure to the desired temperature value on the abscissa.

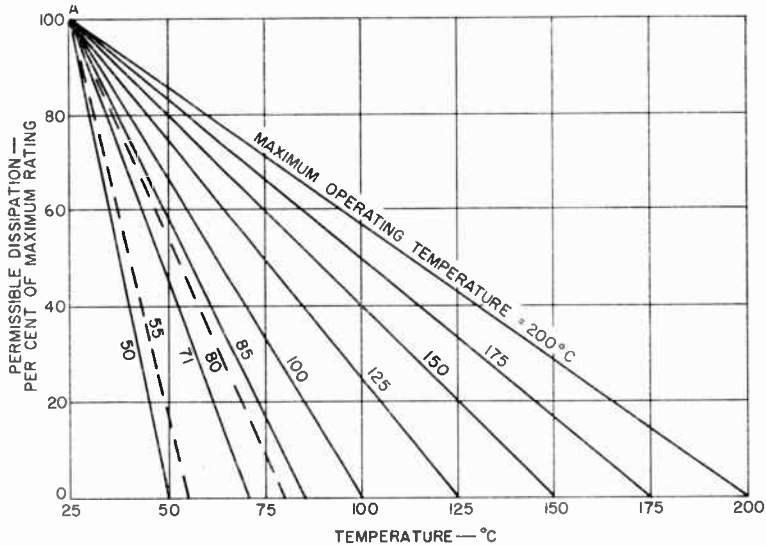


Figure 157. Chart showing maximum permissible percentage of maximum rated dissipation as a function of temperature.

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 2N1487 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 2N1487 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	time
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

$r_{bb'}$	intrinsic base spreading resistance
$r_{CE}(sat)$	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
$V_{BE}(sat)$	base-to-emitter saturation 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_{oss}	small-signal output 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_{DSS}	zero-bias drain 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-2N220	1
JAN-2N274	26 (Sig C)
JAN-2N384	27D
JAN-2N388	65A
JAN-2N396A	64C
JAN-2N398	174 (Navy)
JAN-2N404	20B
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-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 thyristors (SCR's and triacs), rectifiers, 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	40263	40490
2N2614	40359	

Silicon n-p-n

2N718A	40231	40412V2
2N720A	40232	40450
2N2102	40233	40451
2N2270	40234	40452
2N2405	40366○	40453
2N2895	40397	40454
2N2896	40398	40455
2N2897	40399	40456
2N3241A	40400	40458
2N3242A	40412	40459
2N4074	40412V1	40491*
40084		

MOS Field-Effect

40461▲

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	2N2148■	40239
2N1183A	2N2869●	40253
2N1183B	2N2870●	40254●
2N1184	2N2953	40395
2N1184A	40022●	40396
2N1184B	40050●	40421●
2N2147■	40051●	40462●

Dissipations of 50 W or More

2N1905	2N1906

Silicon p-n-p

40319	40406	40410
40362		

Silicon n-p-n

Dissipations up to 5 W

2N1479	40326	40399
2N1480	40327	40400
2N1481	40347	40407
2N1482	40347V1*	40408
2N1700	40347V2	40409
2N1711	40348	40423
2N3241A	40348V1*	40425
2N3242A	40348V2	40427
2N3585	40349	40450
2N4074	40349V1*	40451
40084	40349V2	40452
40309	40360	40453
40311	40361	40454
40314	40366○	40455
40315	40367○	40456
40317	40385○	40457
40320	40397	40500
40321	40398	40501
40323		

• For printed-circuit-board applications.
● High-fidelity power-amplifier type.
■ High-power extended-frequency-range type.
▲ N-channel depletion type; insulated gate.
○ High-reliability type.

Dissipations of 5 W to 50 W

2N1483	40250V1*	40368◇
2N1484	40251	40372*
2N1485	40310	40374*
2N1486	40312	40375*
2N1701	40313	40422
2N3054	40316	40424
2N3583	40318	40426
2N3584	40322	40464●
2N3878	40324	40465●
2N3879	40328	40466●
40250	40364	

Dissipations of 50 W or More

2N1487	2N3055	2N3773
2N1488	2N3263	2N4347
2N1489	2N3264	2N4348
2N1490	2N3265	40251
2N1702	2N3266	40325
2N1703	2N3442	40363
2N2015	2N3771	40369◇
2N2016	2N3772	40411
2N2338		

Radio-Frequency Applications

SMALL SIGNAL, UHF and VHF

Germanium p-n-p

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

Silicon n-p-n

2N917	2N4081*	40296◇
2N918	2N4259	40391
2N2708	2N4397*	40392
2N2857	2N4934*	40394
2N3053	2N4935*	40404‡
2N3478	2N4936*	40405‡
2N3600	40242	40413◇
2N3839	40272*	40414◇
2N3932	40294	40478*
2N3933	40295	

Silicon p-n-p

2N4036	2N4037

MOS Field-Effect

3N128▲	40467▲	40468▲
40461▲		

LARGE SIGNAL, UHF and VHF

Silicon n-p-n

2N699	2N4427†‡	40280†
2N1491	2N4440†‡	40281†
2N1492	2N4932†	40282†
2N1493	2N4933†	40290†
2N2631	2N5016†	40291†
2N2876	2N5017†	40292†
2N3229	2N5070†	40305†◇
2N3375†‡	2N5071†	40306†◇
2N3553†‡	2N5090†‡	40307†◇
2N3632†‡	2N5102†	40340†
2N3733†‡	2N5108†‡	40341†
2N3866†‡	40279†	40444†
2N4012†‡		

HIGH FREQUENCY

Germanium p-n-p

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

Silicon n-p-n

40081	40244	40246
40082	40245	40446
40243		

MIXER, OSCILLATOR, and CONVERTER

Germanium p-n-p

2N274	2N1225	2N1639
2N374	2N1226	2N3839
2N384	2N1395	2N5108†‡
2N1023	2N1396	40080
2N1066	2N1397	40261
2N1178	2N1426	40296◇
2N1179	2N1526	40487
2N1224	2N1527	40488

Silicon n-p-n

40243	40414◇	40479
40244	40473	40480
40413◇	40474	

MOS Field-Effect

3N128▲

† Overlay type.
‡ Frequency-multiplier type.
* For printed-circuit-board applications.
◇ High-reliability type.
● High-fidelity power-amplifier type.
▲ N-channel depletion type; insulated gate.

IF AMPLIFIER

Germanium p-n-p

2N139	2N1066	2N1397
2N218	2N1180	2N1524
2N274	2N1224	2N1525
2N384	2N1225	2N1638
2N409	2N1226	40262
2N410	2N1395	40489
2N1023	2N1396	

Silicon n-p-n

40080	40243	40246
40081	40244	40481*
40082	40245	40482*

WIDE-BAND AMPLIFIERS

Silicon n-p-n

2N4068	2N4297	2N5071†
2N4069	2N4298	2N5109†
2N4296	2N4299	

VIDEO AMPLIFIER

Germanium p-n-p

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

Silicon n-p-n

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

Television Applications

TV DEFLECTION

Germanium p-n-p

2N3730	2N3732	40439
2N3731	2N4346	40440

TV TUNER

Silicon n-p-n

40235	40469*	40473*
40236	40472*	40474*
40237		

MOS Field-Effect

40467▲

TV VIDEO OUTPUT

Silicon n-p-n

2N4068	2N4297	40354
2N4069	2N4298	40355
2N4296	2N4299	

* For printed-circuit-board applications.
† Overlay type.

TV IF AMPLIFIER

Silicon n-p-n

40238	40470*	40476*
40239	40471*	40477*
40240	40475*	

Power Switching

Dissipations up to 5 W

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

2N697	2N1613	2N3119
2N718A		

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

2N720A	2N1893

Dissipations from 5 W to 50 W

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

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

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

2N1479	2N2270	40317
2N1481	2N3053	40348
2N1483	2N3054	40367○
2N1485	40082	40368○
2N1700	40250	40369○
2N1701	40278	

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

2N1480	2N3878	40367○
2N1482	2N3879	40368○
2N1484	40346	40373*
2N1486	40346V1	40375*
2N2102	40346V2	40412
2N2405	40349	40412V1
2N3262	40366○	40412V2
2N3441		

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

2N3439	2N3585	2N4298
2N3440	2N4240	2N4299
2N3583	2N4296	40374*
2N3584	2N4297	40385○

Dissipations of 50 W or More

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

2N1905

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

2N1906

▲ N-channel depletion type; insulated gate.
○ High-reliability type.

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

2N1487	2N3055	2N5034●
2N1488	2N3771	2N5035●*
2N1489	2N3772	2N5036●
2N1490	2N4347	2N5037●*
2N1702	2N4348	40251
2N1703	2N4395	40513●*
2N2015	2N4396	40514●
2N2338		

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

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

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

Germanium p-n-p

2N1183	2N1183B	2N1184A
2N1183A	2N1184	2N1184B

Silicon n-p-n

2N1487	2N3265	2N4298
2N1488	2N3266	2N4299
2N1489	2N3439	2N4347
2N1490	2N3440	2N4348
2N1700	2N3441	2N4395
2N1701	2N3442	2N4396
2N1702	2N3583	40366○
2N1703	2N3584	40367○
2N2015	2N3585	40368○
2N2016	2N4063	40369○
2N2338	2N4064	40374*
2N3054	2N4240*	40385○
2N3055	2N4296	40389*
2N3263	2N4297	40390*
2N3264		

MOS Field-Effect

40460▲

DIFFERENTIAL and OPERATIONAL AMPLIFIERS

Silicon n-p-n

2N1613	2N3440	40346
2N2102	2N4063	40346V1
2N2270	2N4064	40346V2
2N3439	2N4240	40366○

Computer Applications

MEMORY DRIVERS

Silicon n-p-n

2N2476	2N3261	2N3512
2N2477	2N3262	40283

LOGIC CIRCUITS

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

2N404	2N1301	2N1309
2N404A	2N1303	2N1683
2N414	2N1305	40269
2N1300	2N1307	40403

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

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

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

2N3241A	40450	40451
2N3242A		

Silicon n-p-n (High Speed)

2N706	2N2369A	40219
2N706A	2N2475	40220
2N708	2N2938	40221
2N709	2N3011	40222
2N834	2N3261	40458
2N914	40217	40459
2N2205	40218	

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

Germanium p-n-p

2N398	2N398A	2N398B

Silicon n-p-n

2N4068	2N4390	40346V1
2N4069	40346	40346V2

▲ N-channel depletion type; insulated gate.
○ High-reliability type.
* For printed-circuit-board applications.
● High-fidelity power-amplifier type.

Technical Data for RCA Transistors

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, thyristors (SCR's and triacs), 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).

TRANSISTOR 2N104

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
Transistor Dissipation:			
T_A = 25°C	P_T	150	mW
Temperature Range:			
Operating (Ambient)	T_A (opr)	−65 to 70	°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
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_C = −1 mA)	h_{fe}	44 min	
Small-Signal Forward-Current Transfer Ratio Cutoff Frequency	f_{hfb}	0.7	MHz
Output Capacitance	C_{obo}	40	pF
Power Gain	G_{pe}	32.4	dB
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	0.4	°C/mW

TRANSISTOR 2N109

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
Transistor Dissipation:			
T_A = 25°C	P_T	165	mW
T_A above 25°C	P_T	See curve page 116	

MAXIMUM RATINGS (cont'd)

Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 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)	$V_{(BR)CBO}$	−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}	−14 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}	75 min	
Power Gain▲ (f = 0.001 MHz)	G_{pe}	33	dB
Total Harmonic Distortion▲ (P_{oe} = 0.16 W)		10 max	%
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_E = −1 mA, f = 1 kHz)	h_{fe}	50 to 150	
Small-Signal Input Impedance (V_{CE} = −6 V, I_E = −1 mA, f = 1 kHz)	h_{ie}	1000 to 4000	Ω
Output Capacitance (V_{CB} = −6 V, I_C = −1 mA, f = 0.5 MHz)	C_{obo}	20 to 60	pF

▲ This characteristic does not apply to type 2N217.

2N139 TRANSISTOR

Ge p-n-p alloy-junction type used primarily in 455-kHz 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
Collector Current	I_C	−15	mA
Transistor Dissipation:			
T_A = 25°C	P_T	35	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 70	°C

CHARACTERISTICS

Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−6 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = −9 V, I_C = −1 mA)	h_{FE}	48 min	
Gain-Bandwidth Product	f_T	4.7	MHz
Output Capacitance	C_{obo}	9.5	pF
Power Gain (f = 0.455 MHz)	G_{pe}	33	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
Collector Current	I_C	−15	mA
Transistor Dissipation:			
T_A = 25°C	P_T	80	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 71	°C

CHARACTERISTICS

Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−6 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = −9 V, I_C = −0.6 mA)	h_{FE}	75 min	
Gain-Bandwidth Product	f_T	10	MHz
Oscillator Injection Voltage (f = 1 MHz)		100 max	mV
Output Capacitance	C_{obo}	9.5	pF
Power Gain (f = 1 MHz)	G_{pe}	32	dB

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
Collector Current	I_C	−2	mA
Transistor Dissipation:			
T_A = 25°C	P_T	50	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 50	°C

CHARACTERISTICS

Collector-Cutoff Current (V_{CB} = −25 V, I_E = 0)	I_{CBO}	−12 max	µA
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = −4 V, I_C = −0.5 mA)	f_{hfb}	0.85	MHz
Power Gain	G_{pe}	43	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
Transistor Dissipation:			
T_{MF} = 80°C	P_T	10	W
Temperature Range:			
Operating (Mounting Flange)	T_{MF}(opr)	−65 to 90	°C

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-Cutoff Current (V_{CB} = −30 V, I_E = 0)	I_{CBO}	−3 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = −2 V, I_C = −0.5 A)	h_{FE}	63 min	
Power Gain (f = 0.001 MHz)	G_{pe}	35.5	dB
Total Harmonic Distortion (P_{oe} = 2 W)		2 max	%
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	1 max	°C/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 except for the following items:

CHARACTERISTICS

Collector-Cutoff Current (V_{CB} = −30 V, I_E = 0)	I_{CBO}	−7	μA
Static Forward-Current Transfer Ratio (V_{CE} = −1 V, I_C = −50 mA)	h_{FE}	65 to 120	

2N218 TRANSISTOR

Ge p-n-p alloy-junction type used primarily in 455-kHz 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	−150	mA
Emitter Current	I_E	150	mA

MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_A up to 25°C	P_T	250	mW
T_A above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (Ambient)	T_A(opr)	71	°C
Storage	T_{STG}	−65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −0.016 mA, I_E = 0)	$V_{(BR)CBO}$	−30 min	V
Collector-to-Emitter Breakdown Voltage (V_{EB} = −5 V, I_C = −0.016)	$V_{(BR)CEX}$	25 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.012 mA, I_C = 0)	$V_{(BR)EBO}$	−12 min	V
Collector-Cutoff Current (V_{CB} = −30 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}	50 to 140	
Gain-Bandwidth Product (V_{CE} = −12 V, I_C = −2 mA)	f_T	1	MHz
Intrinsic Base-Spreading Resistance (V_{CE} = −12 V, I_C = −2 mA)	r_{bb}'	150 max	Ω
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	0.24 max	°C/W

TRANSISTOR 2N274

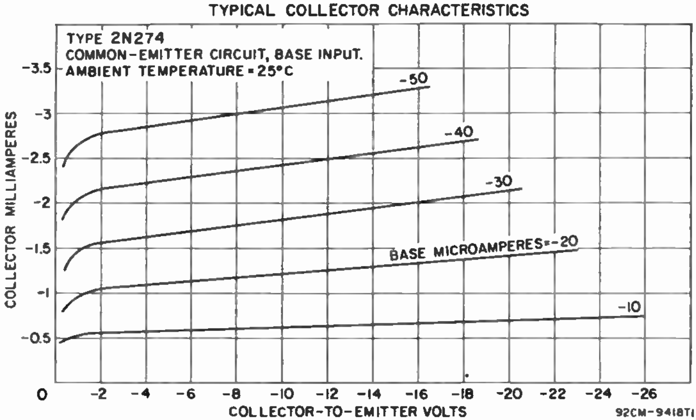
Ge p-n-p alloy drift-field type used in rf and if amplifier, oscillator, mixer, and converter circuits, and in low-level video-amplifier circuits in industrial and military equipment. JEDEC TO-44, Outline No.14. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - interlead shield and case.

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 116	
T_A = 25°C (with heat sink)	P_T	240	mW
T_A above 25°C (with heat sink)	P_T	See curve page 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 100	°C
Storage	T_{STG}	−65 to 100	°C

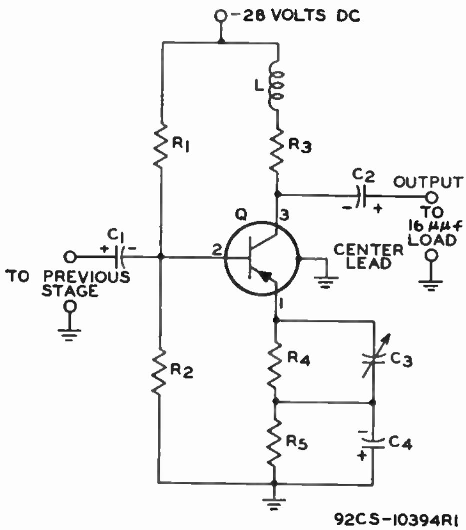
CHARACTERISTICS

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 kHz, 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	MHz
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 MHz	R_{ie}	150	Ω
V_{CE} = −12 V, I_E = 1.5 mA, f = 1.5 MHz	R_{ie}	1350	Ω
Output Resistance:			
V_{CE} = −12 V, I_E = 1.5 mA, f = 12.5 MHz	R_{oe}	4000	Ω
V_{CE} = −12 V, I_E = 1.5 mA, f = 1.5 MHz	R_{oe}	70000	Ω
Power Gain:			
V_{CE} = −12 V, I_E = 1.5 mA, f = 12.5 MHz	G_{pe}	17 to 27	dB
V_{CE} = −12 V, I_E = 1.5 mA, f = 1.5 MHz	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 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 Hz to 9	MHz
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

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	
Power Gain (f = 0.001 MHz)	G_{pe}	33.5	dB
Total Harmonic Distortion (P_{oe} = 4 W)		5 max	%

TRANSISTOR 2N370

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
Transistor Dissipation: T_A = 25°C	P_T	80	mW
Temperature Range: Operating (Ambient)	T_A(opr)	−65 to 71	°C

CHARACTERISTICS

Collector-Cutoff Current	I_{CBO}	−20 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = −12 V, I_C = −1 mA)	h_{FE}	60 min	
Gain-Bandwidth Product	f_T	30	MHz
Output Capacitance*	C_{obo}	1.7	pF
Power Gain* (f = 1.5 MHz)	G_{pe}	31	dB

* 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 item:

CHARACTERISTICS

Static Forward-Current Transfer Ratio (I_C = −1 mA)	h_{FE}	80 min

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 min	
Power Gain (f = 0.001 MHz)	G_{pe}	35	dB
Total Harmonic Distortion (P_{oe} = 4 W)		5 max	%

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, 4 - 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 116	
T_C = 25°C (with heat sink)	P_T	240	mW
T_C above 25°C (with heat sink)	P_T	See curve page 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 100	°C
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, f = 1 kHz)	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	MHz
Input Resistance:			
V_{CE} = −12 V, I_E = 1.5 mA, f = 50 MHz	R_{ie}	30	Ω
V_{CE} = −12 V, I_E = 1.5 mA, f = 12.5 MHz	R_{ie}	250	Ω
Output Resistance:			
V_{CE} = −12 V, I_E = 1.5 mA, f = 50 MHz	R_{oe}	5000	Ω
V_{CE} = −12 V, I_E = 1.5 mA, f = 12.5 MHz	R_{oe}	16000	Ω
Output Capacitance (V_{CB} = −12 V, I_E = 0)	C_{obo}	3 max	pF
Power Gain:			
V_{CB} = −12 V, I_E = 1.5 mA, f = 50 MHz	G_{pe}	15 to 21	dB
V_{CE} = −12 V, I_E = 1.5 mA, f = 12.5 MHz	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 Hz to 10 MHz	
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 Ω	V_{CER}	20	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 116		
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	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 Ω	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	MHz
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 Ω)	$t_d + t_r$	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 Ω)	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 Ω)	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 Ω)	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 116	
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	MHz
Output Capacitance (V_{CB} = −5 V, I_C = −1 mA, f = 1 MHz)	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. Each of these types is identical with type 2N395 except for the following items:

MAXIMUM RATINGS

		2N396	*2N396A*	
Collector-to-Emitter Voltage:				
R_{BE} = 10000 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 116		

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	MHz
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	
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	MHz

2N398
2N398A
2N398B

TRANSISTORS

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 116	
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

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
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-to-Emitter Saturation Voltage (I_C = −5 mA, I_B = −0.25 mA)	V_{CE}(sat)	−0.35	−0.35	−0.25 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} = 10 kΩ, T_A = 25°C	I_{CER}	—	—	−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} = −75 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 kHz)	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	MHz
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	—	0.5	0.3 max	°C/W

2N404
2N404A

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, 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 above 25°C	P_T	See curve page 116		
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
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	MHz
Output Capacitance:				
V_{CB} = −6 V, I_C = 0	C_{obo}	20	— max	pF
V_{CB} = −6 V, I_E = 1 mA, f = 2 MHz	C_{obo}	—	20 max	pF
Stored Base Charge (I_C = −10 mA, I_B = −1 mA)	Q_S	1400	1400 max	pC

● For higher dissipation values in switching applications, see RCA Application Note AN-181.
* 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 Current	I_C	−35	mA
Emitter Current	I_E	35	mA
Transistor Dissipation:			
T_A = 25°C	P_T	150	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 71	°C

CHARACTERISTICS

Collector-Cutoff Current	I_{CBO}	−14 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = −6 V, I_E = 1 mA)	h_{FE}	35 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −6 V, I_C = −1 mA)	f_{hfb}	650	kHz
Output Capacitance	C_{obo}	40	pF
Power Gain	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 Current	I_C	−70	mA
Emitter Current	I_E	70	mA
Transistor Dissipation:			
$T_A = 25°C$	P_T	150	mW
Temperature Range:			
Operating (Ambient)	$T_A(opr)$	−65 to 71	°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	
Power Gain (f = 0.001 MHz)	G_{pe}	33	dB
Total Harmonic Distortion ($P_{oe} = 0.16$ W)		10 max	%

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-kHz 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.

TRANSISTOR 2N410

Ge p-n-p alloy-junction type used in 455-kHz 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
Collector Current	I_C	−15	mA
Transistor Dissipation:			
$T_A = 25°C$	P_T	80	mW

MAXIMUM RATINGS (cont'd)

Temperature Range:			
Operating (Ambient)	$T_A(opr)$	−65 to 71	°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
Static Forward-Current Transfer Ratio (V_{CE} = −9 V, I_C = −1 mA)	h_{FE}	48	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency	f_{hfb}	6.7	MHz
Output Capacitance	C_{obo}	9.5	pF
Power Gain (f = 0.455 MHz)	G_{pe}	38.8	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
Collector Current	I_C	−15	mA
Transistor Dissipation:			
T_A = 25°C	P_T	80	mW
Temperature Range:			
Operating (Ambient)	$T_A(opr)$	−65 to 71	°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
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	MHz
Oscillator Injection Voltage (f = 1 MHz)		100	mV
Output Capacitance	C_{obo}	9.5	pF
Power Gain (f = 1 MHz)	G_{pe}	32	dB

2N414 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.

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

MAXIMUM RATINGS (cont'd)

Emitter-to-Base Voltage	V_{EBO}	−20	mA
Peak Collector Current	i_C	−400	mA
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 116	
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 kHz)	h_{fe}	80	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −6 V, I_E = 1 mA)	f_{hfb}	8	MHz
Output Capacitance (V_{CB} = −6 V, I_C = −1 mA)	C_{obo}	11	pF
Small-Signal Short-Circuit Input Impedance (V_{CB} = −6 V, I_E = 1 mA, f = 1 kHz)	h_{ib}	30	Ω
Small-Signal Open-Circuit Reverse-Voltage Transfer Ratio (V_{CB} = −6 V, I_E = 0, f = 1 kHz)	h_{rb}	0.5 x 10^{-4}	
Noise Figure (V_{CE} = −6 V, I_E = 1 mA, f = 1.5 MHz)	NF	6	dB
Power Gain (V_{CE} = −6 V, I_E = 1 mA, f = 1.5 MHz)	G_{pe}	16	dB

COMPUTER TRANSISTOR 2N581

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
Base-to-Emitter Saturation Voltage (I_C = −20 mA, I_B = −1 mA)	$V_{BE}(sat)$	−0.5 max	V
Collector-to-Emitter Saturation Voltage (I_C = −20 mA, I_B = −1 mA)	$V_{CE}(sat)$	−0.2 min	V
Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0, T_A = 25°C)	I_{CBO}	−10 max	µA
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 Saturation Voltage:			
$I_C = -24$ mA, $I_B = -0.6$ mA	$V_{BE}(sat)$	−0.4 max	V
$I_C = -100$ mA, $I_B = -5$ mA	$V_{BE}(sat)$	−0.8 max	V
Static Forward-Current Transfer Ratio:			
$V_{CE} = -0.2$ 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	MHz
Stored Base Charge ($I_C = -24$ mA, $I_B = -1.2$ mA)	Q_S	1200 max	pC

2N585 COMPUTER TRANSISTOR

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 up to 25°C	P_T	120	mW
T_A above 25°C	P_T	See curve page 116	
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 ($I_C = 25$ 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
Base-to-Emitter Saturation Voltage ($I_C = 20$ mA, $I_B = 1$ mA)	$V_{BE}(sat)$	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 ($V_{BE} = 5$ 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	MHz
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 up to 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
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage:			
I_C = −50 μA, V_{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_{BE} = −1 V, I_E = 0)	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_{BE} = −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	

TRANSISTOR 2N591

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-Base Voltage	V_{CBO}	−32	V
Collector-to-Emitter Voltage	V_{CEO}	−32	V
Collector Current	I_C	−40	mA
Transistor Dissipation:			
T_A up to 55°C	P_T	85	mW
T_C up to 55°C	P_T	200	mW
T_A or T_C above 55°C	P_T	See curve page 116	
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-Cutoff Current (V_{CB} = −10 V, I_E = 0)	I_{CBO}	−7 max	μA
Emitter-Cutoff Current (V_{EB} = −1 V, I_C = 0)	I_{EBO}	−20 max	μA
Collector-to-Base Breakdown Voltage (I_C = −0.05 mA, I_E = 0)	$V_{(BR)CBO}$	−32 min	V
Collector-to-Emitter Breakdown Voltage (I_C = −0.3 mA, I_B = 0)	$V_{(BR)CEX}$	−32 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.05 mA, I_C = 0)	$V_{(BR)EBO}$	−12 min	V
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12 V, I_C = −2 V, f = 1 kHz)	h_{fe}	40 to 120	
Thermal Resistance:			
Junction-to-Ambient	θ_{J-A}	353 max	°C/W
Junction-to-Case	θ_{J-C}	150 max	°C/W

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 up to 25°C	P_T	100	mW
T_A above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 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 = 0.05 mA, I_E = 0)	$V_{(BR)CBO}$	25 min	V
Collector-to-Emitter Breakdown Voltage (V_{EB} = 5 V, I_C = 0.014 mA)	$V_{(BR)CEV}$	25 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.014 mA, I_C = 0)	$V_{(BR)EBO}$	12 min	V
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}	50 to 150	
Gain Bandwidth Product (V_{CE} = 6 V, I_C = 2 mA)	f_T	2	MHz
Intrinsic Base-Spreading Resistance (V_{CE} = 6 V, I_C = 2 mA)	r_{bb}'	350 max	Ω

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	kHz
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

2N649 TRANSISTOR

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 up to 25°C	P_T	100	mW
T_A above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 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 = 0.05 mA, I_E = 0)	$V_{(BR)CBO}$	20 min	V

CHARACTERISTICS (cont'd)

Collector-to-Emitter Breakdown Voltage (V_{EB} = 2 V, I_C = 0.05 mA)	$V_{(BR)CEV}$	18 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.014 mA, I_C = 0)	$V_{(BR)EBO}$	2.5 min	V
Collector-Cutoff Current (V_{CB} = 12 V, I_E = 0)	I_{CBO}	14 max	μA
Emitter-Cutoff Current (V_{EB} = 2.5 V, I_C = 0)	I_{EBO}	14 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 1 V, I_C = 50 mA)	h_{FE}	50 to 150	
Gain-Bandwidth Product (V_{CE} = 6 V, I_C = 2 mA)	f_T	2	MHz
Intrinsic Base-Spreading Resistance (V_{CE} = 6 V, I_C = 2 mA)	$r_{bb'}$	350 max	Ω

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	kHz
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

COMPUTER TRANSISTOR 2N697

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} ≦ 10 Ω	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 116	
Temperature Range: Operating (T_A and T_C)	T(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)	$V_{(BR)CBO}$	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 ≦ 12 ms, df ≦ 2%, R_{BE} = 10 Ω)	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
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 150 mA, tp ≦ 12 ms, df ≦ 2%)	h_{FE}	40 to 120	
Small-Signal Forward-Current Transfer Ratio (f = 20 MHz, V_{CE} = 10 V, I_C = 50 mA)	h_{fe}	2.5 min	
Gain-Bandwidth Product	f_T	100	MHz
Output Capacitance (V_{CB} = 10 V, I_E = 0)	C_{obo}	35 max	pF

2N699 TRANSISTOR

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 ($R_{BE} \leq 10\ \Omega$)	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 116	
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	255	°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 ≦ 300 μs, df ≦ 2%)	V_{CER}(sus)	80 min	V
Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, tp ≦ 300 μs, df ≦ 2%)	V_{CE}(sat)	5 max	V
Base-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, tp ≦ 300 μs, df ≦ 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 ≦ 300 μs, df ≦ 2%)	h_{FE}	40 to 120	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kHz	h_{fe}	35 to 100	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{fe}	45 min	
V_{CE} = 10 V, I_C = 50 mA, f = 20 MHz	h_{fe}	2.5 min	
Gain-Bandwidth Product	f_T	50 min	MHz
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 kHz	h_{ib}	30 max	Ω
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{ib}	10 max	Ω
Voltage-Feedback Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kHz	h_{rb}	2.5×10^{-4} max	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{rb}	3×10^{-4} max	
Output Conductance:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kHz	h_{ob}	0.5 max	μmho
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	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

2N706 2N706A COMPUTER TRANSISTORS

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 Ω)	V_{CER}	20	20	V
Emitter-to-Base Voltage	V_{EBO}	3	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 116		

MAXIMUM RATINGS (cont'd)

Temperature Range:				
Operating (Junction)	T_J(opr)	175	175	°C
Storage	T_{STG}	−65 to 175		°C
Lead-Soldering Temperature (10 s max)	T_L	255		°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, tp ≦ 12 ms, df ≦ 2%	h_{FE}	20	— min	
Small-Signal Forward-Current Transfer Ratio:				
V_{CE} = 15 V, I_C = 10 mA, f = 100 MHz	h_{fe}	2	— min	
V_{CE} = 10 V, I_C = 10 mA, f = 100 MHz	h_{fe}	—	2 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0)	C_{obo}	6	— max	pF
Turn-On Time (V_{CC} = 3 V, I_C = 10 mA, I_{B1} = 3 mA, I_{B2} = −1 mA, R_L = 270 Ω)	$t_d + t_r$	—	40 max	ns
Turn-Off Time (V_{CC} = 3 V, I_C = 10 mA, I_{B1} = 3 mA, I_{B2} = −1 mA, R_L = 270 Ω)	$t_s + t_f$	—	75 max	ns
Storage Time (V_{CC} = 10 V, I_{B1} = 10 mA, I_{B2} = −10 mA, R_L = 1000 Ω)	t_s	60	25 max	ns

COMPUTER TRANSISTOR 2N708

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 Current	I_C	Limited by dissipation	
Transistor Dissipation: T_A = 25°C	P_T	0.36	W
Temperature Range: Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	40 min	V
Collector-to-Emitter Saturation Voltage (I_C = 10 mA, I_B = 1 mA)	V_{CE}(sat)	0.4 max	V
Collector-Cutoff Current	I_{CBO}	0.025 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 1 V, I_C = 10 mA)	h_{FE}	15 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 10 mA, f = 100 MHz)	h_{fe}	3 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 MHz)	C_{obo}	6 max	pF
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)	0.7 to 0.85	V

CHARACTERISTICS (cont'd)

Static Forward-Current Transfer Ratio:			
I_C = 10 mA, V_{CE} = 0.5 V, T_A = 25°C	h_{FE}	20 to 120	
I_C = 30 mA, V_{CE} = 1 V, T_A = 25°C	h_{FE}	15 min	
I_C = 10 mA, V_{CE} = 0.5 V, T_A = −55°C	h_{FE}	10 min	
Small-Signal Forward-Current Transfer Ratio (I_C = 5 mA, V_{CE} = 4 V, f = 100 MHz)	h_{fe}	6 min	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 140 kHz)	C_{ibo}	2 max	pF
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 140 kHz)	C_{obo}	3 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

2N718A COMPUTER TRANSISTOR

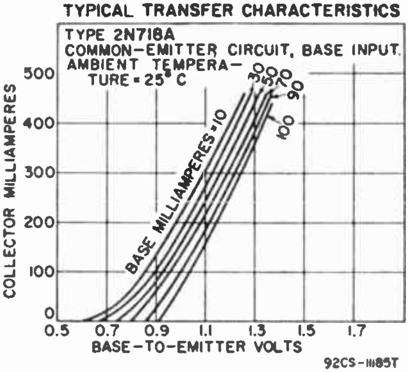
Si n-p-n planar triple-diffused-junction type used primarily for small-signal and switching applications in data-processing equipment. JEDEC TO-18, Outline No.9. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

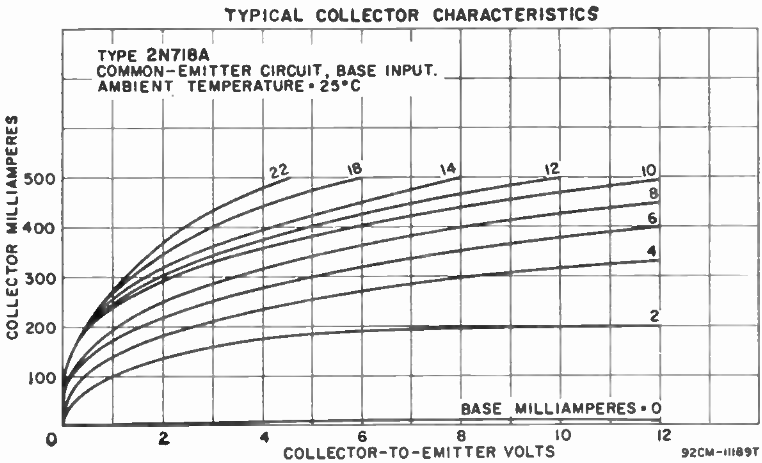
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	75	V
Collector-to-Emitter Voltage:			
Base open	V_{CEO}	32	V
R_{BE} ≦ 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 116	
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
Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0, R_{BE} = 10 Ω, t_p ≦ 300 μs, df ≦ 2%)	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 kHz	h_{fe}	30 to 100	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{fe}	35 to 150	
V_{CE} = 10 V, I_C = 50 mA, f = 20 MHz	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 kHz	h_{ib}	24 to 34	Ω
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{ib}	4 to 8	Ω
Voltage-Feedback Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kHz	h_{rb}	3×10^{-4} max	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{rb}	3×10^{-4} max	
Output Conductance:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kHz	h_{ob}	0.5 max	μmhos
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{ob}	1 max	μmhos
Noise Figure (V_{CE} = 10 V, I_C = 0.3 mA, f = 1 kHz)	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:			
$R_{BE} \leq 10\ \Omega$	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 116	

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	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, $t_p \leqq$ 300 μs, df $\leqq$ 2%	V_{CEO}(sus)	80 min	V
I_C = 100 mA, I_B = 0, R_{BE} = 10 Ω, $t_p \leqq$ 300 μs, df $\leqq$ 2%	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 kHz	h_{fe}	30 to 100	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{fe}	45 min	
V_{CE} = 10 V, I_C = 50 mA, f = 20 MHz	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 kHz	h_{ib}	20 to 30	Ω
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{ib}	4 to 8	Ω
Voltage-Feedback Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kHz	h_{rb}	1.25 x 10^{-4} max	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{rb}	1.5 x 10^{-4} max	
Output Conductance:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kHz	h_{ob}	0.5 max	μmhos
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	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 116	
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

CHARACTERISTICS (cont'd)

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 MHz)	h_{fe}	3.5 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 100 kHz)	C_{obo}	4 max	pF
Gain-Bandwidth Product (V_{CE} = 15 V, I_C = 10 mA, f = 100 MHz)	f_T	350 min	MHz
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

COMPUTER TRANSISTOR 2N914

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 Current	I_C	Limited by power dissipation	
Transistor Dissipation:			
T_A = 25°C	P_T	0.36	W
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	40 min	V
Collector-to-Emitter Saturation Voltage (I_C = 200 mA, I_B = 20 mA)	V_{BE}(sat)	0.7 max	V
Collector-Cutoff Current (V_{CB} = 20 V, I_E = 0)	I_{CBO}	0.025 max	μA
Static Pulse Forward-Current Transfer Ratio (V_{CE} = 5 V, I_C = 500 mA)	h_{FE}	10 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 MHz)	C_{obo}	6 max	pF
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-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 116	

MAXIMUM RATINGS (cont'd)

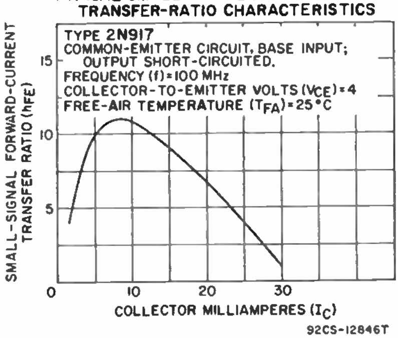
Temperature Range:			
Operating (Junction)	T_J	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (60 s max)	T_L	300	°C

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 MHz)	h_{fe}	5 min	
Input Capacitance† (V_{EB} = 0.5 V, I_C = 0, f = 0.1 to 1 MHz)	C_{ibo}	1.6 max	pF
Output Capacitance† (V_{CB} = 10 V, I_E = 0, f = 0.1 to 1 MHz)	C_{obo}	1.7 max	pF
Collector-to-Base Time Constant* (V_{CB} = 10 V, I_C = 4 mA, f = 40 MHz)	$r_b'C_c$	75 max	ps
Small-Signal Power Gain, Unneutralized Amplifier Circuit* (V_{CE} = 10 V, I_C = 5 mA, f = 200 MHz)	G_{pe}	9 min	dB
Power Output in Oscillator Circuit† (V_{CB} = 15 V, I_C = 8 mA, f = 500 MHz)	P_{oe}	10 min	mW
Noise Figure† (V_{CE} = 6 V, I_C = 1 mA, R_G = 400 Ω, f = 60 MHz)	NF	6 max	dB

* Fourth lead (case) grounded.
† Fourth lead (case) floating.

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



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* ($f = 100$ MHz, $V_{CB} = 10$ V, $I_C = 4$ mA)	h_{fe}	6 min	
Input Capacitance ($f = 0.1$ to 1 MHz, $V_{EB} = 0.5$ V, $I_C = 0$)	C_{ibo}	2 max	pF
Output Capacitance:■			
$V_{CB} = 10$ V, $I_E = 0$, $f = 0.1$ to 1 MHz	C_{obo}	1.7 max	pF
$V_{CB} = 0$, $I_E = 0$, $f = 0.1$ to 1 MHz	C_{obo}	3 max	pF
Collector-to-Base Time Constant* ($f = 40$ MHz, $V_{CB} = 6$ V, $I_C = 2$ mA)	$r_b'C_c$	15	ps
Small-Signal Power Gain:*			
Unneutralized Amplifier Circuit ($V_{CB} = 10$ V, $I_C = 5$ mA, $f = 200$ MHz)	G_{pe}	13	dB
Neutralized Amplifier Circuit ($V_{CB} = 12$ V, $I_C = 6$ mA, $f = 200$ MHz)	G_{pe}	15 min 18 typ	dB dB
Power Output, Oscillator Circuit† ($V_{CB} = 10$ V, $I_E = 12$ mA, $f = 500$ MHz)	P_{oe}	30 min	mW
Noise Figure* ($V_{CE} = 6$ V, $I_C = 1$ mA, $R_G = 400$ Ω, $f = 60$ MHz)	NF	6 max	dB

* Fourth lead (case) grounded.

■ Three-terminal measurement of the collector-to-base capacitance with the case and emitter leads connected to the guard terminal.

† 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 Current	I_C	2	mA
Transistor Dissipation:			
$T_A = 25°C$	P_T	20	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 55	°C

CHARACTERISTICS

Collector-Cutoff Current ($V_{CB} = 10$ V, $I_E = 0$)	I_{CBO}	10 max	μA
Small-Signal Forward-Current Transfer Ratio ($V_{CE} = 3.5$ V, $I_E = -0.3$ mA, $f = 1$ kHz)	h_{fe}	35	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency ($V_{CB} = 3.5$ V, $I_C = 0.3$ mA)	f_{hfb}	2	MHz

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 116	
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 116	

MAXIMUM RATINGS (cont'd)

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 kHz)	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	MHz
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 MHz	R_{ie}	25	Ω
V_{CE} = −12 V, I_E = 1.5 mA, f = 30 MHz	R_{ie}	100	Ω
Output Resistance (ac input circuit shorted):			
V_{CB} = −12 V, I_E = 1.5 mA, f = 50 MHz	R_{oe}	8000	Ω
V_{CE} = −12 V, I_E = 1.5 mA, f = 30 MHz	R_{oe}	8000	Ω
Power Gain, Single-Tuned Unilateral Circuit):			
V_{CB} = −12 V, I_E = 1.5 mA, f = 50 MHz	G_{pe}	18 to 24	dB
V_{CE} = −12 V, I_E = 1.5 mA, f = 30 MHz	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 Hz to 11 MHz	
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 up to 25°C	P_T	120	mW
T_A above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (Ambient)	T_A(opr)	85	°C
Storage	T_{STG}	−65 to 85	°C
Lead-Soldering Temperature (10s max)	T_L	255	°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 Saturation Voltage:			
I_C = 20 mA, I_B = 0.67 mA	$V_{BE}(sat)$	0.4 max	V
I_C = 200 mA, I_B = 10 mA	$V_{BE}(sat)$	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
Collector-Cutoff Current (V_{CB} = 12 V, I_E = 0)	I_{CBO}	8 max	µA
Emitter-Cutoff Current (V_{BE} = 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	MHz
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 µA, I_B = 0)	$V_{(BR)CEO}$	12 min	V
Base-to-Emitter Saturation Voltage:			
I_C = 20 mA, I_B = 0.5 mA	$V_{BE}(sat)$	0.35 max	V
I_C = 200 mA, I_B = 6.7 mA	$V_{BE}(sat)$	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
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	MHz
Stored Base Charge (I_C = 20 mA, I_B = 1 mA)	Q_S	1000 max	pC

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
Collector Current	I_C	−10	mA
Transistor Dissipation:			
T_A = 25°C	P_T	80	mW
Temperature Range:			
Operating (Ambient)	$T_A(opr)$	−65 to 71	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (V_{BE} = 0.5 V, I_C = −50 µA)	$V_{(BR)CBO}$	−30 min	V

CHARACTERISTICS (cont'd)

Collector-Cutoff Current (V_{CB} = −12 V, I_E = 0)	I_{CBO}	−12 max	μA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	100 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency	f_{hfb}	140	MHz
Output Capacitance	C_{obo}	2	pF
Power Gain (f = 100 MHz)	G_{pe}	14	dB

2N1178 TRANSISTOR

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 item:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	40 min

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} = −12 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	80 min	
Oscillator Injection Voltage (f = 100 MHz)		125 max	mV
Power Gain (f = 100 MHz)	G_{pe}	17	dB

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:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	80 min	
Small-Signal Forward-Current Transfer Ratio Cutoff Frequency (V_{CB} = −12 V, I_C = −1 mA)	f_{hfb}	100	MHz
Power Gain (f = 10.7 MHz)	G_{pe}	35	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.

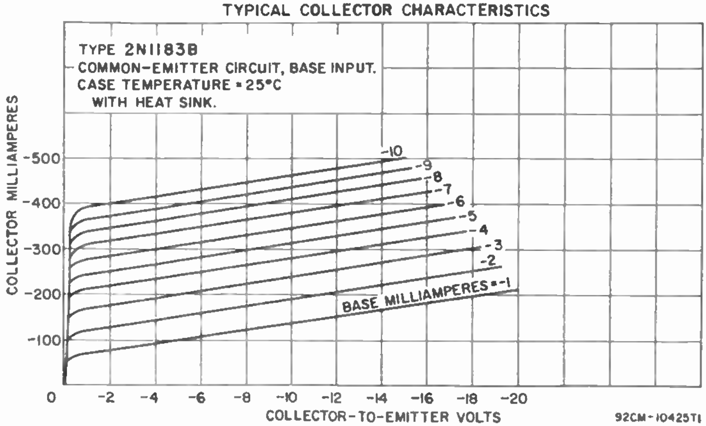
MAXIMUM RATINGS

		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 116		
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 116		
Temperature Range:					
Operating (Ambient)	T_A(opr)		−65 to 100		°C
Storage	T_{STG}		−65 to 100		°C

CHARACTERISTICS (At mounting-flange temperature = 25°C.)

		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
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	MHz
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

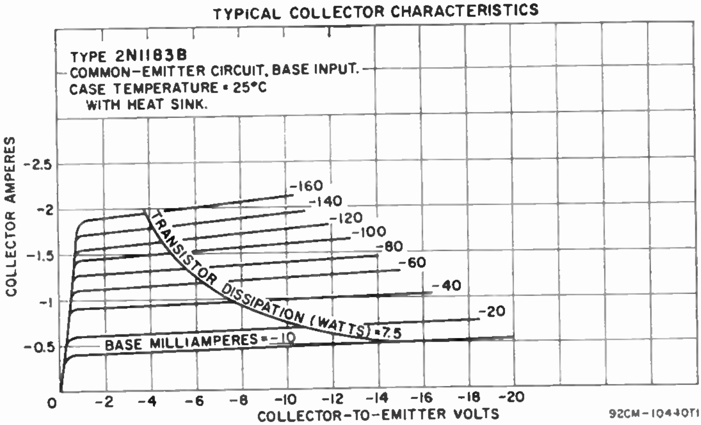
TYPICAL COLLECTOR CHARACTERISTICS



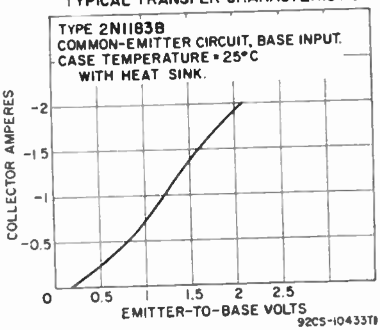
TYPICAL OPERATION IN POWER-SWITCHING CIRCUIT

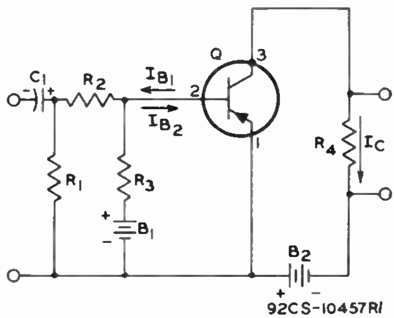
DC Supply Voltage	V_{CC}	−12	V
DC Base-Bias Voltage	V_{BB}	12	V
"On" DC Collector Current	I_C	−400	mA
"Turn-On" Base Current	I_{B1}	−40	mA
"Turn-Off" Base Current	I_{B2}	40	mA
Generator Resistance	R_G	50	Ω
Delay Time	t_d	0.2	μs
Rise Time	t_r	2	μs
Storage Time	t_s	1.8	μs
Fall Time	t_f	1.4	μs

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

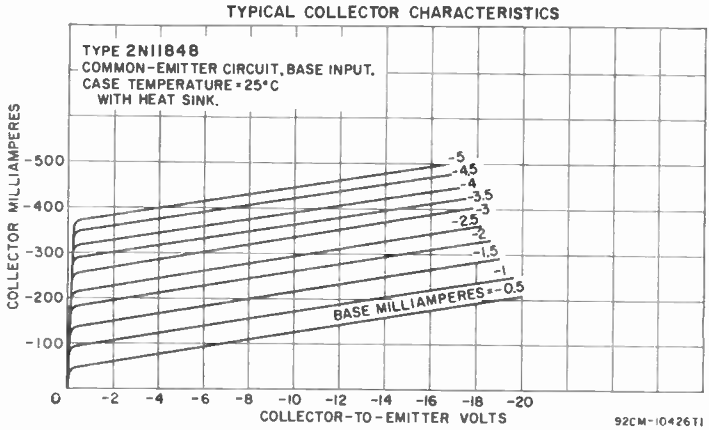
2N1184
2N1184A
2N1184B

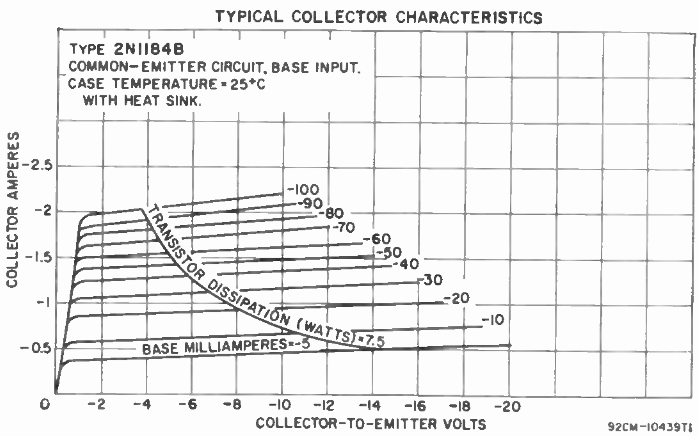
POWER TRANSISTORS

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 (At mounting-flange temperature = 25°C.)

		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





TRANSISTOR 2N1224

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.

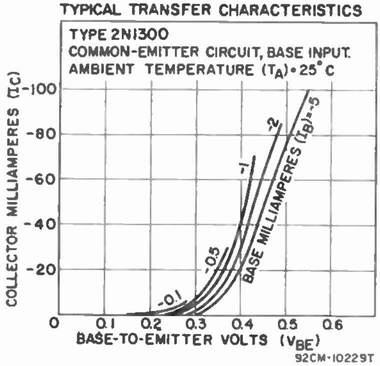
MAXIMUM RATINGS

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	225	°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
Collector-to-Emitter Breakdown Voltage	$V_{(BR)CEL}$	−12	V
Base-to-Emitter Voltage (I_C = −10 mA, I_B = −0.33 mA)	V_{BE}	−0.4 max	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	MHz
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	MHz
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

* This rating may be exceeded and the emitter-to-base junction operated in the breakdown condition provided the emitter dissipation is limited to 30 millivolts at 25°C. For ambient temperatures above 25°C, reduce the dissipation by 0.5 millivolts per °C.

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

MAXIMUM RATINGS (cont'd)

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 116	
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	MHz
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 116	
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	MHz
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

CHARACTERISTICS (cont'd)

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	MHz

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	MHz

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	MHz

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
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	MHz

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	MHz

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:

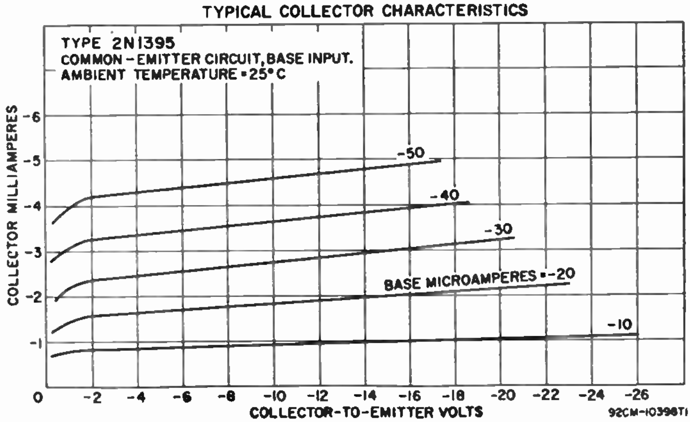
CHARACTERISTICS

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	MHz

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 indus-

TYPICAL COLLECTOR CHARACTERISTICS



trial 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 item:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12 V, I_E = 1.5 mA, f = 1 kHz)	h_{fe}	50 to 175

TRANSISTOR 2N1396

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 item:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12 V, I_E = 1.5 mA, f = 1 kHz)	h_{fe}	50 to 175

TRANSISTOR 2N1397

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 item:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12 V, I_E = 1.5 mA, f = 1 kHz)	h_{fe}	50 to 175

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

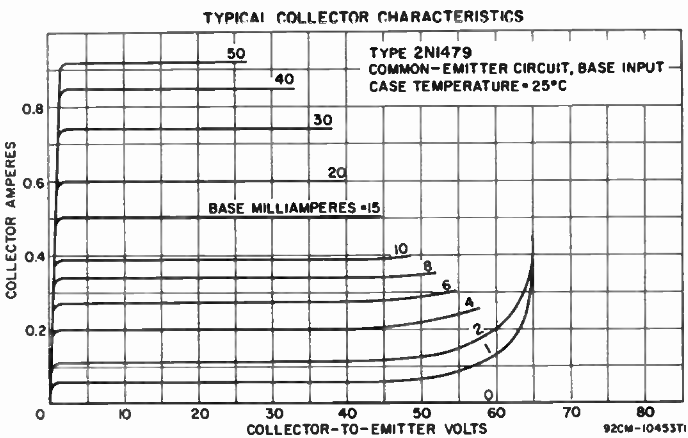
Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	60	V
Base open (sustaining voltage)	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	12	V
Collector Current	I_C	1.5	A
Emitter Current	I_E	−1.75	A
Base Current	I_B	1	A
Transistor Dissipation:			
T_C up to 25°C	P_T	5	W
T_C above 25°C	P_T	See curve page 116	
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
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 kHz)	h_{fe}	50	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 28 V, I_C = 5 mA)	f_{hfb}	1.5	MHz
Gain-Bandwidth Product	f_T	50 max	kHz
Output Capacitance (V_{CB} = 40 V, I_C = 0, f = 1 kHz)	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
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



2N1480

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. 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

POWER TRANSISTOR 2N1483

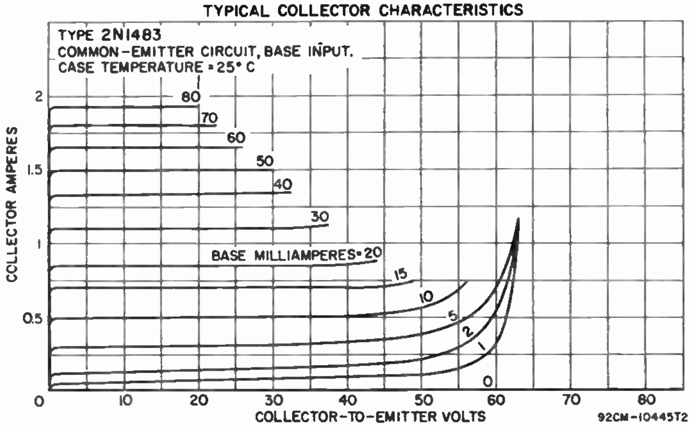
Si **n-p-n diffused-junction** type used in dc-to-dc converters, inverters, choppers, dc and servo amplifiers, relay- and solenoid-actuating circuits in industrial and military equipment. JEDEC TO-8, Outline No.5. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

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 116	
Temperature Range:			
Operating (T_C) and Storage (T_{STG})		−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	235	°C

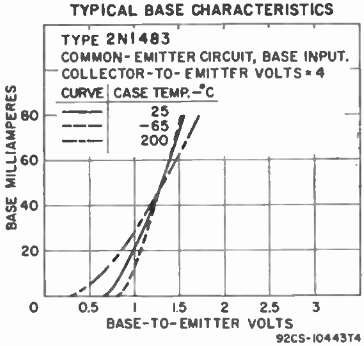
CHARACTERISTICS (At case temperature = 25°C)

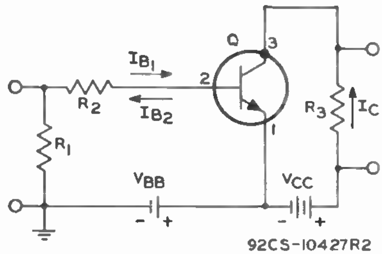
Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 0.25 mA)	V_{CEV}	60 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 750 mA)	V_{BE}	3.5 max	V
Collector-Cutoff Current:			
V_{CB} = 30 V, I_E = 0, T_A = 25°C	I_{CBO}	15 max	µA
V_{CB} = 30 V, I_E = 0, T_A = 150°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	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = 28 V, I_C = 5 mA)	f_{hfb}	1.25	MHz
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	
Collector-to-Emitter Saturation Resistance (I_C = 750 mA, I_B = 40 mA)	r_{CE}(sat)	1 max	Ω

POWER TRANSISTOR 2N1486

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)

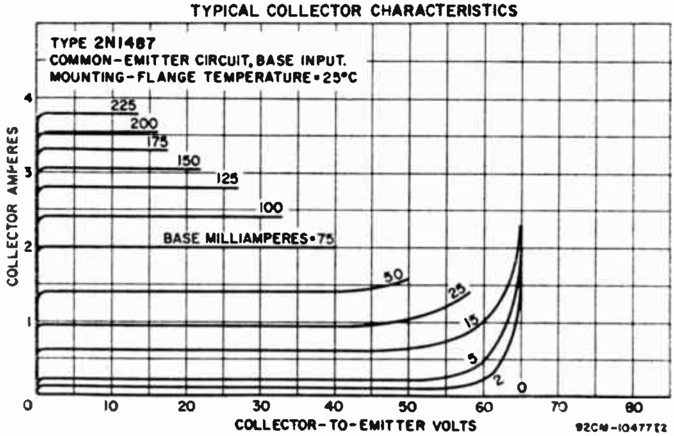
Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	55 min	V
Collector-to-Emitter Voltage ($V_{BE} = -1.5$ V, I_C = 0.25 mA)	V_{CEV}	100 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 750 mA)	V_{BE}	2.5 max	V
Static Forward-Current Transfer Ratio (V_{CE} = 4 V, I_C = 750 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 116	
Temperature Range:			
Operating (T_{MF}) and Storage (T_{STG})		−65 to 200	°C

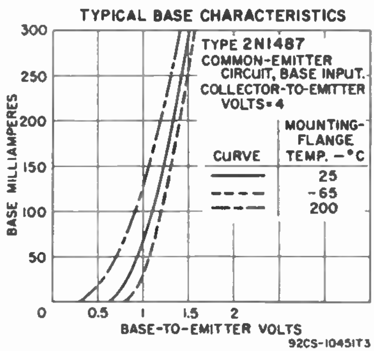


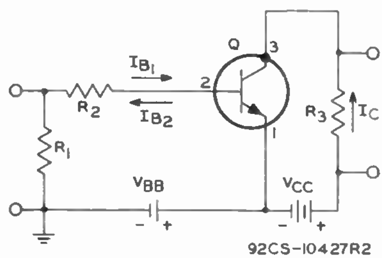
CHARACTERISTICS (At mounting-flange temperature = 25°C)

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
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	MHz
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-39, **Outline** No. 12. **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	100	mA
Base Current	I_B	20	mA
Emitter Current	I_E	−100	mA
Transistor Dissipation:			
T_C up to 25°C	P_T	3	W
T_C above 25°C	P_T	See curve page 116	

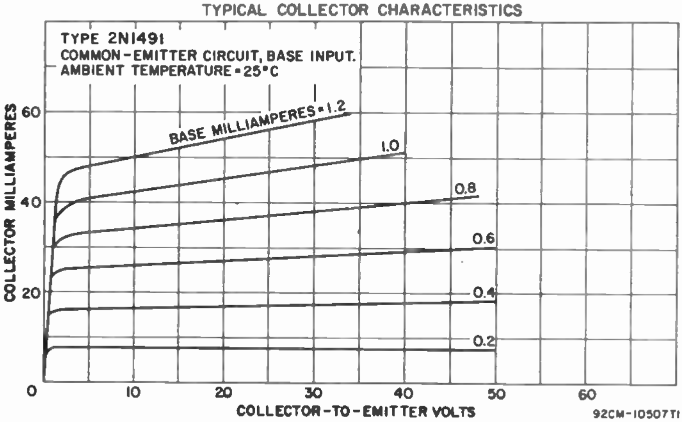
MAXIMUM RATINGS (cont'd)

Temperature Range:			
Operating (T_C) and Storage (T_{STG})		−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

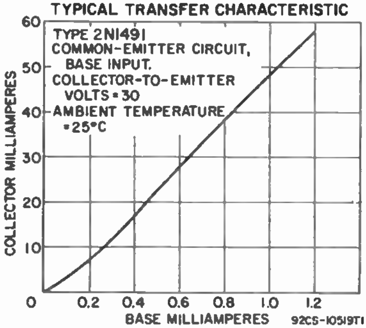
CHARACTERISTICS

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 kHz)	h_{fe}	15 to 200	
Gain-Bandwidth Product (V_{CB} = 30 V, I_C = 15 mA)	f_T	300	MHz
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 0.15 MHz)	C_{obo}	5 max	pF
Small-Signal Power Gain (V_{CB} = 15 V, I_E = −15 mA, P_{oe} = 10 mW, f = 70 MHz)	G_{pe}	13 min	dB
Thermal Resistance, Junction-to-Case	θ_{J-C}	50	°C/W

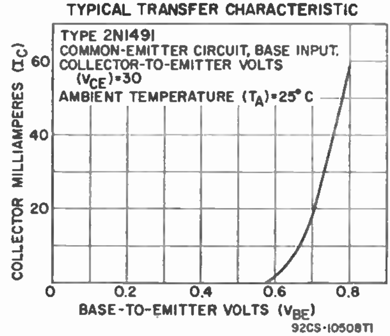
TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC



TYPICAL TRANSFER CHARACTERISTIC



TRANSISTOR 2N1492

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-39, Outline No.12. 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_{CB} = 30 V, I_E = —15 mA, P_{oe} = 100 mW, f = 70 MHz)	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-39, Outline No. 12. **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_{CB} = 50 V, I_E = —25 mA, P_{oe} = 500 mW, f = 70 MHz)	G_{pe}	10 min	dB

2N1524 TRANSISTOR

Ge p-n-p drift-field type used in 455-kHz 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

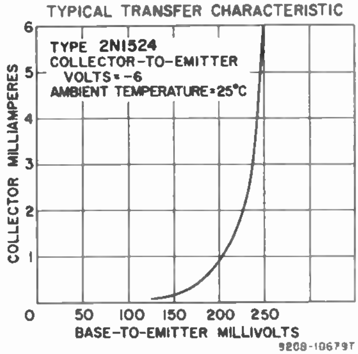
Collector-to-Base Voltage	V_{CBO}	—24	V
Emitter-to-Base Voltage	V_{EBO}	—0.5	V
Collector Current	I_C	—10	mA
Emitter Current	I_E	10	mA
Transistor Dissipation:			
T_A = 25°C	P_T	80	mW
T_A = 55°C	P_T	50	mW
T_A = 71°C	P_T	35	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	—65 to 71	°C
Storage	T_{STG}	—65 to 85	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (V_{EB} = —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 (V_{CE} = —12 V, I_E = —1 mA, f = 1 kHz)	h_{fe}	60	
Collector-to-Base Feedback Capacitance (V_{CE} = —8.5 V, I_E = 1 mA)	C_{cb}	2.1	pF
Maximum Available Amplifier Gain▲ (V_{CE} = —8.5 V, I_E = 1 mA, f = 455 kHz)	MAG•	52.4	dB

CHARACTERISTICS (cont'd)

Maximum Usable Amplifier Gain, Unneutralized▲ (V_{CE} = −8.5 V, I_E = 1 mA, f = 455 kHz)	MUG	30	dB
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	0.4	°C/mW



▲ This characteristic does not apply to type 2N1526.
• Measured in a single-tuned unilateralized circuit matched to the generator and load impedances for maximum transfer of power (transformer insertion losses not included).

TRANSISTOR 2N1525

Ge p-n-p drift-field type used in 455-kHz 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_{CE} = −12 V, I_E = 1 mA, f = 1 kHz)	h_{fe}	130	
Maximum Available Conversion Power Gain (V_{CE} = −8 V, I_E = 0.65 mA, f = 1.5 MHz)	MAG_C	46.1	dB
Maximum Usable Conversion Power Gain (V_{CE} = −8 V, I_E = 0.65 mA, f = 1.5 MHz)	MUG_C	34.5	dB
Base-to-Emitter Oscillator-Injection Voltage (V_{CE} = −8 V, I_E = 0.65 mA)		100	mV(rms)

TRANSISTOR 2N1527

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

			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 116		
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 min 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	MHz
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 MHz)	C_{obo}	20	20 max	pF

2N1613

TRANSISTOR

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 (At case temperature = 25°C)

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 kHz	h_{fe}	30 to 100	
V_{CE} = 10 V, I_C = 50 mA, f = 20 MHz	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 kHz, R_G = 510 Ω, circuit bandwidth = 1 Hz)	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
Collector Current	I_C	−10	mA
Transistor Dissipation:			
T_A = 25°C	P_T	80	mW
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 71	°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
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	80 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CB} = −12 V, I_E = 1 mA)	f_{hfb}	45	MHz
Output Capacitance	C_{obo}	2	pF
Power Gain (f = 1.5 MHz)	G_{pe}	47.7	dB
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	0.4 max	°C/W

TRANSISTOR 2N1632

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.

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)	−65 to 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 = −0.05 mA, 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 = 0.05 mA)	I_{EBO}	−16 max	μA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12V, I_E = 1 mA, f = 1 kHz)	h_{fe}	40 to 170	
Collector-to-Base Feedback Capacitance (V_{CE} = −8.5 V, I_E = 1 mA)	C_{cb}	2.1	pF
Maximum Available Amplifier Gain* (V_{CE} = −8.5 V, I_E = 1 mA, f = 1 kHz)	MAG	44.3	dB
Maximum Usable Amplifier Gain, Unneutralized (V_{CE} = −8.5 V, I_E = 1 mA, f = 1.5 kHz)	MUG	25.5	dB

* Measured in a single-tuned unilateralized circuit matched to the generator and load impedances for maximum transfer of power (transformer insertion losses not included).

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.

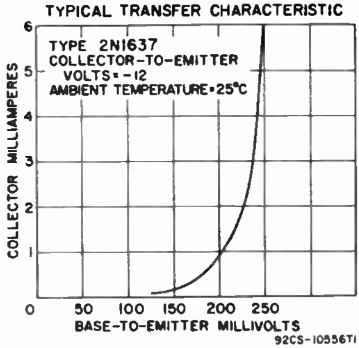
MAXIMUM RATINGS

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)	−65 to 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}	−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} = −12 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	80	
Collector-to-Base Feedback Capacitance (V_{CE} = −12 V, I_C = −1 mA)	C_{cb}	2	pF
Maximum Available Amplifier Gain* (V_{CE} = −11 V, I_E = 1 mA, f = 1.5 MHz)	MAG	47.7	dB

TYPICAL TRANSFER CHARACTERISTIC



CHARACTERISTICS (cont'd)

Maximum Usable Amplifier Gain, Unneutralized (V_{CE} = −11 V, I_E = 1 mA, f = 1.5 MHz)	MUG	25.6	dB
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	0.4 max	°C/mW

* Measured in a single-tuned unilateralized circuit matched to the generator and load impedances for maximum transfer of power (transformer insertion losses not included).

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:

CHARACTERISTICS

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_C = −1 mA, f = 1 kHz)	h_{fe}	75	
Maximum Available Amplifier Gain▲* (V_{CE} = −11 V, I_E = 2 mA, f = 262.5 kHz)	MAG	61.5	dB
Maximum Usable Amplifier Gain, Unneutralized▲ (V_{CE} = −11 V, I_E = 2 mA, f = 262.5 kHz)	MUG	36.6	dB
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	0.4 max	°C/mW

▲ This characteristic does not apply to type 2N1639.

* Measured in a single-tuned unilateralized circuit matched to the generator and load impedances for maximum transfer of power (transformer insertion losses not included).

TRANSISTOR 2N1639

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:

CHARACTERISTICS

Small-Signal Forward-Current Transfer Ratio (V_{CE} = −12 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	75	
Maximum Usable Conversion Power Gain (V_{CE} = −11 V, I_E = 0.25 mA, f = 1.5 MHz)	MUG_C	37	dB
Base-to-Emitter Oscillator-Injection Voltage (RMS) (V_{CE} = −11 V, I_E = 0.25 mA)		100	mV(rms)

COMPUTER TRANSISTOR 2N1683

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	MHz
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.

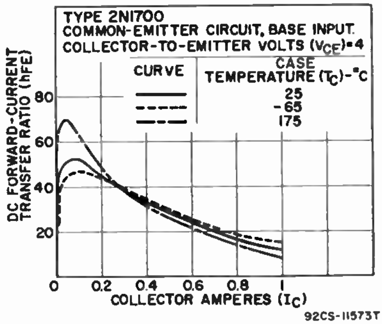
MAXIMUM RATINGS

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
Transistor Dissipation:			
T_C up to 25°C	P_T	5	W
T_C above 25°C	P_T	See curve page 116	
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)

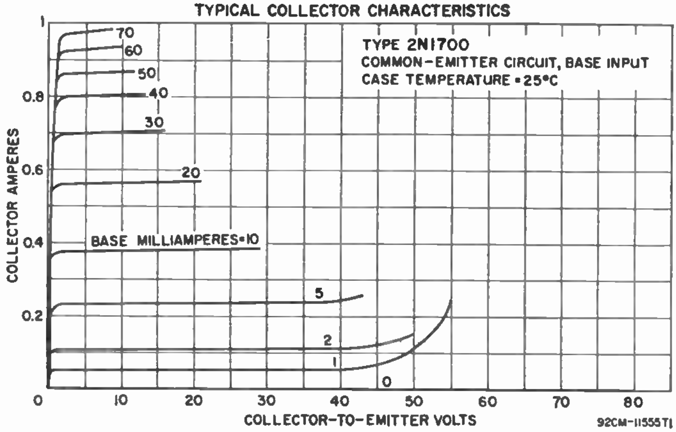
Collector-to-Emitter Sustaining Voltage (I_C = 50 mA, I_B = 0)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 0.5 mA)	V_{CEV}	60 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 100 mA)	V_{BE}	2 max	V
Collector-Cutoff Current:			
V_{CB} = 30 V, I_E = 0, T_C = 25°C	I_{CBO}	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	

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



CHARACTERISTICS (cont'd)

Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	200 max	°C/W



POWER TRANSISTOR **2N1701**

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 116	
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	235	°C

CHARACTERISTICS

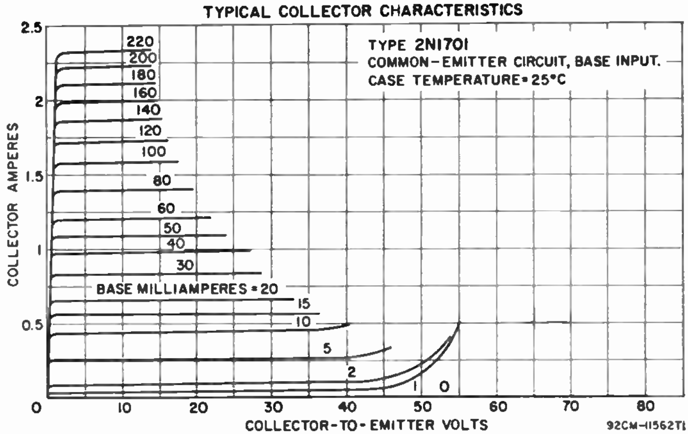
Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5, I_C = 0.75 mA)	V_{CEV}	60 min	V
Collector-to-Emitter Saturation Voltage: (I_C = 2.5 A, I_B = 1 A)	V_{CE}(sat)	12.5 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 300 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

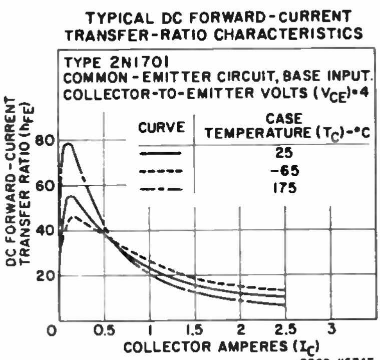
CHARACTERISTICS (cont'd)

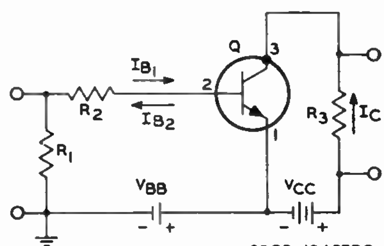
Static Forward-Current Transfer Ratio:			
V_{CE} = 4 V, I_C = 300 mA	h_{FE}	20 to 80	
V_{CE} = 20 V, I_C = 2.5 A	h_{FE}	5 min	
Thermal Resistance, Junction-to-Case	Θ_{J-C}	7 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	100 max	°C/W

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

2N1702 POWER TRANSISTOR

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.

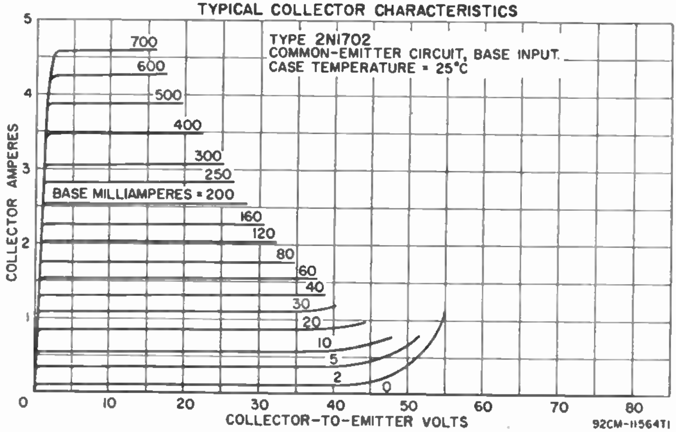
MAXIMUM RATINGS

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 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C

CHARACTERISTICS

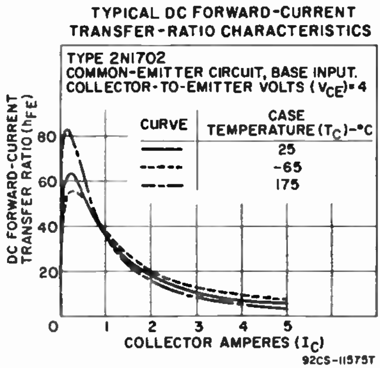
Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0)	V_{CEO}(sus)	40 min	V
Collector-to-Emitter Voltage (V_{BE} = −1.5 V, I_C = 1 mA)	V_{CEV}	60 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 800 mA)	V_{BE}	4 max	V
Collector-Cutoff Current:			
V_{CB} = 30 V, I_E = 0, T_C = 25°C	I_{CBO}	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	
Thermal Resistance, Junction-to-Case	θ_{J-C}	2.33 max	°C/W

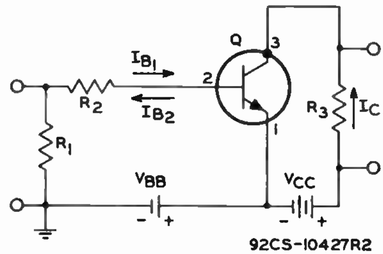
TYPICAL COLLECTOR CHARACTERISTICS



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

2N1711 TRANSISTOR

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

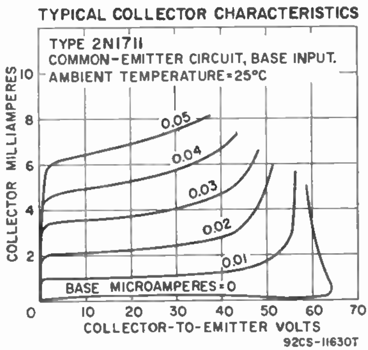
Collector-to-Base Voltage	V_{CBO}	75	V
Collector-to-Emitter Voltage ($R_{BE} \leqq 10\ \Omega$)	V_{CER}	50	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.8	W
T_C up to 25°C	P_T	3	W
T_A or T_C above 25°C	P_T	See curve page 116	
Temperature 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

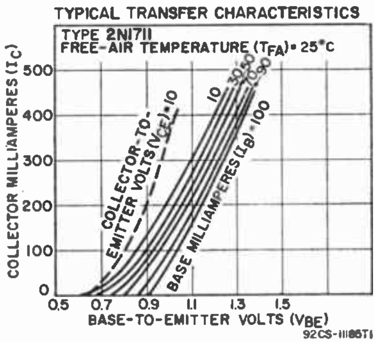
CHARACTERISTICS (At case temperature = 25°C)

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 Ω, I_C = 100 mA, 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)	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 μs, df = 1.8%)	h_{FE}(pulsed)	75min	
V_{CE} = 10 V, I_C = 150 mA, t_p = 300 μs, df = 1.8%	h_{FE}(pulsed)	100 to 300	
V_{CE} = 10 V, I_C = 500 mA, t_p = 300 μs, 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 = 0.1 mA, T_C = 25°C	h_{FE}	35 min	
V_{CE} = 10 V, I_C = 10 mA, T_C = —55°C	h_{FE}	35 min	

CHARACTERISTICS (cont'd)

Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 1 mA, f = 1 kHz	h_{fe}	50 to 200	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{fe}	70 to 300	
V_{CE} = 10 V, I_C = 50 mA, f = 20 MHz	h_{fe}	3.5 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}	25 max	pF
Noise Figure (V_{CE} = 10 V, I_C = 0.3 mA, R_G = 50Ω, f = 1 kHz, circuit bandwidth = 1 Hz)	NF	8 max	dB
Input Resistance (V_{CB} = 10 V, I_C = 5 mA, f = 1 kHz)	h_{ib}	4 to 8	Ω
Voltage-Feedback Ratio (V_{CB} = 10 V, I_C = 5 mA, f = 1 kHz)	h_{rb}	5×10^{-4} max	
Output Conductance (V_{CB} = 10 V, I_C = 5 mA, f = 1 kHz)	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





COMPUTER TRANSISTOR 2N1853

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	mA
Transistor Dissipation:†			
T_A up to 25°C	P_T	150	mW
T_A above 25°C	P_T	See curve page 116	
Emitter-to-Base Dissipation (Under breakdown conditions with reverse bias)	P_T	25	mW
Ambient-Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−55 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

CHARACTERISTICS (cont'd)

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	
Storage Time■ (V_{CC} = −15 V, R_G = 100 Ω)	t_s	0.8 max	μs
Turn-On Time■ (V_{CC} = −15 V, R_G = 100 Ω)	$t_d + t_r$	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 = −20 mA, I_B = −0.5 mA	V_{CE}(sat)	−0.3	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	
V_{CE} = −0.75 V, I_C = −100 mA	h_{FE}	25 min	
Gain-Bandwidth Product (V_{CE} = −1 V, I_C = −10 mA, h_{fe} = 5)	f_T	40 min	MHz
Output Capacitance (V_{CB} = −10 V, I_E = 0, f = 140 kHz)	C_{obo}	12 max	pF
Charge Storage Time:			
I_C = −20 mA, I_{B1} = −1.5 mA, V_{CC} = −15 V, R_L = 750 Ω	tQ_s	60 max	ns
I_C = −80 mA, I_{B1} = −4.5 mA, V_{CC} = −15 V, R_L = 750 Ω	tQ_s	80 max	ns

2N1893 TRANSISTOR

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

MAXIMUM RATINGS (cont'd)

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 116	
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 = 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
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 kHz	h_{fe}	30 to 100	
V_{CE} = 10 V, I_C = 50 mA, f = 20 MHz	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	MHz
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 kHz)	h_{ib}	20 to 30	Ω
Voltage-Feedback Ratio:			
V_{CB} = 5 V, I_C = 1 mA, f = 1 kHz	h_{rb}	1.25 x 10^{-4} max	
V_{CB} = 10 V, I_C = 5 mA, f = 1 kHz	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

POWER TRANSISTOR 2N1905

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 116	
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)

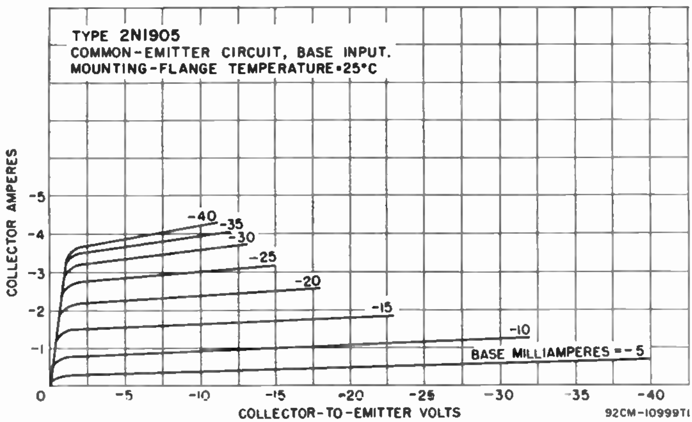
Collector-to-Base Breakdown Voltage (I_C = −10 mA, I_E = 0)	$V_{(BR)CBO}$	−100 min	V
Collector-to-Emitter Breakdown Voltage (I_C = −100 mA, I_B = 0)	$V_{(BR)CEO}$	−50 min	V
Emitter-to-Base Breakdown Voltage (I_E = 5 mA, I_C = 0)	$V_{(BR)EBO}$	−1.5 min	V
Collector-to-Emitter Saturation Voltage (I_C = −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}	− 0.38 typ; −0.5 max	V
Collector-Cutoff Current (V_{CB} = 40 V, I_E = 0)	I_{CBO}	−1 max	mA

CHARACTERISTICS (cont'd)

Emitter-Cutoff Current (V_{EB} = −0.5 V, I_C = 0)	I_{EBO}	−1 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	
Collector-Cutoff Saturation Current			
(V_{CB} = −0.5 V, I_E = 0)	I_{CBO}(sat)	−100	μA
Gain-Bandwidth Product (V_{CE} = −5 V, I_C = −0.5 A)	f_T	2 min	MHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

* This value may be exceeded provided that the power dissipated in the emitter under breakdown conditions is limited to 5 watts.

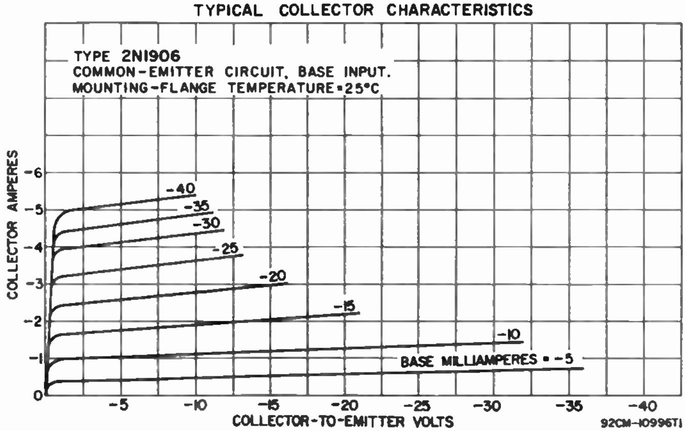
TYPICAL COLLECTOR CHARACTERISTICS



2N1906 POWER TRANSISTOR

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:

TYPICAL COLLECTOR CHARACTERISTICS



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)

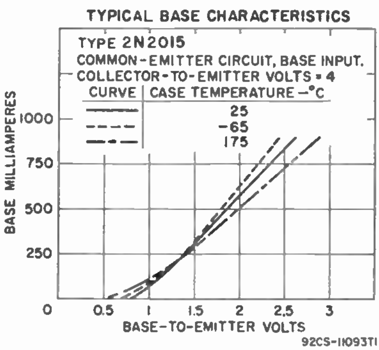
Collector-to-Emitter Saturation Voltage (I_C = −5 A, I_B = −0.25 A)	$V_{CE}(sat)$	−0.5 max	V
Base-to-Emitter Voltage:			
V_{CE} = −2 V, I_C = −1 A	V_{BE}	−0.5 max	V
V_{CE} = −2 V, I_C = −5 A	V_{BE}	−0.9 max	V
Static Forward-Current Transfer Ratio:			
V_{CE} = −2 V, I_C = −5 A	h_{FE}	75 max	
V_{CE} = −2 V, I_C = −1 A	h_{FE}	75 to 250	
Gain Bandwidth Product (V_{CE} = −5 V, I_C = −0.5 A)	f_T	3 min	MHz

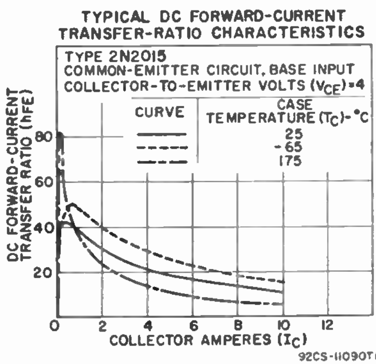
POWER TRANSISTOR 2N2015

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 116	
Temperature Range:			
Operating (T_C) and Storage (T_{STG})		−65 to 200	°C
Lug-Soldering Temperature (10 s max)	T(lug)	235	°C



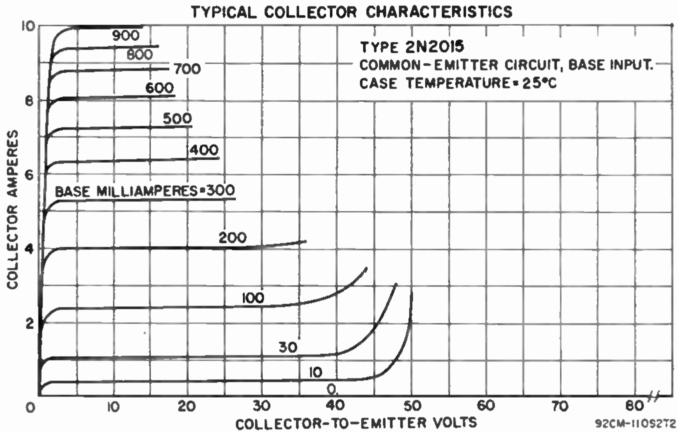


CHARACTERISTICS (At case temperature = 25°C)

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

CHARACTERISTICS (cont'd)

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 kHz)	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	kHz
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 MHz)	C_{obo}	400 max	pF
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.17 max	°C/W



2N2016 POWER TRANSISTOR

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 (At case temperature = 25°C)

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_{CE} = 130 V, V_{BE} = −1.5 V)	I_{CEV}	2 max	mA

TRANSISTOR 2N2102

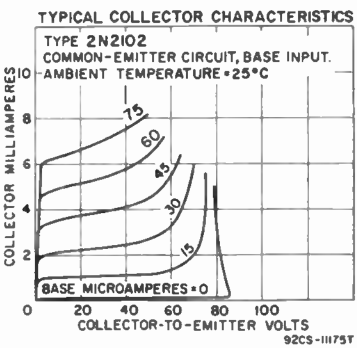
Si n-p-n triple-diffused planar type used in small-signal and medium-power applications in industrial and military equipment. This type features exceptionally low-noise low-leakage characteristics, high switching speed, and high pulse h_{FE}. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

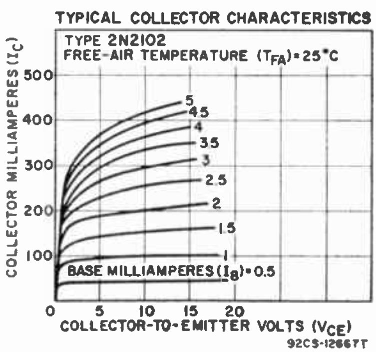
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	120	V
Collector-to-Emitter Voltage:			
$R_{BE} \leq 10\ \Omega$	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 116	
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_{CB} = 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_{CE} = 5 V, I_C = 1 mA, f = 1 kHz	h_{fe}	40 to 125	
V_{CE} = 10 V, I_C = 5 mA, f = 1 kHz	h_{fe}	45 to 190	
V_{CE} = 10 V, I_C = 50 mA, f = 20 MHz	h_{fe}	6 min	





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 kHz	h_{ib}	24 to 34	Ω
V_{CB} = 10 V, I_C = 5 mA, f = 1 kHz	h_{ib}	4 to 8	Ω
Small-Signal Reverse-Voltage (Feedback) Transfer Ratio:			
V_{CB} = 5 V, I_C = 1 mA, f = 1 kHz	h_{rb}	3×10^{-4} max	
V_{CB} = 10 V, I_C = 5 mA, f = 1 kHz	h_{rb}	3×10^{-4} max	
Output Conductance:			
V_{CB} = 5 V, I_C = 1 mA, f = 1 kHz	h_{ob}	0.1 to 0.5	μmho
V_{CB} = 10 V, I_C = 5 mA, f = 1 kHz	h_{ob}	0.1 to 1	μmho
Noise Figure (V_{CE} = 10 V, I_C = 0.3 mA, f = 1 kHz, R_G = 510 Ω, circuit bandwidth = 1 Hz)	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.

2N2147 POWER TRANSISTOR

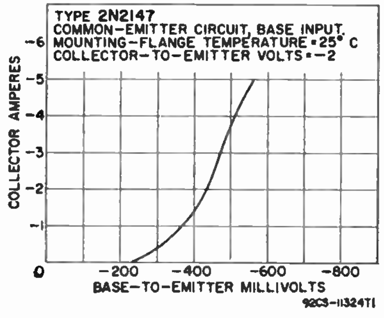
Ge **p-n-p drift-field** type used in high-fidelity amplifiers where wide frequency range and low distortion are required. JEDEC TO-3, **Outline No.2.** **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

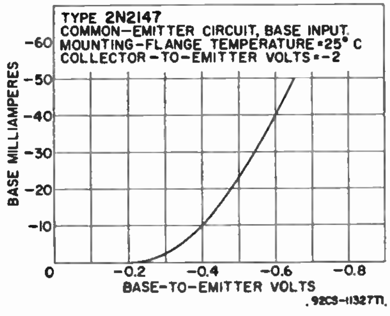
Collector-to-Base Voltage	V_{CBO}	−75	V
Collector-to-Emitter Voltage	V_{CEO}	−50	V
Emitter-to-Base Voltage*	V_{EBO}	−1.5	V
Collector Current	I_C	−5	A
Emitter Current	I_E	5	A
Base Current	I_B	−1	A
Transistor Dissipation:			
T_{MF} up to 81°C	P_T	12.5	W
T_{MF} above 81°C	P_T	Derate linearly 0.66	W/°C
Temperature 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

* 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



CHARACTERISTICS (At mounting-flange temperature = 25°C)

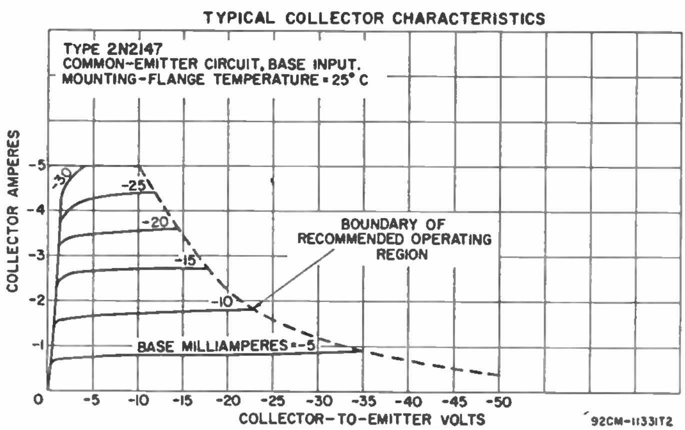
Collector-to-Base Breakdown Voltage (I_C = −10 mA, I_E = 0, t_p = 300 μs, df = 0.01%)	$V_{(BR)CBO}$	−75 min	V
Collector-to-Emitter Sustaining Voltage (I_C = −100 mA, I_B = 0)	V_{CEO}(sus)	−50 min	V

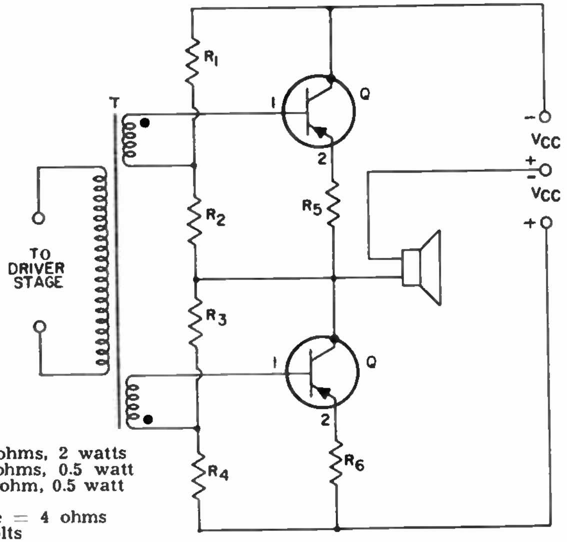
CHARACTERISTICS (cont'd)

Collector-to-Emitter Saturation Voltage (I_B = —250 mA, I_C = —5 A)	V_{CE}(sat)	—0.6 max	V
Base-to-Emitter Voltage: V_{CE} = —10 V, I_C = —50 mA	V_{BE}	—0.2 to —0.27	V
V_{CE} = —2 V, I_C = 1 A	V_{BE}	—0.5 max	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} = —2 V, I_C = —1 A	h_{FE}	100 to 300	
V_{CE} = —2 V, I_C = —4 A	h_{FE}	75 min	
Gain-Bandwidth Product (V_{CE} = —5 V, I_C = —500 mA)	f_T	3 min; 4 typ	MHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	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	—0.035	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
Vcc = 22 volts

2N2148 POWER TRANSISTOR

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:

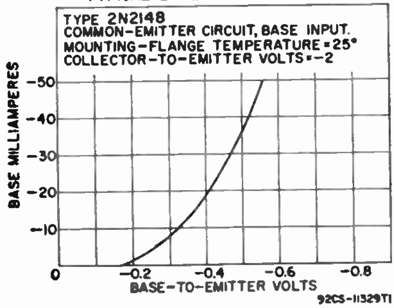
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−60	V
Collector-to-Emitter Voltage	V_{CEO}	−40	V

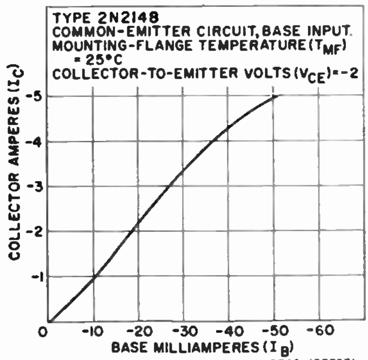
CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Base Breakdown Voltage (I_C = −10 mA, I_E = 0)	$V_{(BR)CBO}$	−60 min	V
Collector-to-Emitter Sustaining Voltage (I_C = −100 mA, I_B = 0)	V_{CEO}(sus)	−40 min	V
Collector-to-Emitter Saturation Voltage (I_C = −5 mA, I_B = −250 mA)	V_{CE}(sat)	−0.75 max	V

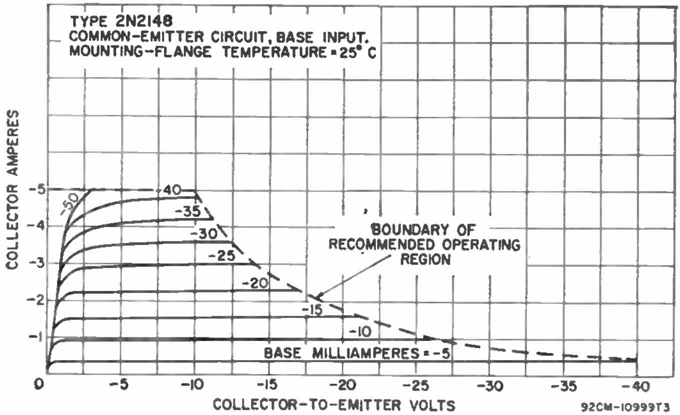
TYPICAL BASE CHARACTERISTIC



TYPICAL TRANSFER CHARACTERISTIC



TYPICAL COLLECTOR CHARACTERISTICS

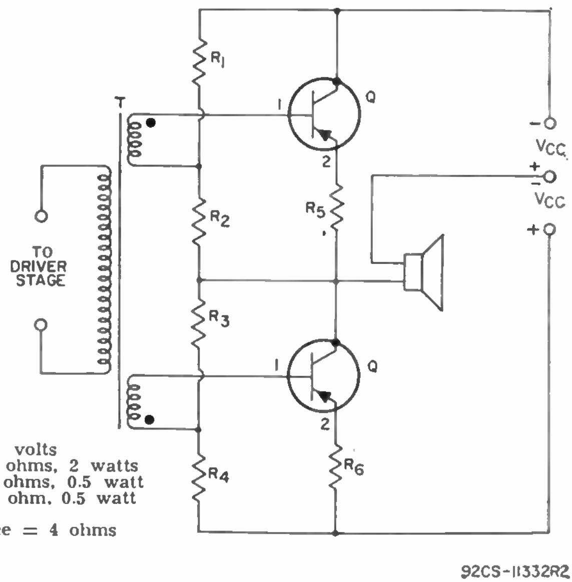


CHARACTERISTICS (cont'd)

Base-to-Emitter Voltage (V_{CE} = −10 V, I_C = −50 mA)	V_{BE}	−0.21 to −0.28	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} = −2 V, I_C = −1 A)	h_{FE}	60 min	
Gain-Bandwidth Product (V_{CE} = −5 V, I_C = −500 mA)	f_T	3 min; 4 typ	MHz

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	−0.035	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	%

2N2205 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-18, **Outline** No.9. **Terminals**: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	25	V
Collector Current	I_C	0.2	A
Transistor Dissipation: T_A = 25°C	P_T	0.3	W
Temperature Range: Operating (Ambient)	T_A(opr)	−65 to 175	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	25 min	V
Collector-to-Emitter Saturation Voltage (I_C = 50 mA, I_B = 5 mA)	V_{CE}(sat)	0.35 max	V
Collector-Cutoff Current (V_{CB} = 15 V, I_E = 0)	I_{CBO}	0.025 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 1 V, I_C = 10 mA)	h_{FE}	20 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 MHz)	C_{obo}	6 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

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.

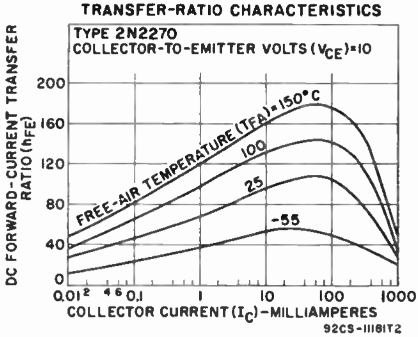
MAXIMUM RATINGS

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 116	
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	
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 kHz	h_{fe}	30 to 180	
V_{CE} = 10 V, I_C = 50 mA, f = 20 MHz	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
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



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.

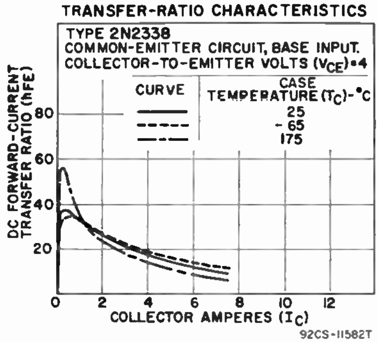
MAXIMUM RATINGS

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 116	
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

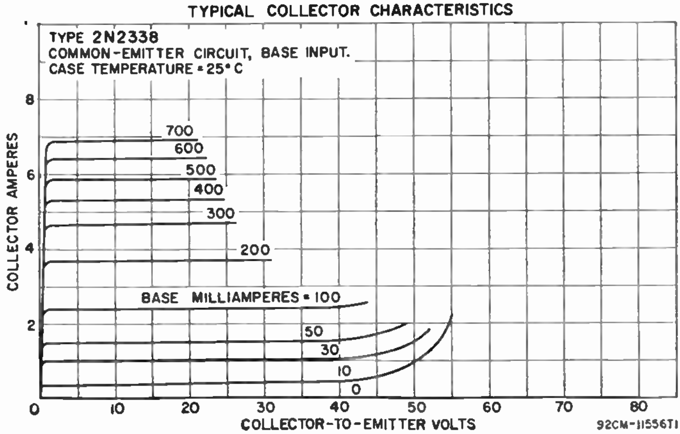
CHARACTERISTICS

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
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 kHz)	h_{fe}	12 to 72	
Output Capacitance (V_{CB} = 40 V, I_E = 0, f = 0.1 MHz)	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	MHz
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 DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



TYPICAL COLLECTOR CHARACTERISTICS



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

COMPUTER TRANSISTOR 2N2369A

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 116	
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, V_{EB} = 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 = 30 mA, I_B = 3 mA	V_{CE}(sat)	0.25 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 = 30 mA, I_B = 3 mA	V_{BE}(sat)	1.15 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, V_{EB} = 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_p = 300 μs, df = 2%	h_{FE}(pulsed)	40 min	
V_{CE} = 0.4 V, I_C = 30 mA, t_p = 300 μs, df = 2%	h_{FE}(pulsed)	30 min	
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 MHz)	h_{fe}	5 min	
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 0.14 MHz)	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

2N2405

POWER TRANSISTOR

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.

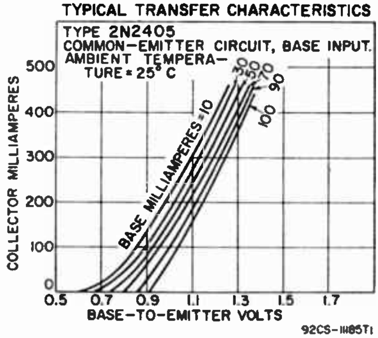
MAXIMUM RATINGS

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 116	
Temperature Range:			
Operating (T_J) and Storage (T_{STG})		−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

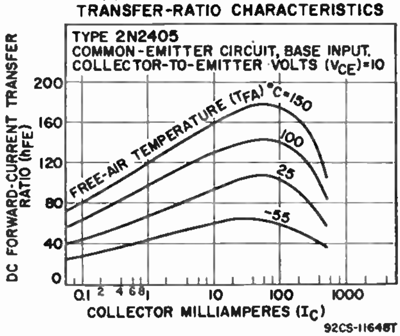
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Base Breakdown Voltage ($I_C = 0.1$ mA, $I_E = 0$)	$V_{(BR)CBO}$	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, $R_{BE} = 10\ \Omega$, $t_p = 300$ µs, df = 1.8%	V_{CER}(sus)	140 min	V
$I_C = 100$ mA, $R_{BE} = 500\ \Omega$, $t_p = 300$ 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
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 kHz	h_{fe}	50 to 275	
$V_{CE} = 10$ V, $I_C = 50$ mA, f = 20 MHz	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	

TYPICAL TRANSFER CHARACTERISTICS



TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



CHARACTERISTICS (cont'd)

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
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 does not apply to type 2N1893.

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.

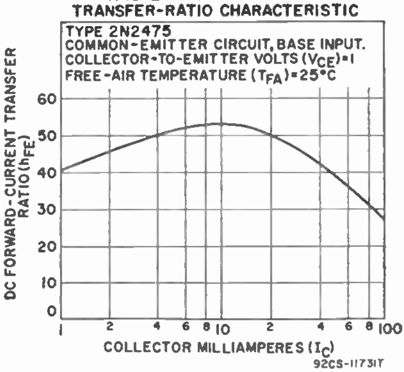
MAXIMUM RATINGS

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	I_C	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 116	
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 ≧ 300 ns, df ≦ 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	
V_{CE} = 0.3 V, I_C = 1 mA, T_A = 25°C	h_{FE}	20 min	

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC



CHARACTERISTICS (cont'd)

Small-Signal Forward-Current Transfer Ratio (V_{CE} = 2 V, I_C = 20 mA, f = 100 MHz)	h_{fe}	6 min	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 0.14 MHz)	C_{ibo}	3 max	pF
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 0.14 MHz)	C_{obo}	2.5 max	pF
Storage Time (I_C = 5 mA, I_{B1} = 5 mA, I_{B2} = 5 mA, V_{CC} = 3 V)	t_s	6 max	ns
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.

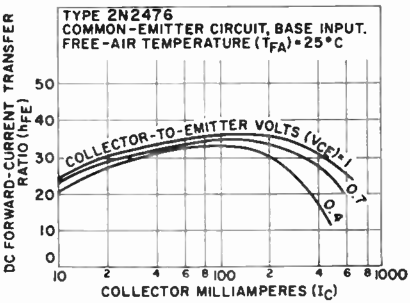
MAXIMUM RATINGS

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	I_C	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 116	
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	200	°C

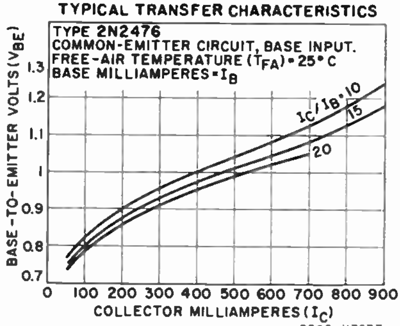
CHARACTERISTICS

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, $t_p \leq$ 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

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



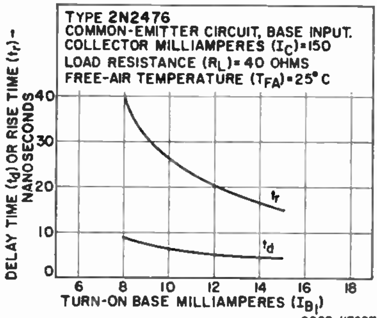
TYPICAL TRANSFER CHARACTERISTICS



CHARACTERISTICS (cont'd)

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 MHz)	h_{fe}	2.5 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 MHz)	C_{obo}	10 max	pF
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



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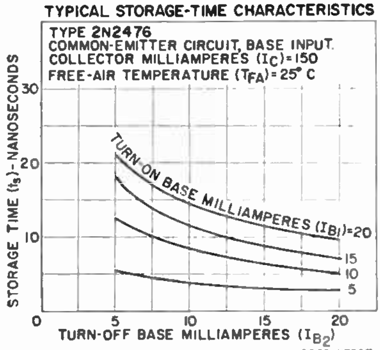
TYPICAL STORAGE-TIME CHARACTERISTICS



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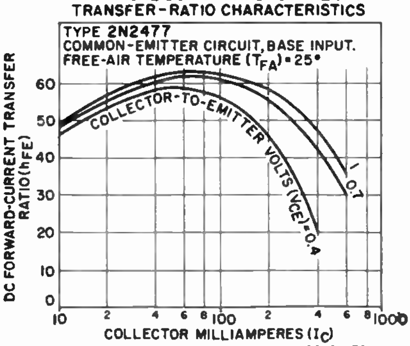
COMPUTER TRANSISTOR 2N2477

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

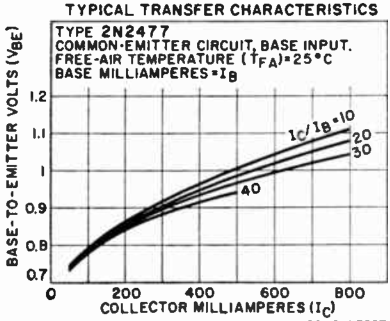
Collector-to-Emitter Saturation Voltage:			
I_C = 150 mA, I_B = 3.75 mA	$V_{CE}(sat)$	0.4 max	V
I_C = 500 mA, I_B = 50 mA	$V_{CE}(sat)$	0.65 max	V
Base-to-Emitter Voltage (I_C = 150 mA, I_B = 3.75 mA)	V_{BE}	0.95 max	V
Static Forward-Current Transfer Ratio (V_{CE} = 0.4 V, I_C = 150 mA)	h_{FE}	40 min	

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



92CS-11756T

TYPICAL TRANSFER CHARACTERISTICS



92CS-11759T

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

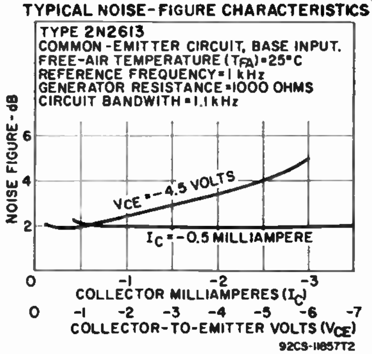
Collector-to-Base Voltage	V_{CBO}	−30	V
Collector-to-Emitter Voltage (R_{BE} = 10 kΩ)	V_{CER}	−25	V
Emitter-to-Base Voltage	V_{EBO}	−25	V
Collector Current	I_C	−50	mA
Emitter Current	I_E	50	mA
Transistor Dissipation:			
T_A up to 55°C	P_T	120	mW
T_A above 55°C	P_T	See curve page 116	
Temperature Range:*			
Operating (Junction)	T_J(opr)	100	°C
Storage	T_{STG}	−65 to 100	°C
Lead-Soldering Temperature (10 s max)			

* This type should not be connected into or disconnected from circuits with the power on because high transient current may cause permanent damage to the transistor.

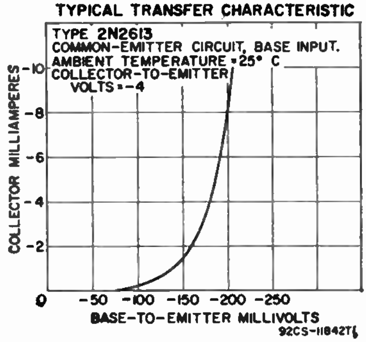
CHARACTERISTICS

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

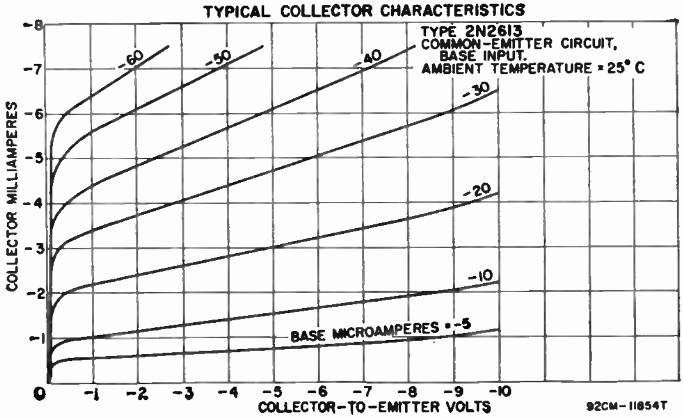
TYPICAL NOISE-FIGURE CHARACTERISTICS



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 V, I_C = —0.5 mA, f = 20 MHz)	$r_{bb'}$	300	Ω
Collector-to-Base Feedback Capacitance (V_{CE} = —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 kHz)	h_{fe}	120 to 300	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = —6 V, I_C = —1 mA)	f_{hfb}	4 min	MHz
RMS Noise Input Current (Equivalent) (V_{CE} = —4.5 V, I_C = —0.5 mA, R_{BE} = 50000 Ω, f = 20 to 20000 Hz)		0.001 max	μA
Noise Figure (Circuit bandwidth = 1.1 kHz, V_{CE} = —4.5 V, I_C = —0.5 mA, R_G = 1000 Ω, f = 1 kHz)	NF	4 max	dB

TRANSISTOR 2N2614

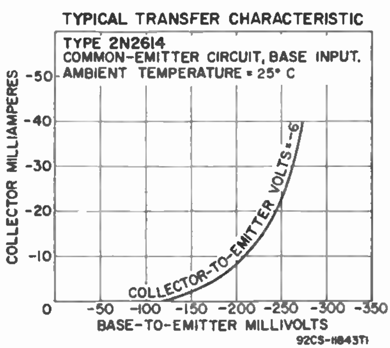
Ge p-n-p alloy-junction type used in small-signal and low-power audio frequency applications. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

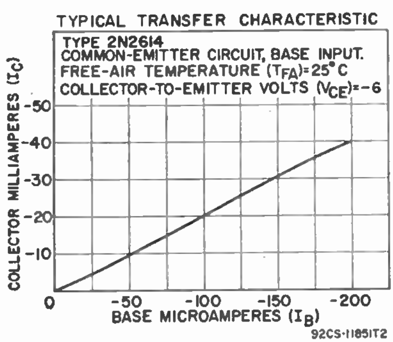
MAXIMUM RATINGS

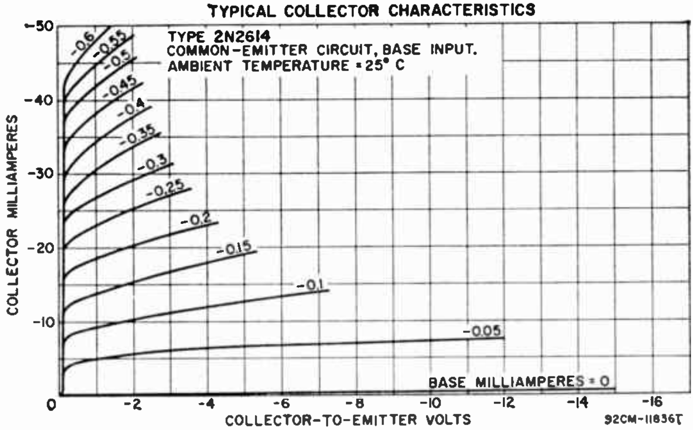
Collector-to-Base Voltage	V_{CBO}	—40	V
Collector-to-Emitter Voltage (R_{BE} = 10 kΩ)	V_{CER}	—35	V
Emitter-to-Base Voltage	V_{EBO}	—25	V
Collector Current	I_C	—50	mA
Emitter Current	I_E	50	mA
Transistor Dissipation:			
T_A up to 55°C	P_T	120	mW
T_C up to 55°C	P_T	300	mW
T_A or T_C above 55°C	P_T	See curve page 116	
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 kHz)	h_{fe}	100 to 250	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = —6 V, I_C = —1 mA)	f_{hfe}	4 min	MHz
Collector-to-Base Feedback Capacitance (V_{CE} = —6 V, I_C = —1 mA)	$c_{b'c}$	12 max	pF
Intrinsic Base-Spreading Resistance (V_{CE} = —6 V, I_C = —1 mA, f = 20 MHz)	$r_{bb'}$	300	Ω







2N2631 POWER TRANSISTOR

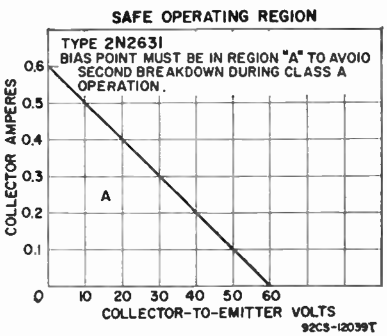
Si **n-p-n triple-diffused planar** type used in large-signal vhf applications such as AM, FM, and cw service at frequencies up to 150 MHz in industrial and military equipment. JEDEC TO-39, **Outline No.12. Terminals:** 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N2876 except for the following items:

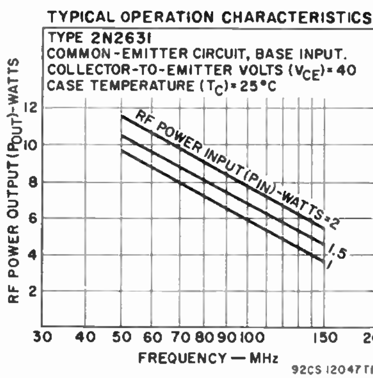
MAXIMUM RATINGS

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 (At case temperature = 25°C)

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 MHz)	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 MHz).

JEDEC TO-72, Outline No.23. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - case.

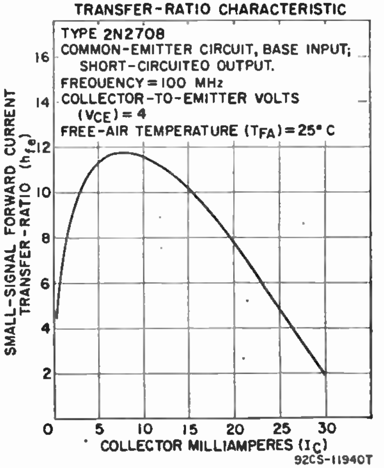
MAXIMUM RATINGS

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	I_C	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 116	
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	265	°C

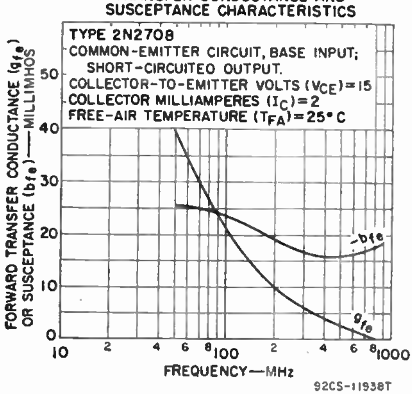
CHARACTERISTICS

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 kHz	h_{fe}	30 to 180	
V_{CE} = 15 V, I_C = 2 mA, f = 100 MHz	h_{fe}	7 to 12	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 0.14 MHz)	C_{ibo}	1.4	pF
Output Capacitance (V_{CB} = 15 V, I_E = 0, f = 0.14 MHz)	C_{obo}	1.5 max	pF
Collector-to-Base Time Constant (V_{CB} = 1.5 V, I_C = 2 mA, f = 31.9 MHz)	$r_b'C_c$	9 to 33	ps
Small-Signal Common-Emitter Power Gain:			
(In neutralized amplifier) V_{CE} = 15 V, I_C = 2 mA, f = 200 MHz	G_{pe}	15 to 22	dB
(In unneutralized amplifier) V_{CE} = 15 V, I_C = 2 mA, f = 200 MHz	G_{pe}	12	dB
Small-Signal Transconductance (V_{CE} = 15 V, I_C = 2 mA, f = 200 MHz)	g_{me}	25	mmhos
Noise Figure:			
V_{CE} = 15 V, I_C = 2 mA, R_S = 50 Ω, f = 200 MHz	NF	7.5 max	dB
V_{CE} = 6 V, I_C = 1 mA, R_S = 400 Ω, f = 60 MHz	NF	3.5	dB

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC



TYPICAL SMALL-SIGNAL FORWARD TRANSFER CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



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 MHz in a common-emitter circuit, and up to 1200 MHz in a common-base circuit. JEDEC TO-72, Outline No.23. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

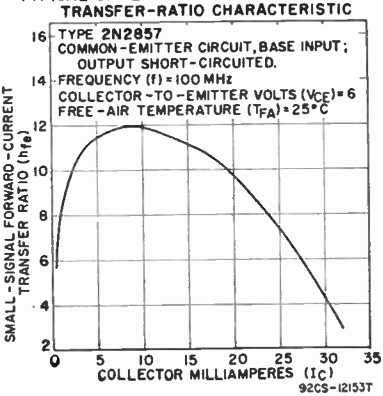
MAXIMUM RATINGS

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	40	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 116	
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	265	°C

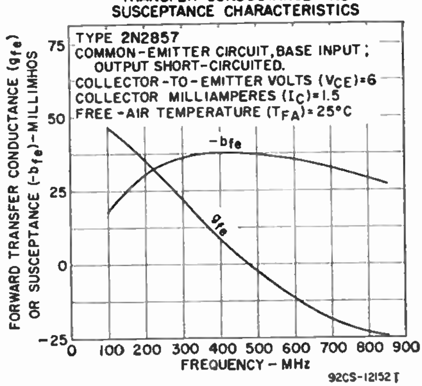
CHARACTERISTICS

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 MHz	h_{fe}	10 to 19	
V_{CE} = 6 V, I_C = 2 mA, f = 1 kHz	h_{fe}	50 to 220	
Collector-to-Base Feedback Capacitance■ (V_{CB} = 10 V, I_E = 0, f = 0.1 to 1 MHz)	C_{cb}	1 max	pF
Input Capacitance* (V_{EB} = 0.5 V, I_C = 0, f = 0.1 to 1 MHz)	C_{ibo}	1.4	pF
Output Capacitance:			
V_{CB} = 10 V, I_E = 0, f = 0.14 MHz	C_{obo}	1.3† max	pF
V_{CB} = 10 V, I_E = 0, f = 0.14 MHz	C_{obo}	1.8* max	pF
Collector-to-Base Time Constant† (V_{CB} = 6 V, I_C = 2, f = 31.9 MHz)	$r_b'C_c$	4 to 15	ps
Small-Signal Power Gain, Neutralized Amplifier† (V_{CE} = 6 V, I_C = 1.5 mA, f = 450 MHz)	G_{pe}	12.5 to 19	dB
Power Output, Oscillator Circuit* (V_{CB} = 10 V, I_E = −12 mA, f = 500 MHz)	P_{oo}	30 min	mW

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC



TYPICAL SMALL-SIGNAL FORWARD TRANSFER CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



CHARACTERISTICS (cont'd)

Noise Figure:†			
V_{CE} = 6 V, I_C = 1.5 mA, R_G = 50 Ω, f = 450 MHz	NF	4.5 max	dB
V_{CE} = 6 V, I_C = 1 mA, R_G = 400 Ω, f = 60 MHz ..	NF	2.2	dB

* Fourth lead (case) not connected †Fourth lead (case) grounded
■ Three-terminal measurement: Lead No. 1 (emitter) and lead No. 4 (case) connected to guard terminal.

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.

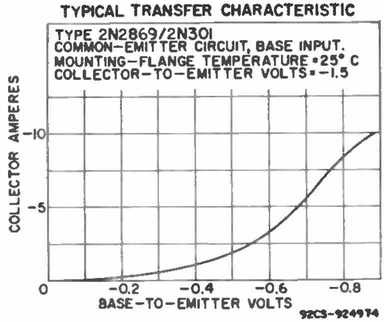
MAXIMUM RATINGS

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 116	
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)	$V_{(BR)CBO}$	−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 = −5 A, I_B = −0.5 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	kHz

TYPICAL TRANSFER CHARACTERISTIC



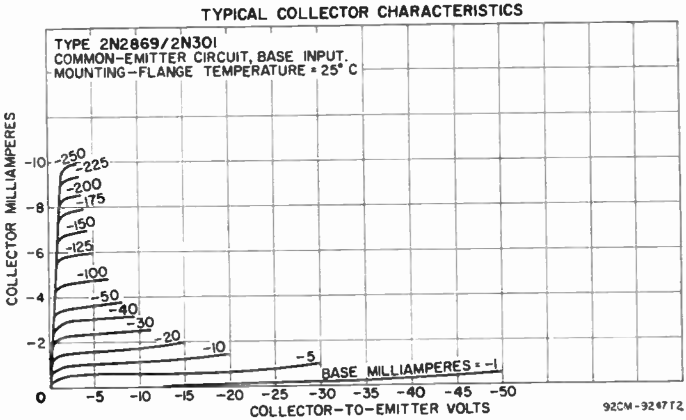
TYPICAL OPERATION IN CLASS A POWER-AMPLIFIER CIRCUIT

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	Hz
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 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	Hz
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 = −5 A, I_B = −0.5 A)	$V_{CE}(sat)$	−0.5 max	V

POWER TRANSISTOR 2N2876

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 MHz in industrial and military equipment. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, 2 - base, 3 - collector.

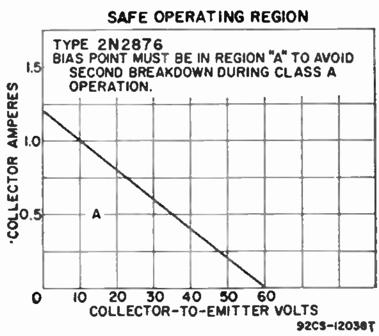
MAXIMUM RATINGS

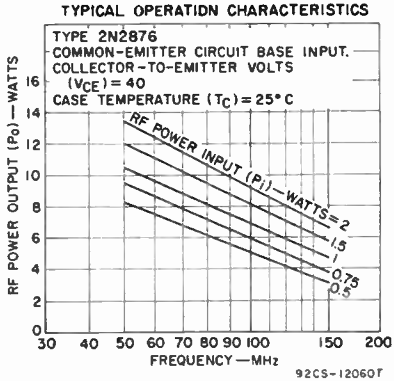
Collector-to-Base Voltage	V_{CBO}	80	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	80	V
Base open	V_{CEO}	60	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	2.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	17.5	W
T_C above 25°C	P_T	See curve page 116	
Temperature Range:			
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 = 0.5 mA, I_E = 0)	$V_{(BR)CBO}$	80 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0.5 A, I_B = 0, $t_p \leq$ 5 µs, df $\leq$ 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 MHz)	$r_{bb'}$	6	Ω
RF Power Output, Unneutralized:			
V_{CE} = 28 V, I_C = 0.5 A, P_{IE} = 2 W, f = 50 MHz	P_{OE}	10 min	W
V_{CE} = 28 V, I_C = 0.275 A, P_{IE} = 1 W, f = 150 MHz	P_{OE}	3 min	W
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 250 mA)	f_T	200	MHz
Collector-to-Case Capacitance	C_c	6 max	pF
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 0.14 MHz)	C_{obo}	20 max*	pF

* This value applies only to type 2N2876.





2N2895 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}	120	V
Collector-to-Emitter Voltage:			
$R_{BE} \leq 10\ \Omega$	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	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 116	
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 = 1.8%	V_{CEO}(sus)	65 min	V
I_C = 100 mA, I_B = 0, R_{BE} = 10 Ω, t_p = 300 µs, df = 1.8%	V_{CER}(sus)	80 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)	0.6 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)	1.2 max	V
Collector-Cutoff Current:			
V_{CB} = 60 V, I_E = 0, T_C = 25°C	I_{CBO}	0.002 max	µA
V_{CB} = 60 V, I_E = 0, T_C = 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 = 1.8%	h_{FE}(pulsed)	40 to 120	
V_{CE} = 10 V, I_C = 500 mA, t_p = 300 µs, df = 1.8%	h_{FE}(pulsed)	25 min	
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 0.01 mA	h_{FE}	20 min	
V_{CE} = 10 V, I_C = 10 mA	h_{FE}	35 min	
V_{CE} = 10 V, I_C = 10 mA, T_C = −55°C	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 5 mA, f = 1 kHz	h_{fe}	50 to 200	
V_{CE} = 10 V, I_C = 50 mA, f = 20 MHz	h_{fe}	6 min	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 0.14 MHz)	C_{ibo}	80 max	pF
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 MHz)	C_{obo}	15 max	pF
Noise Figure (V_{CE} = 10 V, I_C = 0.3 mA, f = 1 kHz, R_G = 510 Ω, circuit bandwidth = 1 Hz)	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

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

MAXIMUM RATINGS (cont'd)

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 116	
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)	$V_{(BR)CBO}$	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 = 1.8%	V_{CEO}(sus)	90 min	V
I_C = 100 mA, I_B = 0, R_{BE} = 10 Ω, t_p = 300 μs, df = 1.8%	V_{CER}(sus)	140 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)	0.6 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)	1.2 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
Pulsed Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 150 mA, t_p = 300 μs, df = 1.8%)	h_{FE}(pulsed)	60 to 200	
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 1 mA	h_{FE}	35 min	
V_{CE} = 10 V, I_C = 10 mA, T_C = 55°C	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA, f = 20 MHz)	h_{fe}	6 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 MHz)	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

TRANSISTOR 2N2897

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 116	
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 = 1.8%	V_{CEO}(sus)	45 min	V
I_C = 100 mA, I_B = 0, R_{BE} = 10 Ω, t_p = 300 μs, df = 1.8%	V_{CER}(sus)	60 min	V

CHARACTERISTICS (cont'd)

Collector-to-Emitter Saturation Voltage (I_C = 150 mA, I_B = 15 mA, t_p = 300 μs, df = 1.8%)	V_{CE}(sat)	1 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}	0.05 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 = 1.8%)	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} = 10 V, I_C = 50 mA, f = 20 MHz)	h_{fe}	5 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 MHz)	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

2N2938 COMPUTER TRANSISTOR

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 Current	I_C	0.5	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.3	W
Temperature Range:			
Operating (Ambient)	T_A(opr)	−65 to 175	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.01 mA, I_E = 0)	$V_{(BR)CBO}$	25 min	V
Collector-to-Emitter Saturation Voltage (I_C = 50 mA, I_B = 1.6 mA)	V_{CE}(sat)	0.4 max	V
Collector-Cutoff Current	I_{CBO}	0.025 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 0.35 V, I_C = 10 mA)	h_{FE}	25 min	
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 1 MHz)	C_{obo}	3.5 max	pF
Turn-On Time (V_{CC} = 6 V, I_C = 50 mA, I_{B1} = 2.5 mA, I_{B2} = −2.5 mA)	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

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	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	−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 (in an infinite heat sink)	P_T	300	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 116	

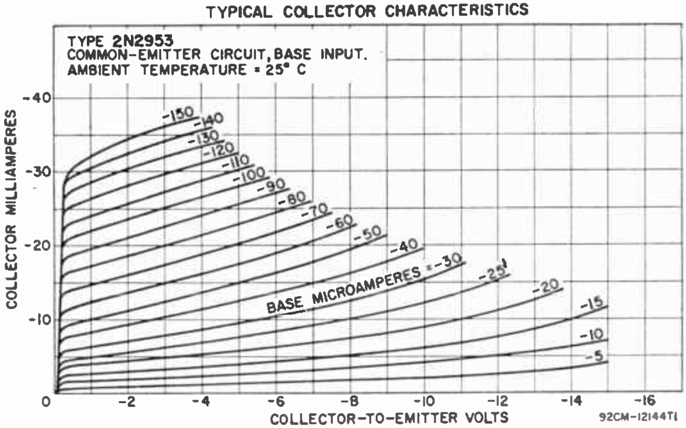
MAXIMUM RATINGS (cont'd)

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

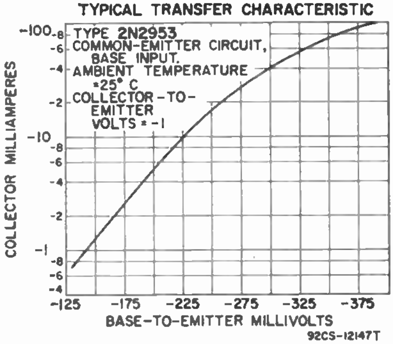
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −0.05 A, V_{EB} = −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 kHz)	h_{fe}	200 min	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = −12 V, I_C = −1 mA)	f_{hfb}	10	MHz
Intrinsic Base-Spreading Resistance (V_{CE} = −10 V, I_C = −10 mA, f = 20 MHz)	$r_{bb'}$	300	Ω
Collector-to-Base Feedback Capacitance (V_{CE} = −12 V, I_C = −1 mA)	$C_{b'c}$	6.5	pF

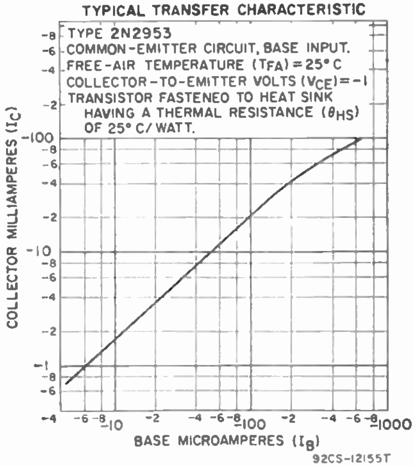
TYPICAL COLLECTOR CHARACTERISTICS



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 116	
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, V_{EB} = 0)	$V_{(BR)CES}$	30 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 = 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
I_C = 30 mA, I_B = 3 mA, t_p = 300 μs, df = 2%, T_A = 25°C	V_{CE}(sat) pulsed	0.25 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 = 30 mA, I_B = 3 mA, T_A = 25°C	V_{BE}(sat)	1.15 max	V
I_C = 100 mA, I_B = 10 mA	V_{BE}(sat)	1.6 max	V
Collector-Cutoff Current:			
V_{CE} = 20 V, V_{EB} = 0, T_A = 85°C	I_{CES}	10 max	μA
V_{CE} = 20 V, V_{EB} = 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} = 0.4 V, I_C = 30 mA, t_p = 300 μs, df = 2%	h_{FE}(pulsed)	25 min	
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 MHz)	h_{fe}	4 min	
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 0.14 MHz)	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 MHz) 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 Sustaining Voltage:			
V_{BE} = −1.5 V	V_{CEV}(sus)	60	V
R_{BE} = 10 Ω	V_{CER}(sus)	50	V
Base open	V_{CEO}(sus)	40	V

MAXIMUM RATINGS (cont'd)

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 116	
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 = 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
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 250	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA, f = 20 MHz)	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	θ_{J-C}	35* max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175● max	°C/W

* This value does not apply to type 40389.
● This value does not apply to type 40392.

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 Sustaining Voltage:			
V_{BE} = –1.5 V	V_{CEV}(sus)	90	V
R_{BE} = 100 Ω	V_{CER}(sus)	60	V
Base open	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 116	
Temperature Range:			
Operating (T_C) and Storage (T_{STG})		–65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	235	°C

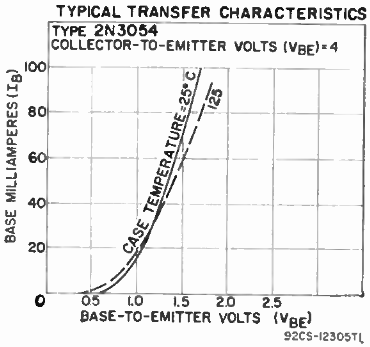
CHARACTERISTICS (At case temperature = 25°C)

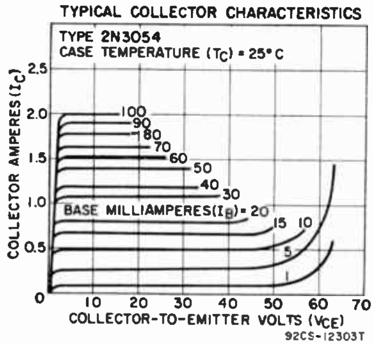
Emitter-to-Base Breakdown Voltage (I_E = 1 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 100 mA, R_{BE} = 100 Ω	V_{CER}(sus)	60 min	V
I_C = 100 mA, I_B = 0	V_{CEO}(sus)	55 min	V
Collector-to-Emitter Saturation Voltage (I_C = 500 mA, I_B = 50 mA)	V_{CE}(sat)	1 max	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
V_{CE} = 30 V, V_{BE} = –1.5 V, T_C = 150°C	I_{CEV}	5 max	mA
Emitter-Cutoff Current (V_{EB} = 7 V, I_C = 0)	I_{EBO}	1 max	mA

CHARACTERISTICS (cont'd)

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

* This value applies only to type 2N3054.





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.

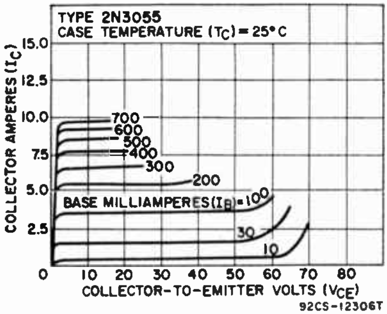
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	100	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = −1.5 V	V_{CEV}(sus)	100	V
R_{BE} = 100 Ω	V_{CER}(sus)	70	V
Base open	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 116	
Temperature Range:			
Operating (T_C) and Storage (T_{STG})		−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	235	°C

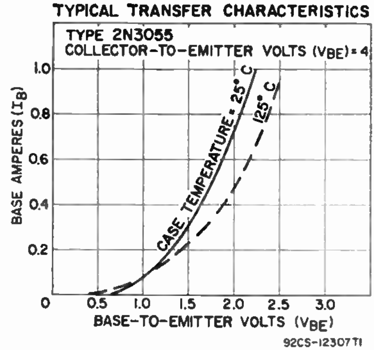
CHARACTERISTICS (At case temperature = 25°C)

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, t_p = 300 µs, df = 1.8%)	V_{BE}	1.8 max	V
Collector-Cutoff Current:			
V_{CE} = 100 V, V_{BE} = −1.5 V	I_{CEV}	5	mA
V_{CE} = 60 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	10	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 = 4 A, t_p = 300 µs, df = 1.8%)	h_{FE}(pulsed)	20 to 70	
Power Rating Test (V_{CE} = 39 V, I_C = 3 A, t = 1 s)		115	W
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.

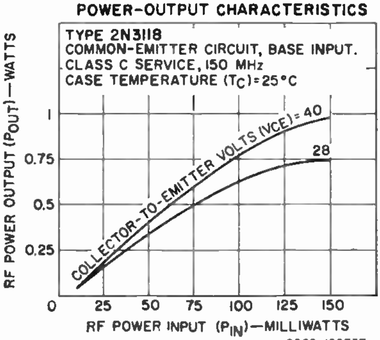
MAXIMUM RATINGS

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 116	
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

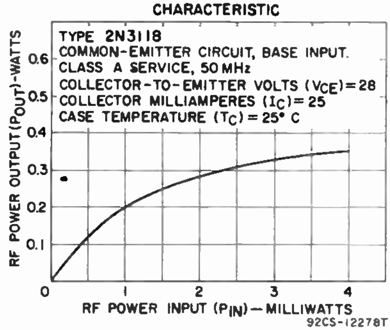
CHARACTERISTICS (At case temperature = 25°C)

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 MHz)	$R_e(h_{ie})$	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 MHz)	$\frac{1}{Y_{22}}$ (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 MHz)	h_{fe}	5 min	
$r_{bb'}$ $C_{b'c}$ Product (V_{CB} = 28 V, I_C = 25 mA, f = 50 MHz)	$r_{bb'}C_{b'c}$	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 MHz)	G_{pe}	18 min	dB
Collector-to-Base Feedback Capacitance (V_{CB} = 28 V, I_C = 0, f = 1 MHz)	$C_{b'c}$	6 max	pF
Power Output, Class C Oscillator Service (with heat sink):			
V_{CE} = 28 V, P_{ie} = 0.1 W, f = 50 MHz	P_{oe}	1 min	W
V_{CE} = 28 V, P_{ie} = 0.1 W, f = 150 MHz	P_{oe}	0.4 min	W

2N3119 TRANSISTOR

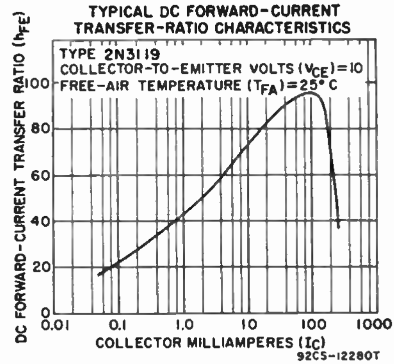
Si n-p-n triple-diffused planar type used in high-voltage, high-frequency pulse-amplifier and high-voltage saturated-switching applications in industrial and military equipment. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

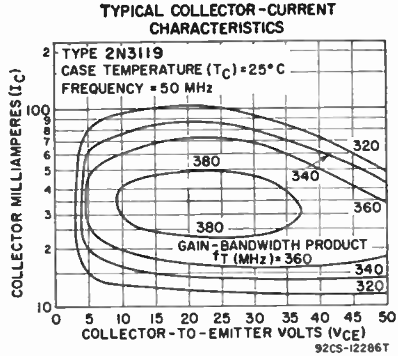
MAXIMUM RATINGS

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 116	
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_{CB} = 28 V, I_C = 25 mA, f = 50 MHz)	f_T	250 min	MHz
Collector-to-Base Feedback Capacitance (V_{CB} = 28 V, I_C = 0, f = 1 MHz)	$C_{b'c}$	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





TRANSISTOR 2N3229

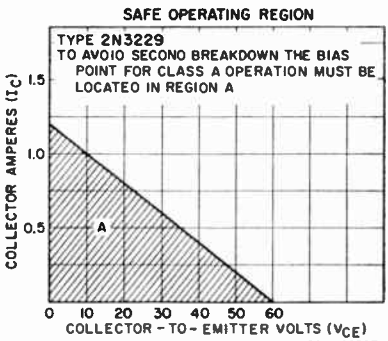
Si n-p-n triple-diffused planar type used in large-signal, high-power AM, FM, and cw applications at vhf frequencies in industrial and military, communications equipment. JEDEC TO-60, **Outline** No.20. **Terminals:** 1 - emitter, 2 - base, 3 - collector.

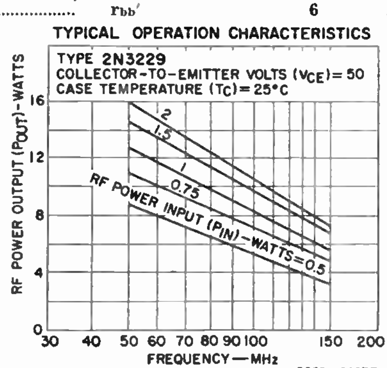
MAXIMUM RATINGS

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 116	
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 = 0.5 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, $t_p \leq$ 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 MHz)	$r_{bb'}$	6	Ω





CHARACTERISTICS (cont'd)

Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 250 mA)	f_T	200	MHz
Collector-to-Base Feedback Capacitance (V_{CB} = 30 V, I_E = 0, f = 140 kHz)	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 MHz	P_{OE}	15 min	W
V_{CC} = 50 V, I_C = 250 mA, P_{IE} = 1 W, f = 150 MHz	P_{OE}	5 min	W

2N3241A TRANSISTOR

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier and switching service in commercial, industrial, and computer equipment. JEDEC TO-104, Outline No.26 (3-lead). Terminals: 1 - emitter, 2 - base, 3 - collector and case.

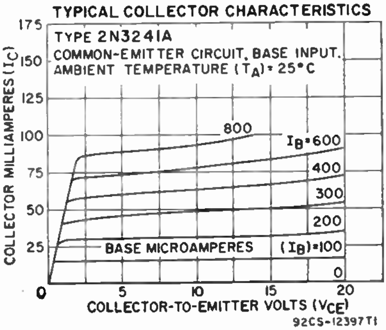
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	30	V
Collector-to-Emitter Voltage:			
V_{BE} = −1 V	V_{CEV}	25	V
Base open	V_{CEO}	25	V
Emitter-to-Base Voltage	V_{EBO}	7.5	V
Collector Current	I_C	Limited by dissipation	
Transistor Dissipation:			
T_C up to 75°C	P_T	2	W
T_C above 75°C	P_T	See curve page 116	
T_A up to 25°C	P_T	0.5	W
T_A above 25°C	P_T	See curve page 116	
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	265	°C

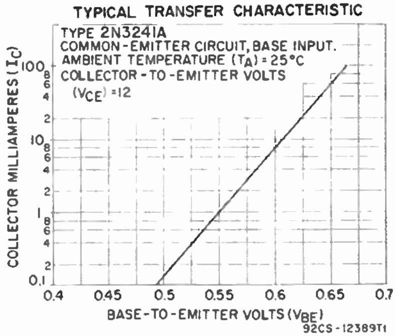
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.05 mA, I_E = 0)	$V_{(BR)CBO}$	30 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 10 mA, I_B = 0	$V_{(BR)CEO}$	25 min	V
V_{BE} = −1 V, I_C = 0.01 mA	$V_{(BR)CEV}$	25 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.05 mA, I_C = 0)	$V_{(BR)EBO}$	7.5 min	V
Collector-to-Emitter Saturation Voltage (I_C = 200 mA, I_B = 10 mA)	V_{CE}(sat)	0.22 typ; 0.25 max	V
Base-to-Emitter Saturation Voltage (I_C = 200 mA, I_B = 10 mA)	V_{BE}(sat)	0.88 typ; 1.25 max	V
Collector-Cutoff Current:			
V_{CB} = 25 V, I_E = 0	I_{CBO}	100 max	nA
V_{CB} = 25 V, I_E = 0, T_A = 150°C	I_{CBO}	10 max	μA
Emitter-Cutoff Current (V_{BE} = 2.5 V, I_C = 0)	I_{EBO}	100 max	nA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 10 mA)	h_{FE}	100 to 200	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{fe}	100 to 250	

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC



CHARACTERISTICS (cont'd)

Magnitude of Small-Signal Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 1 mA, f = 100 MHz)	$\|h_{fe}\|$	0.5 min; 1 typ	
Gain-Bandwidth Product (V_{CE} = 10 V, I_C = 10 mA, f = 50 MHz)	f_T	175	MHz
Collector-to-Base Feedback Capacitance* (V_{CB} = 6 V, I_E = 0, f = 1 MHz)	C_{cb}	20 max	pF
Intrinsic Base-Spreading Resistance (V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	$r_{bb'}$	20	Ω
Noise Figure:			
V_{CE} = 6 V, I_C = 0.1 mA, f = 10 kHz, R_G = 1000 Ω, circuit bandwidth = 1 Hz	NF	2.5	dB
V_{CE} = 6 V, I_C = 0.5 mA, f = 1 kHz, R_G = 1000 Ω, circuit bandwidth = 1 Hz	NF	8 typ; 10 max	dB
Small-Signal Input Impedance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{ie}	200 to 1000	Ω
Small-Signal Output Admittance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{oe}	30 to 350	μmhos
Thermal Resistance, Junction-to-Case	θ_{J-C}	50 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	300 max	°C/W

* Emitter terminal guarded.

TRANSISTOR 2N3242A

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier and switching service in commercial, industrial, and computer equipment. JEDEC TO-104, Outline No.26 (3-lead). Terminals: 1 - emitter, 2 - base, 3 - collector and case. For collector-characteristics and transfer-characteristics curves, refer to type 2N3241A.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage:			
V_{BE} = −1 V	V_{CEV}	40	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	8	V
Collector Current	I_C	Limited by dissipation	
Transistor Dissipation:			
T_C up to 75°C	P_T	2	W
T_C above 75°C	P_T	See curve page 116	
T_A up to 25°C	P_T	0.5	W
T_A above 25°C	P_T	See curve page 116	
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	265	°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	$V_{(BR)CEO}$	40 min	V
V_{BE} = −1 V, I_C = 0.01 mA	$V_{(BR)CEV}$	40 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.05 mA, I_C = 0)	$V_{(BR)EBO}$	8 min	V
Collector-to-Emitter Saturation Voltage (I_C = 300 mA, I_B = 15 mA)	V_{CE}(sat)	0.24 typ; 0.3 max	V
Base-to-Emitter Saturation Voltage (I_C = 300 mA, I_B = 15 mA)	V_{BE}(sat)	0.93 typ; 1.5 max	V
Collector-Cutoff Current:			
V_{CB} = 25 V, I_E = 0	I_{CBO}	10 max	nA
V_{CB} = 25 V, I_E = 0, T_A = 150 °C	I_{CBO}	1 max	μA
Emitter-Cutoff Current (V_{BE} = 2.5 V, I_C = 0)	I_{EBO}	10 max	nA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 10 mA)	h_{FE}	125 to 300	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{fe}	125 to 375	
Magnitude of Small-Signal Forward-Current Transfer Ratio (V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	$\|h_{fe}\|$	0.5 min; 1 typ	
Gain-Bandwidth Product (V_{CE} = 10 V, I_C = 10 mA, f = 50 MHz)	f_t	175	MHz
Collector-to-Base Feedback Capacitance* (V_{CB} = 6 V, I_E = 0, f = 1 MHz)	C_{cb}	20 max	pF
Intrinsic Base-Spreading Resistance (V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	$r_{bb'}$	20	Ω

CHARACTERISTICS (cont'd)

Noise Figure:			
V_{CE} = 6 V, I_C = 0.1 mA, f = 10 kHz, R_G = 1000 Ω, circuit bandwidth = 1 Hz	NF	2	dB
V_{CE} = 6 V, I_C = 0.5 mA, f = 1 kHz, R_G = 1000 Ω, circuit bandwidth = 1 Hz	NF	4 typ; 6 max	dB
Small-Signal Input Impedance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{ie}	250 to 1500	Ω
Small-Signal Output Admittance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{oe}	30 to 350	μmhos
Thermal Resistance, Junction-to-Case	Θ_{J-C}	50 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	300 max	°C/W

* Emitter terminal guarded.

2N3261 COMPUTER TRANSISTOR

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.

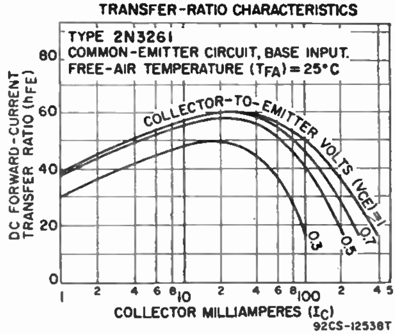
MAXIMUM RATINGS

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 116	
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

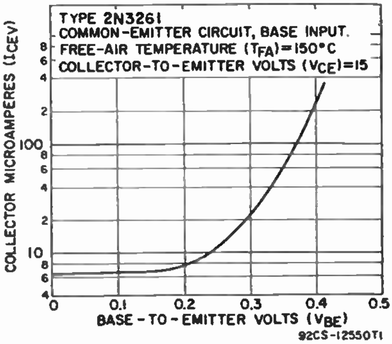
CHARACTERISTICS

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_{EB} = 0, T_A = 15°C	I_{CEV}	25 max	nA
V_{CE} = 15 V, V_{EB} = 0, T_A = 150°C	I_{CEV}	25 max	μA

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



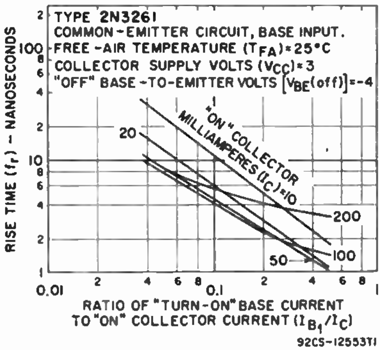
TYPICAL TRANSFER CHARACTERISTICS



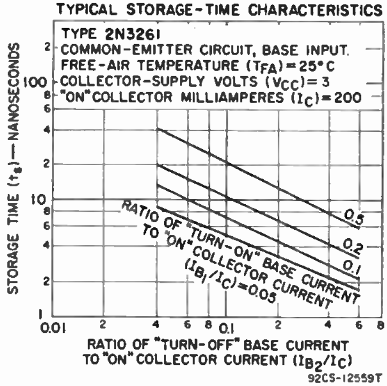
CHARACTERISTICS (cont'd)

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 ≦ 2%	h_{FE}(pulsed)	30 min	
V_{CE} = 1 V, I_C = 200 mA, t_p = 300 μs, df ≦ 2%	h_{FE}(pulsed)	20 min	
Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 1 V, I_C = 100 mA, f = 100 MHz	h_{fe}	3 min	
V_{CE} = 10 V, I_C = 10 mA, f = 100 MHz	h_{fe}	6 min	
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 1 MHz)	C_{ibo}	4 max	pF
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 1 MHz)	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



TYPICAL STORAGE-TIME CHARACTERISTICS



TRANSISTOR 2N3262

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 116	
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 MHz)	h_{fe}	3 min	
Collector-to-Base Feedback Capacitance (V_{CB} = 28 V, I_C = 0, f = 1 MHz)	$C_{b'c}$	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_{CE} = 28 V, I_C = 1 A, I_{B1} = 100 mA, I_{B2} = —100 mA)	$t_d + t_r$	40 max	ns
Turn-On Time, Saturated Swith (V_{CE} = 28 V, I_C = 1 A, I_{B1} = 100 mA, I_{B2} = —100 mA)	$t_s + t_f$	750 max	ns

2N3263 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. **Outline** No.24. **Terminals:** B - base, E - emitter, C - collector and case.

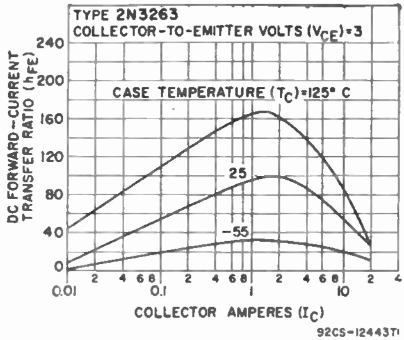
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	150	V
Collector-to-Emitter Voltage:			
V_{BE} = —1.5 V	V_{CEV}	150	V
R_{BE} ≦ 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

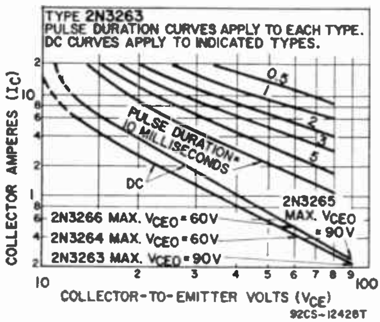
CHARACTERISTICS (At case temperature = 25°C)

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} ≦ 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 ≤ 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 ≤ 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
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 = 5 A, t_p ≤ 350 μs, df ≤ 2%	h_{FE}(pulsed)	40 min	
(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 MHz)	$C_{b'c}$	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 MHz)	f_T	20 min	MHz
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

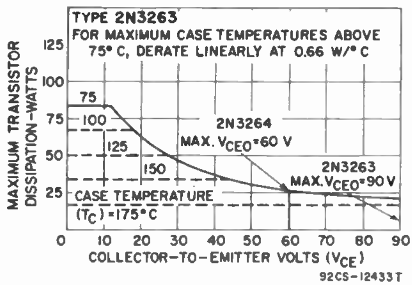
TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



SAFE OPERATING REGION



RATING CHART



TRANSISTOR 2N3264

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 Ω	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} ≤ 50 Ω	V_{CER}(sus)	80 min	V
Collector-to-Emitter Saturation Voltage (I_C = 15 A, I_B = 1.2 A, t_p ≤ 350 μs, 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 μs, df ≤ 2%)	V_{BE}(sat)	1.8 max	V

CHARACTERISTICS (cont'd)

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 = 5 A, $t_p \leq$ 350 μs, df ≤ 2%	h_{FE}(pulsed)	35 min	
V_{CE} = 3 V, I_C = 15 A, $t_p \leq$ 350 μs, df ≤ 2%	h_{FE}(pulsed)	20 to 80	
V_{CE} = 4 V, I_C = 20 A, $t_p \leq$ 350 μs, df ≤ 2%	h_{FE}(pulsed)	15 min	
Collector-to-Base Feedback Capacitance (V_{CB} = 10 V, I_E = 0, f = 1 MHz)	$C_{b'c}$	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 MHz)	f_T	20 min	MHz
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 Ω, L = 40 μH)	$E_{S/b}$	2 min	mJ
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

2N3265 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. This type is identical with type 2N3263 except for the following items:

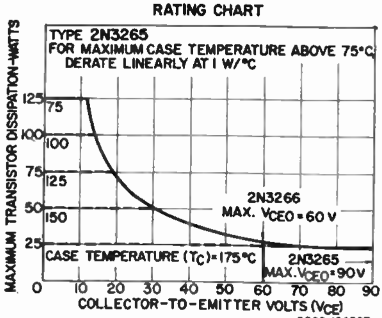
MAXIMUM RATINGS

Transistor Dissipation	P_T	See Rating Chart

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Case	θ_{J-C}	1 max	°C/W

RATING CHART



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 (At case temperature = 25°C)

Thermal Resistance, Junction-to-Case	θ_{J-C}	1 max	°C/W

TRANSISTOR 2N3375

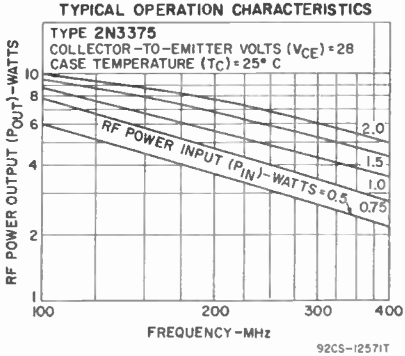
Si n-p-n "overlay" epitaxial planar type used in large-signal, high-power vhf-uhf applications for industrial and military communications equipment in class A, B, or C amplifier, frequency-multiplier, or oscillator operation. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, 2 - base, 3 - collector.

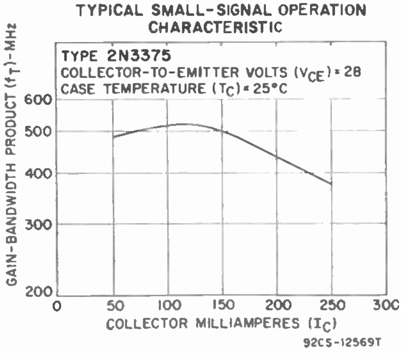
MAXIMUM RATING

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_B	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 116	
Temperature Range:			
Operating (Junction)	T_J	−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)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0 to 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 = 500 mA, I_B = 100 mA)	$V_{CE}(sat)$	1 max	V
Collector-Cutoff Current (V_{CE} = 30 V, I = 0)	I_{CEO}	0.1 max	mA





CHARACTERISTICS (cont'd)

RF Power Output:			
Unneutralized Amplifier			
V_{CE} = 28 V, P_{IE} = 1 W, f = 100 MHz	P_{OE}	7.5● min	W
V_{CE} = 28 V, P_{IE} = 1 W, f = 400 MHz	P_{OE}	3* min	W
Oscillator			
V_{CE} = 28 V, f = 500 MHz	P_{OE}	2.5■	W
Collector-to-Case Capacitance	C_c	6 max	pF
Collector-to-Base Feedback Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{cb}	10 max	pF
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 150 mA)	f_T	500	MHz
Intrinsic Base-Spreading Resistance (V_{CE} = 28 V, I_C = 250 mA, f = 400 MHz)	r_{bb}'	10	Ω

▲ Measured at a current where the breakdown voltage is a minimum.
● For conditions given, minimum efficiency = 65 per cent.
* For conditions given, minimum efficiency = 40 per cent.
■ For conditions given, typical efficiency = 40 per cent.

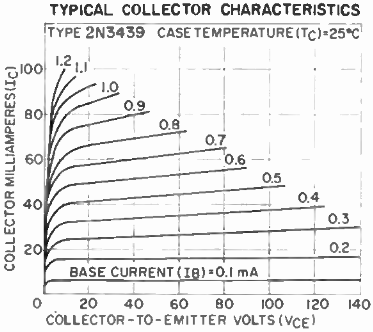
2N3439 TRANSISTOR

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 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 25°C	P_T	10	W
T_A above 25°C	P_T	See curve page 116	
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



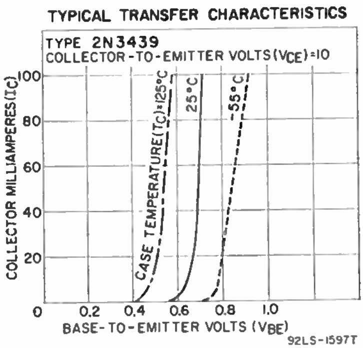
CHARACTERISTICS (At case temperature = 25°C)

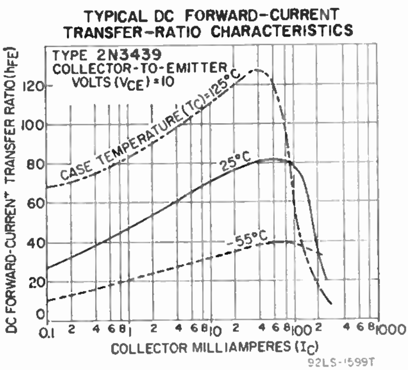
Collector-to-Emitter Sustaining Voltage (I_C = 50 mA, I_B = 0)	V_{CEO}(sus)	350 min	V
Collector-to-Emitter Saturation Voltage (I_C = 50 mA, I_B = 4 mA)	V_{CE}(sat)	0.5 max	V
Base-to-Emitter Saturation Voltage (I_C = 50 mA, I_B = 4 mA)	V_{BE}(sat)	1.3 max	V
Collector-Cutoff Current:			
V_{CE} = 300 V, 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

CHARACTERISTICS (cont'd)

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 MHz)	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 MHz)	C_{obo}	10 max	pF
Thermal Resistance, Junction-to-Case	θ_{J-C}	17.5 max	°C/W

* This value does not apply to type 2N3440.
● This value does not apply to types 2N4063 and 2N4064.





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. This type features a base comprised of a homogeneous-resistivity silicon material. JEDEC TO-66, Outline No. 22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

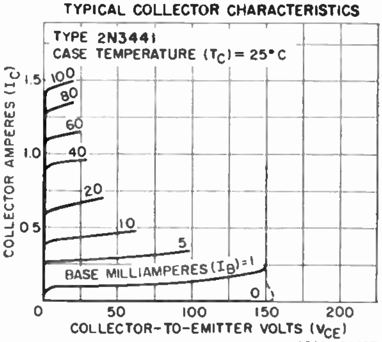
Collector-to-Base Voltage	V_{CBO}	160	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	160	V
Base open (sustaining voltage)	V_{CEO}(sus)	140	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	3	A
Peak Collector Current	i_C	4	A
Base Current	I_B	2	A
Transistor Dissipation:			
T_C up to 25°C	P_T	25	W
T_A up to 25°C	P_T	5.8	W
T_A or T_C above 25°C	P_T	See curve page 116	
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)

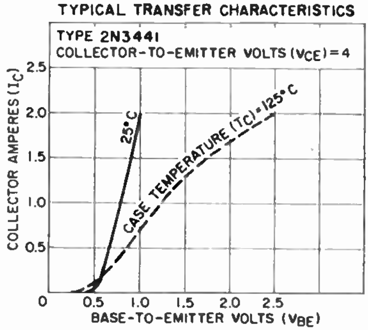
Collector-to-Emitter Sustaining Voltage:			
I_C = 0.1 to 2 A, I_B = 0	V_{CEO}(sus)	140 min	V
I_C = 0.1 to 1 A, V_{BE} = −1.5 V	V_{CEV}(sus)	160 min	V
I_C = 0.1 to 1 A, R_{BE} = 100 Ω	V_{CER}(sus)	150* min	V
Collector-to-Emitter Saturation Voltage (I_C = 0.5 A, I_B = 50 mA)	V_{CE}(sat)	1 max	V
Base-to-Emitter 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}	1 max	mA
V_{CE} = 140 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	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	
Power Rating Test:			
V_{CE} = 32.5 V, I_C = 0.9 A, t = 1 s		29	W
V_{CE} = 120 V, I = 0.24 A, t = 1 s		29	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	7● max	°C/W

* This value does not apply to type 2N3442.
● This value does not apply to type 40373.

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



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. This type features a base comprised of a homogeneous-resistivity silicon material. 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:

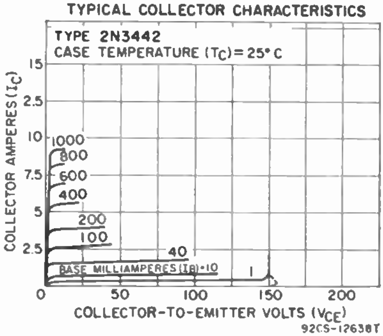
MAXIMUM RATINGS

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 116	

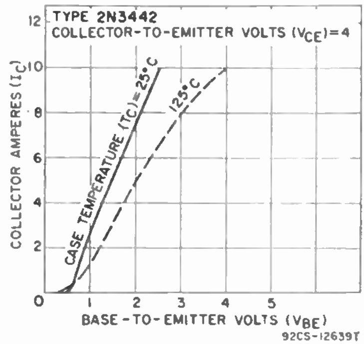
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage:			
I_C = 0.2 to 3 A, I_B = 0	V_{CEO}(sus)	140 min	V
I_C = 0.1 to 1.5 A, V_{BE} = −1.5 V	V_{CEV}(sus)	160 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}	10 max	mA
V_{CB} = 140 V, I_E = 0	I_{CEV}	1	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	
Power Rating Test (V_{CE} = 78 V, I_C = 1.5 A, t = 1 s)		117	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



TRANSISTOR 2N3478

Si n-p-n epitaxial planar type for vhf-uhf applications at frequencies up to 470 MHz in industrial and commercial equipment. JEDEC TO-104, 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 116	
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	265	°C

CHARACTERISTICS

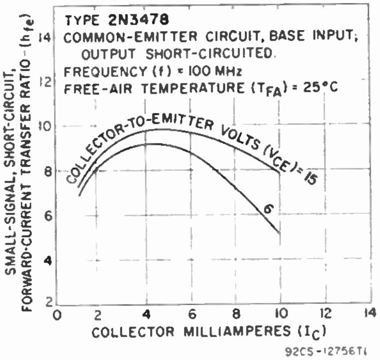
Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	30 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 0.001 mA, I_B = 0)	$V_{(BR)CEO}$	15 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.001 mA, I_C = 0)	$V_{(BR)EBO}$	2 min	V
Collector-Cutoff Current (V_{CB} = 1 V, I_E = 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	
Small-Signal Forward-Current Transfer Ratio* (V_{CE} = 8 V, I_C = 2 mA, f = 100 MHz)	h_{fe}	7.5 to 16	
Collector-to-Base Feedback Capacitance (V_{CB} = 8 V, I_E = 0, f = 0.1 to 1 MHz)	C_{cb}	0.7 max	pF

CHARACTERISTICS (cont'd)

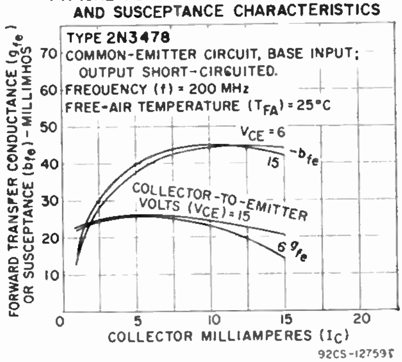
Small-Signal Power Gain:			
Unneutralized Amplifier Circuit*			
V_{CE} = 8 V, I_C = 2 mA, f = 200 MHz	G_{pe}	11.5 to 17	dB
Neutralized Amplifier Circuit			
R_S = 50 Ω, I_C = 1.5 mA, V_{CE} = 6 V, f = 470 MHz	G_{pe}	12	dB
Noise Figure*			
UHF—R_S = 50 Ω, V_{CE} = 6 V, I_C = 1.5 mA, f = 470 MHz	NF	5	dB
VHF—V_{CE} = 8 V, I_C = 2 mA, f = 200 MHz	NF	4.5 max	dB

* Lead 4 (case) grounded.

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



TYPICAL FORWARD TRANSFER CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



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

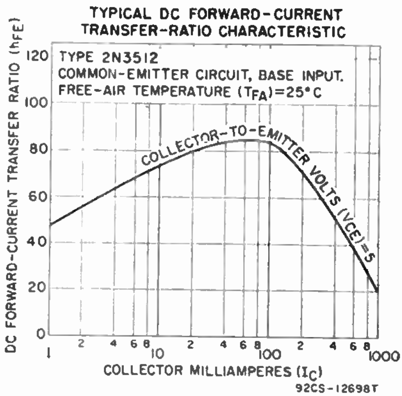
Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage	V_{CEO}	35	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	Limited by power dissipation	
Transistor Dissipation:			
T_A up to 25°C	P_T	0.8	W
T_C up to 25°C (with heat sink)	P_T	4	W
T_A or T_C (with heat sink) above 25°C	P_T	See curve page 116	
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

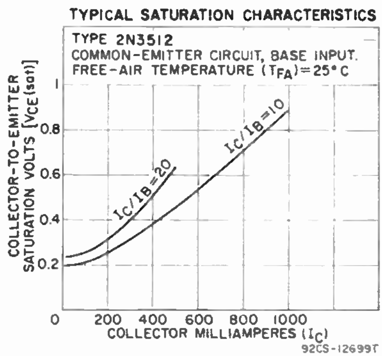
CHARACTERISTICS

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, t_p = 400 μs, df ≤ 3%	V_{CE}(sat) (pulsed)	1 max	V
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

CHARACTERISTICS (cont'd)

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 MHz)	h_{fe}	2.5 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 0.14 MHz)	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	0.33	A
Peak 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 116	
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

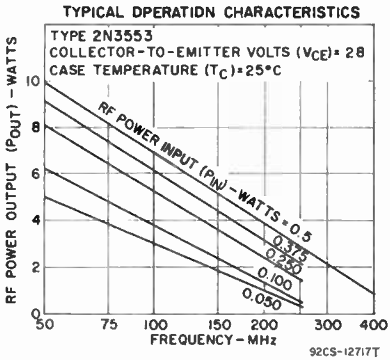
CHARACTERISTICS (At case temperature = 25°C)

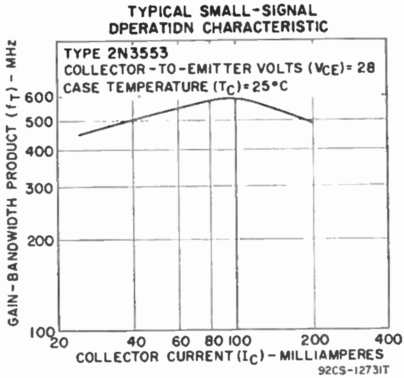
Collector-to-Base Breakdown Voltage (I_C = 0.3 mA, I_E = 0)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0 to 0.2 A, I_B = 0, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	40 min	V
I_C = 0 to 0.2 A, V_{BE} = −1.5 V, pulsed through an inductor L = 25 mH, df = 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

CHARACTERISTICS (cont'd)

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
Intrinsic Base-Spreading Resistance (V_{CE} = 28 V, I_C = 100 mA, f = 100 MHz)	$r_{bb'}$	12	Ω
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 100 mA)	f_T	500	MHz
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{obo}	10 max	pF
RF Power Output:			
Unneutralized Amplifier—V_{CC} = 28 V, P_{IE} = 0.25 W, R_G and R_L = 50 Ω, f = 175 MHz	P_{OE}	2.5* min	W
Oscillator—V_{CC} = 28 V, f = 500 MHz	P_{OE}	1.5†	W

* For conditions given, minimum efficiency = 50 per cent.
† For conditions given, typical efficiency = 30 per cent.





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 Chart, Maximum DC Operating Areas	
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)

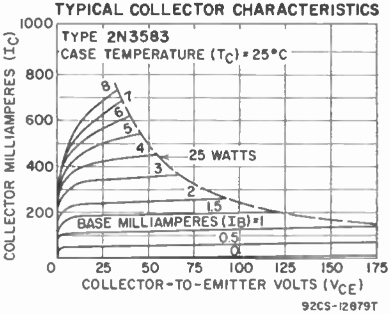
Collector-to-Emitter Sustaining Voltage:			
I_C = 200 mA, I_B = 0	V_{CEO}(sus)	175 min	V
R_{BE} = 50 Ω, I_C = 200 mA	V_{CER}(sus)	250 min	V
Base-to-Emitter Voltage (I_C = 1 A, V_{CE} = 10 V)	V_{BE}	1.4 max	V
Collector-Cutoff Current:			
V_{CE} = 150 V, I_B = 0, T_C = 25°C	I_{CEO}	10 max	mA
V_{BE} = −1.5 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 = 150°C	I_{CEV}	3 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 = 100 mA	h_{FE}	40 min	
V_{CE} = 10 V, I_C = 1 A	h_{FE}	10 min	

CHARACTERISTICS (cont'd)

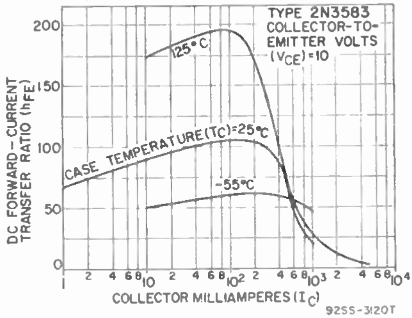
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 200 mA, f = 5 MHz)	h_{fe}	3 min	
Second-Breakdown Collector Current (Base forward-biased from zero up, V_{CE} = 100 V)	$I_{S/b}$	350 min	mA
Second-Breakdown Energy (Base reverse-biased, R_{BE} = 20 Ω, L = 100 μH, V_{BE} = −4 V)	$E_{S/b}$	50 min	μJ
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 1 MHz)	C_{obo}	120 max	pF
Thermal Resistance, Junction-to-Case (I_C = 500 mA)	θ_{J-C}	5* max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	70 max	°C/W

* This values does not apply to type 40374.

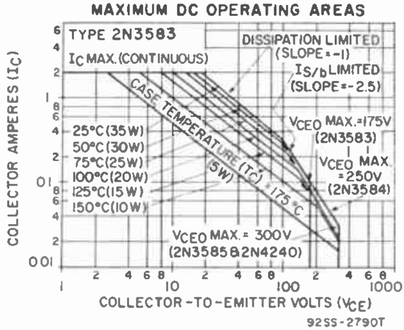
TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



MAXIMUM DC OPERATING AREAS



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. For Maximum DC Operating Areas Chart, refer to type 2N3583.

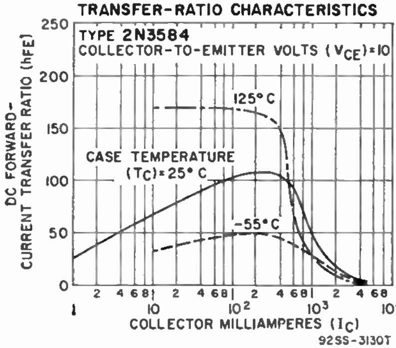
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	375	V
Collector-to-Emitter Sustaining Voltage	V_{CEO}(sus)	250	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 Chart, Maximum DC Operating Areas	
Operating Temperature	T_C(opr)	−65 to 200	°C
Pin-Soldering Temperature (10 s max)	T_P	255	°C

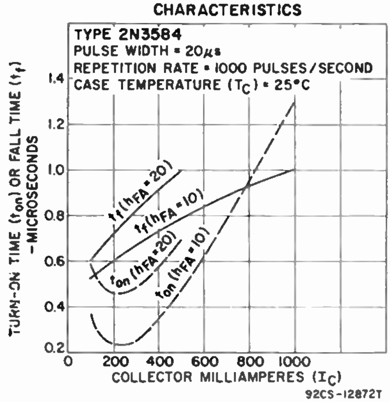
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage:			
I_C = 200 mA, I_B = 0	$V_{CEO}(sus)$	250 min	
R_{BE} = 50 Ω, I_C = 200 mA	$V_{CER}(sus)$	300 min	V
Base-to-Emitter Voltage (I_C = 1 A, V_{CE} = 10 V)	V_{BE}	1.4 max	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 = 150°C	I_{CEV}	3 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	
V_{CE} = 10 V, I_C = 100 mA	h_{FE}	40 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 200 mA, f = 5 MHz)	h_{fe}	3 min	
Second-Breakdown Collector Current (Base forward-biased from zero up, V_{CE} = 100 V)	$I_{S/b}$	350 min	mA
Second-Breakdown Energy (Base reverse-biased, R_{BE} = 20 Ω, L = 100 μH, V_{BE} = −4 V)	$E_{S/b}$	200 min	μJ
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 1 MHz)	C_{obo}	120 max	pF
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
Thermal Resistance, Junction-to-Case (I_C = 500 mA)	θ_{J-C}	5 max	°C/W
Thermal Resistance, Junction-to-Ambient (I_C = 500 mA)	θ_{J-A}	70 max	°C/W

TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



TYPICAL TURN-ON TIME AND FALL-TIME CHARACTERISTICS



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 2N3584 except for the following items:

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 Ω, I_C = 200 mA	V_{CER}(sus)	400 min	V
Collector-Cutoff Current:			
(V_{BE} = −1.5 V, V_{CE} = 400 V, T_C = 25°C)	I_{CEV}	1 max	mA
Turn-On Time, Saturated Switch (V_{CC} = 30 V, I_C = 1 A, I_B = 100 mA)	$t_d + t_r$	2* max	µs

* This value does not apply to type 2N4240.

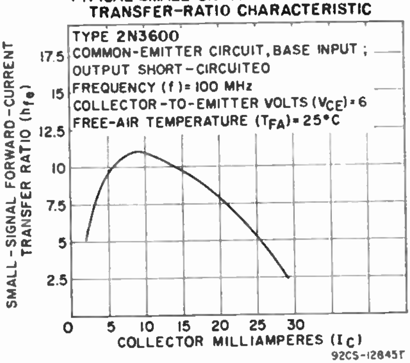
TRANSISTOR 2N3600

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	
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 116	
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



CHARACTERISTICS

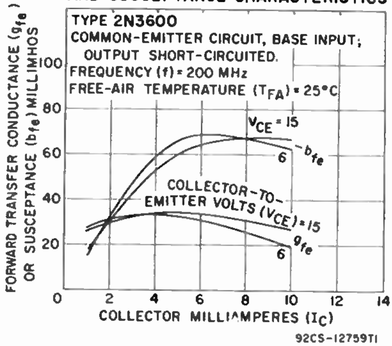
Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	30 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.01 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V
Collector-to-Emitter Sustaining Voltage (I_C = 3 mA, I_B = 0)	$V_{(BR)CEO}$(sus)	15 min	V
Collector-to-Emitter Saturation Voltage (I_C = 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

CHARACTERISTICS (cont'd)

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 MHz	h_{fe}	8.5 to 15▲	
V_{CE} = 6 V, I_C = 2 mA, f = 1 kHz	h_{fe}	40 to 200▲	
Input Capacitance† (V_{EB} = 0.5 V, I_C = 0, f = 0.1 to 1 MHz)	C_{ibo}	1.4	pF
Output Capacitance† (V_{CB} = 10 V, I_E = 0, f = 0.1 to 1 MHz)	C_{obo}	1.7 max	pF
Collector-to-Base Feedback Capacitance■ (V_{CB} = 10 V, I_E = 0, f = 0.1 to 1 MHz)	C_{cb}	1 max▲	pF
Collector-to-Base Time Constant* (V_{CB} = 6 V, I_C = 5 mA, f = 31.9 MHz)	$r_b'C_c$	4 to 15	ps
Small-Signal Power Gain, Amplifier Circuit, Neutralized* (V_{CE} = 6 V, I_C = 5 mA, f = 200 MHz)	G_{pe}	17 to 24▲	dB
Power Output, Oscillator Circuit† (V_{CB} = 10 V, I_E = 12 mA, f = 500 MHz)	P_{oe}	20 min	mW
Noise Figure:*			
V_{CE} = 6 V, I_C = 1.5 mA, f = 200 MHz	NF	4.5 max▲	dB
V_{CE} = 6 V, I_C = 1 mA, f = 60 MHz	NF	3	dB

* Lead 4 (case) grounded.
† Lead 4 (case) floating.
▲ This value does not apply to type 2N918.
■ Three-terminal measurement of the collector-to-base capacitance with the case and emitter leads connected to the guard terminal.

TYPICAL FORWARD TRANSFER CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



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
Peak Collector Current	i_C	1	A
Transistor Dissipation:			
T_C up to 25°C	P_T	23	W
T_C above 25°C	P_T	See curve page 116	
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

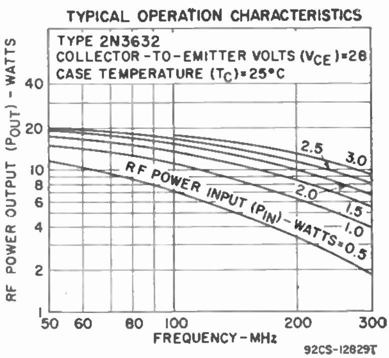
CHARACTERISTICS (At case temperature = 25°C)

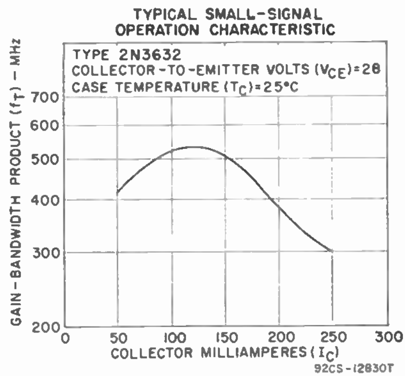
Collector-to-Base Breakdown Voltage (I_C = 0.5 mA, I_E = 0)	$V_{(BR)CBO}$	65 min	V

CHARACTERISTICS (cont'd)

Collector-to-Emitter Breakdown Voltage:			
I_C = 0 to 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
Collector-Cutoff Current (V_{CE} = 30 V, I_B = 0)	I_{CEO}	0.25 max	mA
Collector-to-Case	C_C	6 max	pF
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 150 mA)	f_T	400	MHz
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{obo}	20 max	pF
RF Power Output, Unneutralized:			
V_{CC} = 28 V, P_{IE} = 3.5 W, R_G and R_L = 50 Ω, f = 175 MHz	P_{OE}	13.5* min	W
V_{CC} = 28 V, P_{IE} = 3 W, R_G and R_L = 50 Ω, f = 260 MHz	P_{OE}	10†	W

* For conditions given, minimum efficiency = 70 per cent.
† For conditions given, minimum efficiency = 60 per cent.





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 116	
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-Emitter Breakdown Voltage (I_C = 5 mA, V_{EB} = 0)	$V_{(BR)CES}$	−200 min	V
Emitter-to-Base Breakdown Voltage (I_E = −100 mA, I_C = 0)	$V_{(BR)EBO}$	−0.5 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 116	
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-Emitter Breakdown Voltage (I_C = −0.025 A, V_{EB} = 0)	$V_{(BR)CES}$	−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
I_C = −3 A, I_B = −0.2 A	V_{CE}(sat)	−1.5▲ max	V
Base-to-Emitter Voltage (I_C = −6 A, I_B = −0.4 A)	V_{BE}	−0.8	V
Collector-Cutoff Current (V_{CB} = −10 V, I_E = 0)	I_{CBO}	−200 max	µA
Turn-off Time	$t_s + t_f$	1.2 max	µs
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

▲ This value does not apply to type 40439.

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.

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 116	
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-Emitter Breakdown Voltage (I_C = 5 A, V_{EB} = 0)	$V_{(BR)CES}$	−100 min	V
Emitter-to-Base Breakdown Voltage (I_E = −100 mA, I_C = 0)	$V_{(BR)EBO}$	−0.5 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

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

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 116	
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)

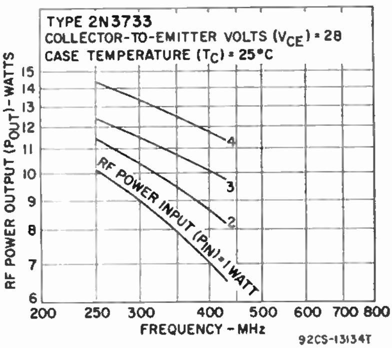
Collector-to-Base Breakdown Voltage (I_C = 0.5 mA, I_B = 0)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage:			
I_C = 0 to 200 mA, V_{BE} = −1.5 V, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	65 min	V
I_C = 0 to 200 mA, I_B = 0, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	40 min	V

CHARACTERISTICS (cont'd)

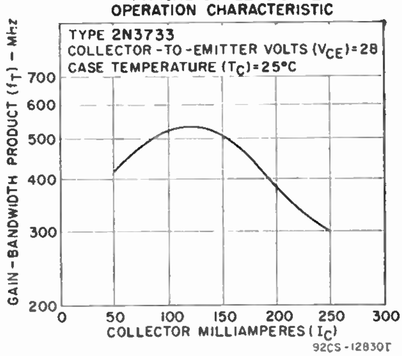
Emitter-to-Base Breakdown Voltage (I_E = 0.25 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage (I_C = 0.5 A, I_B = 100 mA)	$V_{CE}(sat)$	1 max	V
Collector-Cutoff Current (V_{CE} = 30 V, I_B = 0)	I_{CEO}	0.25 max	mA
Intrinsic Base-Spreading Resistance (V_{CE} = 28 V, I_C = 250 mA, f = 200 MHz)	$r_{bb'}$	6.5	Ω
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 150 mA)	f_T	400	MHz
Collector-to-Case Capacitance	C_c	6 max	pF
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{obo}	20 max	pF
RF Power Output Amplifier, Unneutralized:			
V_{CE} = 28 V, P_{IE} = 4 W, R_G and R_L = 50 Ω, f = 260 MHz)	P_{OE}	14.5*	W
V_{CE} = 28 V, P_{IE} = 4 W, R_G and R_L = 50 Ω, f = 400 MHz)	P_{OE}	10† min	W

* For conditions given, minimum efficiency = 60 per cent.
† For conditions given, minimum efficiency = 45 per cent.

TYPICAL OPERATION CHARACTERISTICS



TYPICAL SMALL-SIGNAL OPERATION CHARACTERISTIC



2N3771 POWER TRANSISTOR

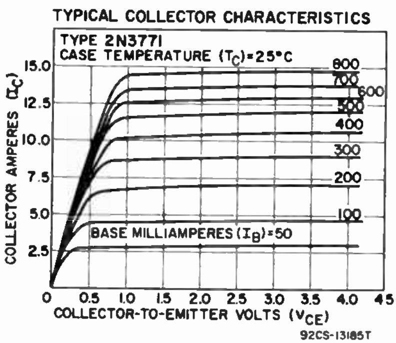
Si n-p-n type with high collector-current rating (30 A max) for intermediate- and high-power applications such as public-address amplifiers, power supplies, and low-speed switching regulators and inverters. This type features a base comprised of a homogeneous-resistivity silicon material. JEDEC TO-3, **Outline** No. 2. **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

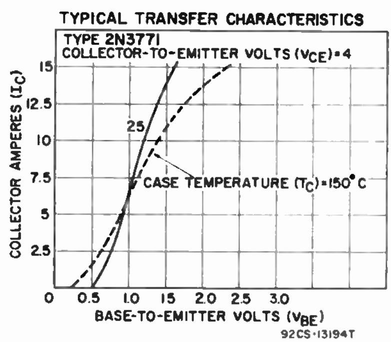
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	50	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V, R_{BE} = 100 Ω	V_{CEV}	50	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	30	A
Peak Collector Current	i_C	30	V
Base Current	I_B	7.5	V
Transistor Dissipation:			
T_C up to 25°C	P_T	150	W
T_C above 25°C	P_T	See curve page 116	
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 Sustaining Voltage:			
R_{BE} = 100 Ω, I_C = 0.2 A	V_{CER}(sus)	45	V
V_{EB} = −1.5 V, I_C = 0.2 A	V_{CEV}(sus)	50	V
V_{BE} = −1.5 V, I_C = 0.3 A, R_{BE} = 100 Ω	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, f = 60 Hz)	V_{CE}(sat)	2 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 15 A, t_p = 300 μs, f = 60 Hz)	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, f = 60 Hz)	h_{FE}(pulsed)	15 to 60	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 1 A)	f_T	800	kHz
Power Rating Test (V_{CE} = 33.5 V, I_C = 4.5 A, t = 1 s)		150	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.17 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. This type features a base comprised of a homogeneous-resistivity silicon material. 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}	90	V
Base open	V_{CEO}	60	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	20	A
Peak Collector Current	i_C	30	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 116	

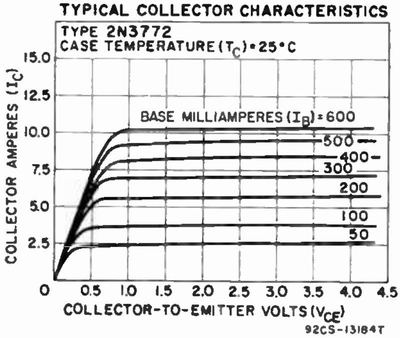
MAXIMUM RATINGS (cont'd)

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

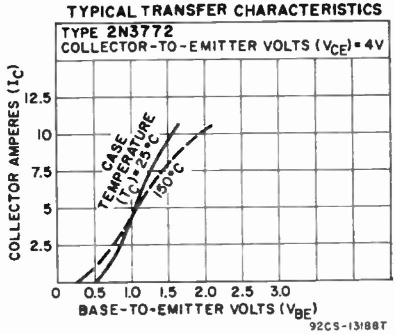
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage:			
V_{BE} = −1.5 V, I_C = 0.3 A, R_{BE} = 100 Ω	V_{CEV}(sus)	90 min	V
V_{EB} = −1.5 V, I_C = 0.2 A	V_{CEV}(sus)	80	V
R_{BE} = 100 Ω, I_C = 0.2 A	V_{CER}(sus)	45	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, f = 60 Hz)	V_{CE}(sat)	1.4 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 10 A, t_p = 300 μs, f = 60 Hz)	V_{BE}	2.2 max	V
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, f = 60 Hz)	h_{FE}(pulsed)	15 to 60	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 1 A)	f_T	800	kHz
Power Rating Test (V_{CE} = 33.5 V, I_C = 4.5 A, t = 1 s)		150	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.17 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



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. This type features a base comprised of a homogeneous-resistivity silicon material. JEDEC TO-3, Outline No. 2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

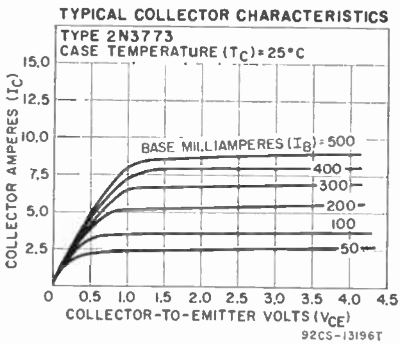
Collector-to-Base Voltage	V_{CBO}	160	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	160	V
Base open	V_{CEO}	140	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	16	A
Peak Collector Current	i_C	30	A
Base Current	I_B	4	A

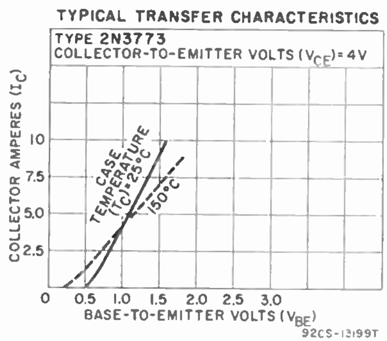
MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_C up to 25°C	P_T	150	W
T_C above 25°C	P_T	See curve page 116	
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 = 0.1 to 1.5 A	V_{CEV}(sus)	160 min	V
I_C = 0.2 to 3 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, f = 60 Hz)	V_{CE}(sat)	1.4 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 8 A, t_p = 300 μs, f = 60 Hz)	V_{BE}	2.2 max	V
Collector-Cutoff Current:			
V_{CE} = 140 V, V_{BE} = −1.5 V, T_C = 25°C	I_{CEV}	2 max	mA
V_{CE} = 140 V, I_B = 0, T_C = 150°C	I_{CEV}	10 max	mA
V_{CE} = 120 V, I_B = 0, T_C = 25°C	I_{CEO}	2 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 = 8 A, t_p = 300 μs, f = 60 Hz)	h_{FE}(pulsed)	15 to 60	
Power Rating Test (V_{CE} = 100 V, I_C = 1.5 A, t = 1 s)		150	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.17 max	°C/W





UHF TRANSISTOR 2N3839

Si n-p-n double-diffused epitaxial planar type used in low-noise amplifier, oscillator, and converter applications at frequencies up to 500 MHz in a common-emitter circuit and 1200 MHz in a common-base circuit. JEDEC TO-72, Outline No.23. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case. For maximum ratings, refer to type 2N2857.

CHARACTERISTICS

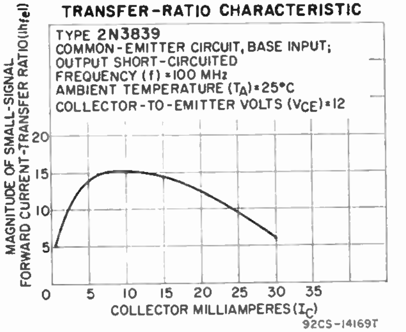
Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	30 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 3 mA, I_B = 0)	$V_{(BR)CEO}$	15 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.01 mA, I_C = 0)	$V_{(BR)EBO}$	2.5 min	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0	I_{CBO}	10 max	μA
V_{CB} = 15 V, I_E = 0, T_A = 150°C	I_{CBO}	1 max	μA

CHARACTERISTICS (cont'd)

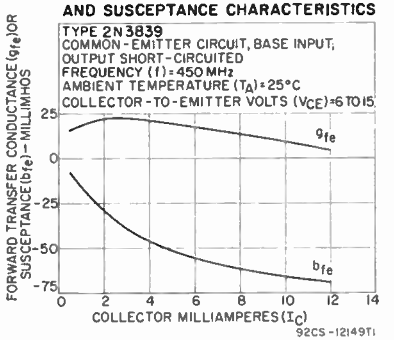
Static Forward-Current Transfer Ratio (V_{CE} = 1 V, I_C = 3 mA)	h_{FE}	30 to 150	
Small-Signal Forward-Current Transfer Ratio*:			
V_{CE} = 6 V, I_C = 2 mA, f = 0.001 MHz	h_{fe}	50 to 220	
V_{CE} = 6 V, I_C = 5 mA, f = 100 MHz	h_{fe}	10 to 20	
Feedback Capacitance• (V_{CB} = 10 V, I_E = 0, f = 0.1 to 1 MHz)	C_{cb}	0.6 typ; 1 max	pF
Input Capacitance (V_{EB} = 0.5 V, I_C = 0, f = 0.1 to 1 MHz)	C_{ibo}	1.4	pF
Collector-to-Base Time Constant▪ (V_{CB} = 6 V, I_E = −2 mA, f = 31.9 MHz)	$r_b'C_c$	1 to 15	ps
Small-Signal Power Gain▪ (V_{CE} = 6 V, I_C = 1.5 mA, f = 450 MHz)	G_{pe}	12.5 to 19	dB
Power Output* (V_{CB} = 10 V, I_E = −12 mA, f ≥ 500 MHz)	P_{oe}	30 min	mW
Noise Figure▪:			
UHF Measured (V_{CE} = 6 V, I_C = 1.5 mA, f = 450 MHz, R_G = 50 Ω)	NF	3.9 max	dB
UHF Device (V_{CE} = 6 V, I_C = 1.5 mA, f = 450 MHz, R_G = 50 Ω)	NF	3.4 max	dB
VHF Measured (V_{CE} = 6 V, I_C = 1 mA, f = 60 MHz, R_G = 400 Ω)	NF	2	dB

* Lead No. 4 (case) not connected.
• Three-terminal measurement with emitter and case connected to guard terminal.
▪ Lead No. 4 (case) grounded.

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC



TYPICAL FORWARD TRANSFER CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



2N3866 TRANSISTOR

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.

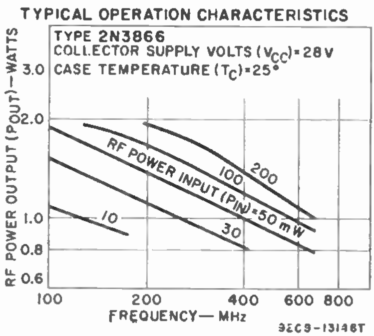
MAXIMUM RATINGS

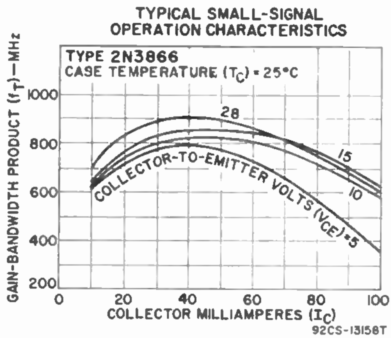
Collector-to-Base Voltage	V_{CBO}	55	V
Collector-to-Emitter Voltage:			
R_{BE} = 10 Ω	V_{CER}	55	V
Base open	V_{CEO}	30	V
Emitter-to-Base Voltage	V_{EBO}	3.5	V
Collector Current	I_C	0.4	A
Transistor Dissipation:			
T_C up to 25°C	P_T	5	W
T_C above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (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	MHz
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{obo}	3 max	pF
RF Power-Output Class C Amplifier, Unneutralized:			
V_{CC} = 28 V, P_{IE} = 0.05 W, f = 100 MHz	P_{OE}	1.8*	W
V_{CC} = 28 V, P_{IE} = 0.1 W, f = 250 MHz	P_{OE}	1.5●	W
V_{CC} = 28 V, P_{IE} = 0.1 W, f = 400 MHz	P_{OE}	1† min	W

* For conditions given, minimum efficiency = 60 per cent.
● For conditions given, minimum efficiency = 50 per cent.
† For conditions given, minimum efficiency = 45 per cent.





POWER TRANSISTOR 2N3878

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	V
Collector-to-Emitter Voltage:			
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
Peak Collector Current	i_C	10	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 116	
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

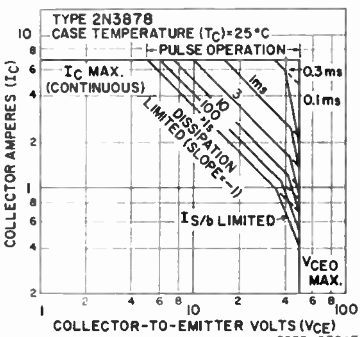
CHARACTERISTICS (At case temperature = 25°C)

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

CHARACTERISTICS (cont'd)

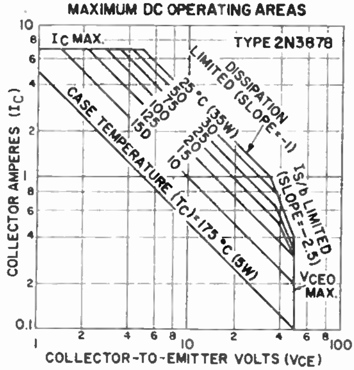
V_{CE} = 100 V, V_{BE} = −1.5 V, T_C = 25°C	I_{CEV}	4 max	mA
V_{CE} = 100 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	4 max	mA
Emitter-Cutoff Current (V_{EB} = 4 V, I_C = 0)	I_{EBO}	4 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = 5 V, I_C = 0.5 A	h_{FE}	50 to 200	
V_{CE} = 5 V, I_C = 4 A	h_{FE}	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 MHz)	h_{fe}	6 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 MHz)	C_{obo}	175 max	pF
Thermal Resistance, Junction-to-Case	θ_{J-C}	5 max	°C/W

MAXIMUM PULSE OPERATING AREAS



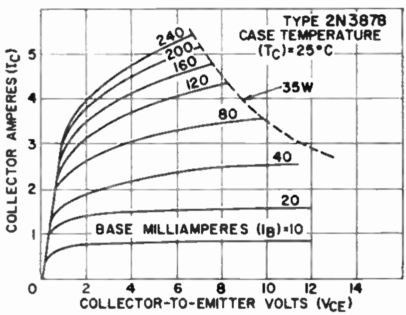
92SS-2794T

MAXIMUM DC OPERATING AREAS



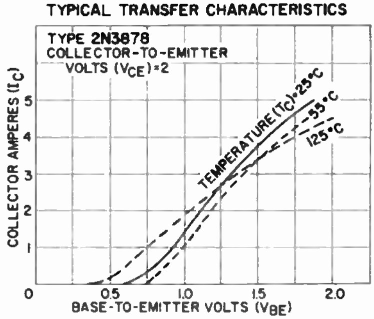
92SS-2795T

TYPICAL COLLECTOR CHARACTERISTICS



92SS 2197T

TYPICAL TRANSFER CHARACTERISTICS



92CS 13228T

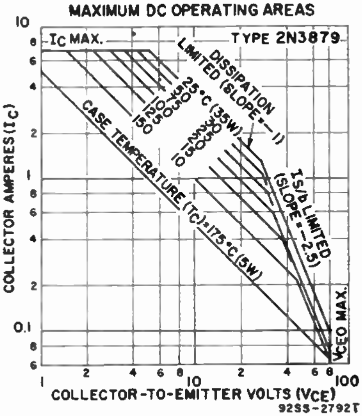
2N3879 POWER TRANSISTOR

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. 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:

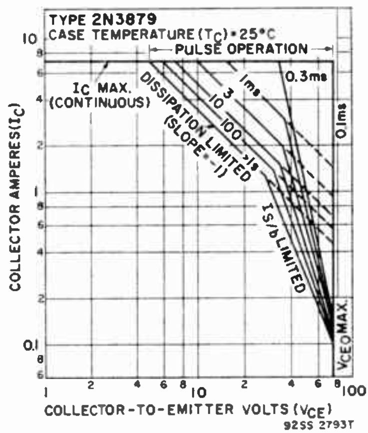
CHARACTERISTICS (At case temperature = 25°C)

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

MAXIMUM DC OPERATING AREAS



MAXIMUM PULSE OPERATING AREAS



TRANSISTOR 2N3932

Si n-p-n epitaxial planar type for general purpose vhf-uhf applications in rf amplifiers. JEDEC TO-104, Outline No. 26 (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	200	mW
T_A above 25°C	P_T	See curve page 116	
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	265	°C

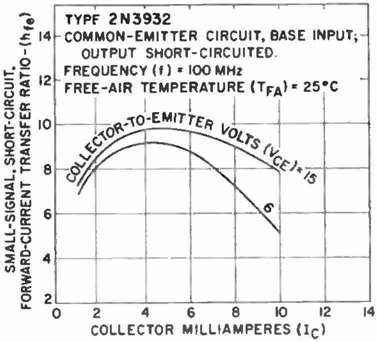
CHARACTERISTICS

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

CHARACTERISTICS (cont'd)

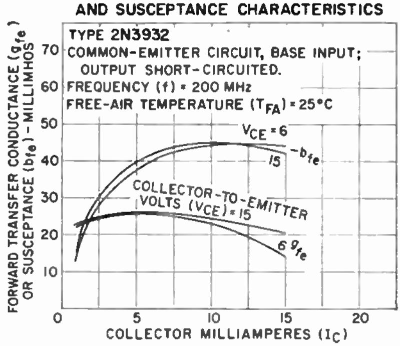
Emitter-to-Base Breakdown Voltage (I_E = 0.001 mA, I_C = 0)	$V_{(BR)EBO}$	2.5 min	V
Collector-Cutoff Current (V_{CB} = 15 V, I_E = 0)	I_{CBO}	0.01 max	μA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 8 V, I_C = 2 mA, f = 100 MHz, lead No. 4 grounded)	h_{fe}	7.5 to 16	
Gain-Bandwidth Product	f_T	750 min	MHz
Collector-to-Base Time Constant (V_{CB} = 8 V, I_E = 2 mA, f = 31.9 MHz)	$r_b'C_c$	1 to 8	ps
Collector-to-Base Feedback Capacitance (V_{CB} = 8 V, I_E = 0, f = 0.1 to 1 MHz, lead Nos. 1 and 4 connected to guard terminal)	C_{cb}	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 MHz, 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 MHz	NF	4.5 max	dB
V_{CE} = 6 V, I_C = 1.5 mA, R_S = 200 Ω, f = 450 MHz	NF	5	dB

TYPICAL SMALL-SIGNAL FORWARO-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. JEDEC TO-104, Outline No. 26 (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 MHz, 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 MHz)	$r_b'C_c$	1 to 6	ps
Noise Figure (V_{CB} = 8 V, I_C = 2 mA, R_S = 200 Ω, f = 200 MHz)	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.

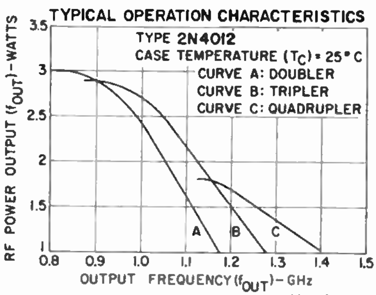
MAXIMUM RATINGS

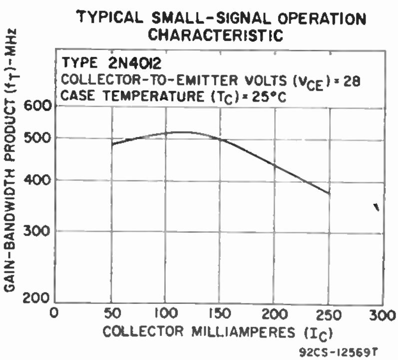
Collector-to-Base Voltage	V_{CBO}	65	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	65	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	1.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	11.6	W
T_C above 25°C	P_T	See curve page 116	
Temperature Range:			
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 = 0.1 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
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 150 mA)	f_T	500	MHz
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{obo}	10 max	pF
Collector-to-Base Cutoff Frequency* (V_{CE} = 28 V, I_C = 0)	f_c	25	GHz
RF Power Output, Multiplier:			
Tripler-V_{CE} = 28 V, f = 1002 MHz, P_{IE} = 1 W at 334 MHz	P_{OE}	2.5† min	W
Doubler-V_{CE} = 28 V, f = 800 MHz, P_{IE} = 1 W at 400 MHz	P_{OE}	3■	W

* Cutoff frequency is determined from Q measurement at 210 MHz. The cutoff frequency of the collector-to-base junction of the transistor, f_c = Q x 210 MHz.
† 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

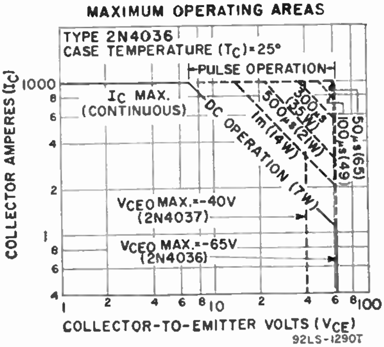
Collector-to-Base Voltage	V_{CBO}	−90	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = 1.5 V	$V_{CEV}(sus)$	−85	V
$R_{BE} \leqq$ 200 Ω	$V_{CER}(sus)$	−85	V
Base open	$V_{CEO}(sus)$	−65	V
Emitter-to-Base Voltage	V_{EBO}	−7	V
Collector Current	I_C	−1	A
Base Current	I_B	−0.5	A
Transistor Dissipation:*			
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 116	
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.

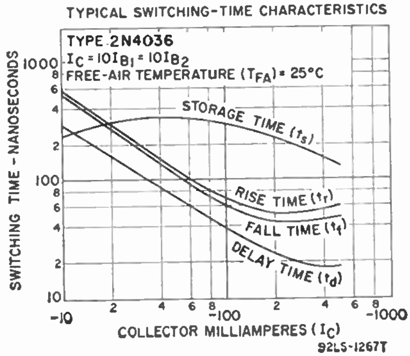
CHARACTERISTICS (At case temperature = 25°C)

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 Ω, 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
Base-to-Emitter Voltage (V_{CE} = −10 V, I_C = −150 mA)	V_{BE}	−1.1	V
Collector-Cutoff Current:			
V_{CB} = −60 V, I_E = 0	I_{CBO}	−0.02 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 140	
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 MHz)	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} ≈ 4 V)	$t_d + t_r$	110 max	ns

MAXIMUM OPERATING AREAS



TYPICAL SWITCHING-TIME CHARACTERISTICS



CHARACTERISTICS (cont'd)

Saturated Switching Turn-Off Time (V_{CB} = −30 V, I_C = −150 mA, I_{B_2} = 15 mA, V_{BB} ≈ 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

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

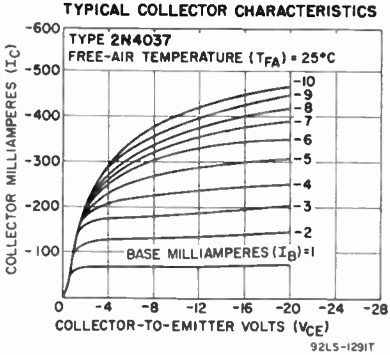
Collector-to-Base Voltage	V_{CBO}	−60	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = 1.5 V	V_{CEV}(sus)	−60	V
R_{BE} ≦ 200 Ω	V_{CER}(sus)	−60	V
Base open	V_{CEO}(sus)	−40	V
Emitter-to-Base Voltage	V_{EBO}	−7	V
Collector Current	I_C	−1	A
Base Current	I_B	−0.5	A
Transistor Dissipation:*			
T_A 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 116	
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.

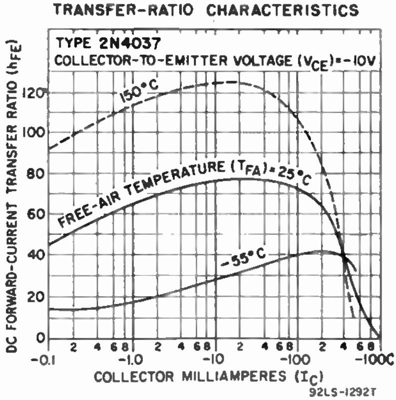
CHARACTERISTICS (At case temperature = 25°C)

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

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



CHARACTERISTICS (cont'd)

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)	50 to 250	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −10 V, I_C = −50 mA, f = 20 MHz)	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}	1.17 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	165 max	°C/W

* This value does not apply to type 40391.

2N4063 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 (with flange), **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with flange). This type is electrically identical with type 2N3439.

2N4064 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 (with flange), **Outline** No.3. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with flange). This type is electrically identical with type 2N3440.

2N4068 TRANSISTOR

Si **n-p-n** type used in wide-band-amplifier and relay-driver applications in critical industrial equipment such as video amplifiers, television cameras, camera chains, monitors, oscilloscopes, and neon-indicator drivers. JEDEC TO-104, **Outline** No.26 (3-lead). **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	200	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_A above 25°C	P_T	See curve page 116	
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

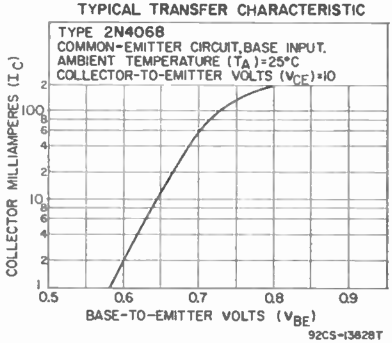
Collector-to-Emitter Breakdown Voltage (I_C = 1 mA, I_B = 0)	$V_{(BR)CEO}$	150 min; 180 typ	V
Emitter-to-Base Breakdown Voltage (I_E = −10 μA, I_C = 0)	$V_{(BR)EBO}$	5 min; 7 typ	V
Collector-to-Emitter Saturation Voltage (I_C = 30 mA, I_B = 1 mA)	V_{CE}(sat)	1 typ; 3 max.	V
Base-to-Emitter Saturation Voltage (I_C = 30 mA, I_B = 1 mA)	V_{BE}(sat)	0.68	V

CHARACTERISTICS (cont'd)

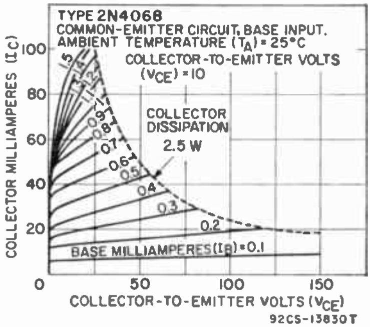
Collector-Cutoff Current (V_{CB} = 120 V, I_E = 0)	I_{CBO}	5 typ; 50 max	nA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 30 mA)	h_{FE}	30 min; 70 typ	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 30 mA, f = 1 kHz)	h_{fe}	80	
Gain-Bandwidth Product:			
V_{CE} = 10 V, I_C = 30 mA, f = 100 MHz	f_T	50 min; 100 typ	MHz
V_{CE} = 140 V, I_C = 2 mA, f = 100 MHz	f_T	50 min; 100 typ	MHz
Output Capacitance* (V_{CB} = 10 V, I_C = 0, f = 1 MHz)	C_{obo}	2.8 typ; 3.5 max	pF
Thermal Resistance, Junction-to-Case	θ_{J-C}	45 typ; 60 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	300 max	°C/W

* Three-terminal measurement with lead No. 1 (emitter) and lead No. 3 (case) connected to guard terminal.

TYPICAL TRANSFER CHARACTERISTIC



TYPICAL COLLECTOR CHARACTERISTICS



TRANSISTOR 2N4069

Si **n-p-n** type used in wide-band-amplifier and relay-driver applications in critical industrial equipment such as video amplifiers, television cameras, camera chains, monitors, oscilloscopes, and neon-indicator drivers. JEDEC TO-104 (with heat radiator), **Outline** No.26 (3-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector and case (with heat radiator). This type is electrically identical with type 2N4068 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	150 max	°C/W

TRANSISTOR 2N4074

Si **n-p-n epitaxial planar** type used in high-voltage, high-current audio and video amplifier service in commercial and industrial equipment. JEDEC TO-104, **Outline** No.26 (3-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Emitter Voltage:			
V_{BE} = −1 V	V_{CEV}	40	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	8	V
Collector Current	I_C	300	mA

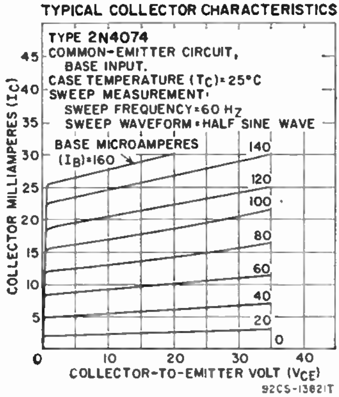
MAXIMUM RATINGS (cont'd)

Emitter Current	I_E	−300	mA
Transistor Dissipation:			
T_C up to 75°C	P_T	2	W
T_C above 75°C	P_T	See curve page 116	
T_A up to 25°C	P_T	0.5	W
T_A above 25°C	P_T	See curve page 116	
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

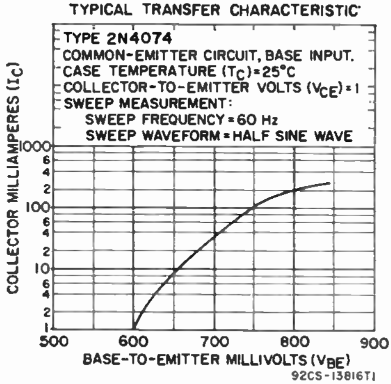
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage (I_C = 10 mA, I_B = 0)	$V_{(BR)CEO}$	40 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.05 mA, I_C = 0)	$V_{(BR)EBO}$	8 min	V
Collector-to-Emitter Saturation Voltage (I_C = 300 mA, I_B = 15 mA)	V_{CE}(sat)	0.22 typ; 0.3 max	V
Base-to-Emitter Saturation Voltage (I_C = 300 mA, I_B = 15 mA)	V_{BE}(sat)	1 typ; 1.5 max	V
Collector-Cutoff Current:			
V_{CB} = 25 V, I_E = 0	I_{CBO}	10 max	nA
V_{CB} = 25 V, I_E = 0, T_C = 85°C	I_{CBO}	1 max	μA
V_{CE} = 40 V, V_{BE} = 1 V	I_{CEV}	10 max	μA
Emitter-Cutoff Current (V_{BE} = −2.5 V, I_C = 0)	I_{EBO}	10 max	nA
Static Forward-Current Transfer Ratio:			
V_{CE} = 6 V, I_C = 0.5 mA	h_{FE}	35 min; 75 typ	
V_{CE} = 10 V, I_C = 10 mA	h_{FE}	75 to 300	
V_{CE} = 1 V, I_C = 100 mA	h_{FE}	50 min; 140 typ	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{fe}	75 min; 175 typ	
Gain-Bandwidth Product (V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	f_T	50 min; 80 typ	MHz
Intrinsic Base-Spreading Resistance (V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	$r_{bb'}$	20 typ; 40 max	Ω
Output Capacitance (V_{CB} = 6 V, I_E = 0, f = 1 MHz)	C_{obo}	12 typ; 20 max	pF
Small-Signal Input Impedance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{ie}	600	Ω
Small-Signal Output Admittance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{oe}	75	μmhos
Small-Signal Reverse-Voltage Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{re}	125 x 10^{-6}	
Thermal Resistance, Junction-to-Case	θ_{J-C}	50 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	300 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC



TRANSISTOR 2N4081

Si n-p-n epitaxial planar type used as low-noise rf amplifier at frequencies up to 500 MHz. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No. 26 (4-lead). Terminals: 1 - base, 2 - emitter, 3 - collector, 4 - case.

MAXIMUM RATINGS (cont'd)

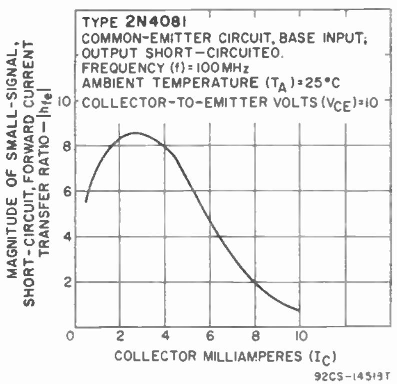
Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	Limited by dissipation	
Transistor Dissipation:			
T_A up to 25°C	P_T	200	mW
T_A above 25°C	P_T	Derate linearly 1.14	mW/°C
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C
Storage	T_{STG}	—65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	265	°C

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	$V_{(BR)CEO}$	40 min	V
I_C = 0.001 mA	$V_{(BR)CES}$	40 min	V
Emitter-to-Base Breakdown Voltage● (I_E = −0.01 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V
Collector-Cutoff Current (V_{CB} = 10 V, I_E = 0)	I_{CBO}	0.02 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 2 mA)	h_{FE}	40 to 180	
Magnitude of Small-Signal Forward-Current Transfer Ratio*:			
V_{CE} = 10 V, I_C = 2 mA, f = 1 kHz	$\|h_{fe}\|$	40 to 200	
V_{CE} = 10 V, I_C = 2 mA, f = 100 MHz	$\|h_{fe}\|$	6 to 11	
Collector-to-Base Feedback Capacitance■ (V_{CB} = 10 V, I_E = 0, f = 0.1 to 1 MHz)	C_{cb}	0.25 max	pF
Power Gain Amplifier, Unneutralized* (V_{CE} = 10 V, I_C = 2 mA, f = 200 MHz)	G_{Pe}	19 to 24	dB
Power Gain, AGC (I_C from 2 mA to 11 mA)		30	dB
Noise Figure* (V_{CE} = 10 V, I_C = 2 mA, R_S = 200 Ω, f = 200 MHz)	NF	3.5 max	dB

* Lead No. 4 (case) grounded.
■ Three-terminal measurement with lead No. 2 (emitter) and lead No. 4 (case) connected to guard terminal.
● Emitter-base termination shorted.

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC



2N4240 TRANSISTOR

Si n-p-n triple-diffused type used in high voltage, high-speed-switching and linear-amplifier applications such as operational amplifiers, switching regulators, converters, inverters, deflection and high-fidelity amplifiers. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical with type 2N3585 except for the following items:

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Saturation Voltage (I_C = 750 mA, I_B = 75 mA)	V_{BE}(sat)	1 max	V
Collector-Cutoff Current:			
V_{CE} = 150 V, I_B = 0	I_{CEO}	5 max	mA
V_{CE} = 400 V, V_{BE} = −1.5 V	I_{CEV}	2 max	mA
V_{CE} = 300 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	5 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 750 mA)	h_{FE}	30 to 150	
Second Breakdown Energy (R_{BE} = 20 Ω, L = 100 μH, V_{BE} = −4 V)	$E_{S/b}$	50 min	μJ

2N4259 TRANSISTOR

Si n-p-n epitaxial planar type used in vhf and uhf applications in industrial and military equipment. JEDEC TO-104, Outline No.26 (4-lead). Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

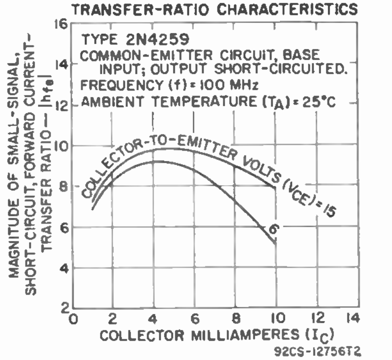
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage	V_{CEO}	30	V
Emitter-to-Base Voltage	V_{EBO}	2.5	V
Collector Current	I_C	Limited by dissipation	
Transistor Dissipation:			
T_A up to 25°C	P_T	175	mW
T_A above 25°C	P_T	See curve page 116	
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	265	°C

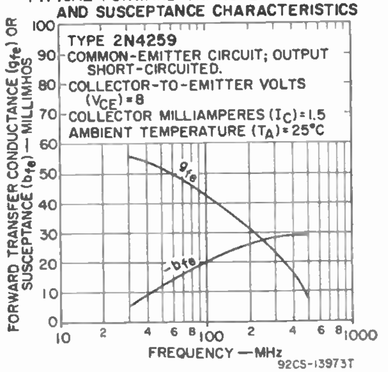
CHARACTERISTICS

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)	$V_{(BR)CEO}$	30 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.001 mA, I_C = 0)	$V_{(BR)EBO}$	2.5 min	V

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



TYPICAL FORWARD TRANSFER CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



CHARACTERISTICS (cont'd)

Collector-Cutoff Current (V_{CB} = 15 V, I_E = 0)	I_{CBO}	0.01 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 8 V, I_C = 2 mA)	h_{FE}	60 to 250	
Small-Signal Forward-Current Transfer Ratio:▲			
V_{CE} = 8 V, I_C = 2 mA, f = 0.001 MHz	h_{fe}	70 to 280	
V_{CE} = 8 V, I_C = 2 mA, f = 100 MHz	h_{fe}	7.5 to 16	
Collector-to-Base Feedback Capacitance* (V_{CB} = 8 V, I_E = 0, f = 0.1 to 1 MHz)	C_{cb}	0.35 typ; 0.55 max	pF
Collector-to-Base Time Constant▲ (V_{CB} = 8 V, I_E = 2 mA, f = 31.9 MHz)	$r_b'C_c$	1 to 8	ps
Small-Signal Power Gain▲ (V_{CE} = 8 V, I_C = 1.5 mA, f = 450 MHz)	G_{pe}	11.5 to 16.5	dB
Noise Figure▲ (V_{CE} = 8 V, I_C = 1.5 mA, R_G and R_L = 50 Ω, f = 450 MHz)	NF	5 max	dB

▲ Lead 4 (case) grounded.
* Three-terminal capacitance measurement with lead No. 1 (emitter) and lead No. 4 (case) connected to guard terminal.

POWER TRANSISTOR 2N4296

Si n-p-n triple diffused type used in critical amplifier and switching applications in military, industrial and commercial equipment. This type is useful as a power amplifier in line-operated equipment. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

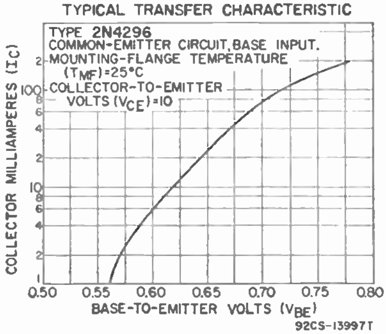
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	350	V
Collector-to-Emitter Voltage	V_{CEO}	250	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	1	A
Base Current	I_B	0.25	A
Transistor Dissipation:			
T_{MF} up to 25°C	P_T	20	W
T_{MF} above 25°C	P_T	See curve page 116	
T_A up to 55°C	P_T	2	W
T_A above 55°C	P_T	See curve page 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 175	°C
Storage	T_{STG}	−65 to 175	°C
Lead-Storage Temperature (10 s max)	T_L	265	°C

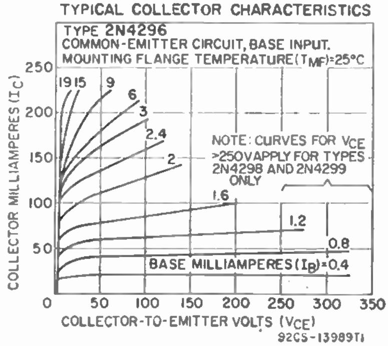
CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 50 mA, I_B = 0)	V_{CEO}(sus)	250 min	V
Collector-to-Emitter Saturation Voltage (I_B = 5 mA, I_C = 50 mA)	V_{CE}(sat)	0.9 max	V

TYPICAL TRANSFER CHARACTERISTIC



TYPICAL COLLECTOR CHARACTERISTICS



CHARACTERISTICS (cont'd)

Base-to-Emitter Saturation Voltage (I_B = 5 mA, I_C = 50 mA)	V_{BE}(sat)	1.5 max	V
Base-to-Emitter Voltage (V_{CE} = 10 V, I_C = 100 mA)	V_{BE}	0.9 max	V
Collector-Cutoff Current:			
V_{CB} = 350 V	I_{CBO}	100 max	μA
V_{CE} = 150 V, V_{BE} = −1.5 V, T_{MF} = 135°C	I_{CEV}	600 max	μA
Emitter-Cutoff Current (V_{BE} = −4 V, I_C = 0)	I_{EBO}	100 max	μA
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 5 mA	h_{FE}	35 min	
V_{CE} = 10 V, I_C = 50 mA	h_{FE}	50 to 150	
V_{CE} = 10 V, I_C = 100 mA	h_{FE}	35 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 20 mA, f = 5 MHz)	h_{fe}	4 min; 6 typ	
Second-Breakdown Collector Current (V_{CE} = 200 V)	$I_{S/b}$	75 min	mA
Collector-to-Base Feedback Capacitance* (V_{CB} = 100 V, I_E = 0, f = 0.1 to 1 MHz)	C_{cb}	3.8 typ; 6 max	pF
Turn-On Time (V_{BB} = 10 V, V_{CC} = 100 V, I_{B1} = 10 mA, I_{B2} = −10 mA)	$t_d + t_r$	5 typ; 7 max	μs
Turn-Off Time (V_{BB} = 10 V, V_{CC} = 100 V, I_{B1} = 10 mA, I_{B2} = −10 mA, I_C = 100 mA)	$t_s + t_f$	7 typ; 10 max	μs
Intrinsic Base-Spreading Resistance (V_{CE} = 50 V, I_C = 20 mA)	$r_{bb'}$	15 typ; 25 max	Ω
Thermal Resistance, Junction-to-Case	θ_{J-C}	7.5 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	60 max	°C/W

* Three-terminal measurement of the collector-to-base capacitance with lead 1 (emitter) connected to the guard terminal.

2N4297 POWER TRANSISTOR

Si **n-p-n** triple **diffused** type used in critical amplifier and switching applications in military, industrial, and commercial equipment. This type is useful as a power amplifier in line-operated equipment. JEDEC TO-66, **Outline** No.22. **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collec-lector and case. This type is identical to type 2N4296 except for the following items:

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Saturation Voltage (I_B = 5 mA, I_C = 50 mA)	V_{CE}(sat)	0.75 max	V
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 5 mA	h_{FE}	50 min	
V_{CE} = 10 V, I_C = 50 mA	h_{FE}	75 to 300	
V_{CE} = 10 V, I_C = 100 mA	h_{FE}	50 min	

2N4298 POWER TRANSISTOR

Si **n-p-n** triple-**diffused** type used in critical amplifier and switching applications in military, industrial, and commercial equipment. This type is useful as a power amplifier in line-operated equipment. JEDEC TO-66, **Outline** No.22. **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical to type 2N4296 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	500	V
Collector-to-Emitter Voltage	V_{CEO}	350	V

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (I_C = 50 mA, I_B = 0)	V_{CEO}(sus)	350 min	V
Collector-Cutoff Current (V_{CB} = 500 V)	I_{CBO}	100 max	μA
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 5 mA	h_{FE}	20 min	
V_{CE} = 10 V, I_C = 50 mA	h_{FE}	25 to 75	
V_{CE} = 10 V, I_C = 100 mA	h_{FE}	20 min	

POWER TRANSISTOR 2N4299

Si n-p-n triple-diffused type used in critical amplifier and switching applications in military, industrial, and commercial equipment. This type is useful as a power amplifier in line-operated equipment. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case. This type is identical to type 2N4298 except for the following items:

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Saturation Voltage (I_B = 5 mA, I_C = 50 mA)	V_{CE}(sat)	0.75 max	V
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 5 mA	h_{FE}	35 min	
V_{CE} = 10 V, I_C = 50 mA	h_{FE}	50 to 150	
V_{CE} = 10 V, I_C = 100 mA	h_{FE}	35 min	

POWER TRANSISTOR 2N4346

Ge p-n-p diffused-collector graded-base type used as a horizontal-output amplifier in conjunction with types 2N3730 (vertical output), 2N3732 (horizontal driver), and 1N4785 (damper) to provide 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
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 116	
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	230	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage (I_C = −0.025 A, V_{EB} = 0)	$V_{(BR)CES}$	−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)	−0.75 max	V
Base-to-Emitter Voltage (I_C = 6 A, I_B = −0.4 A)	V_{BE}	0.8	V
Collector-Cutoff Current (V_{CB} = −10 V, I_E = 0)	I_{CBO}	−200 max	μA
Turn-Off Time	$t_s + t_f$	0.75 max	μs
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

POWER TRANSISTOR 2N4347

Si n-p-n type featuring a base comprised of a homogeneous-resistivity silicon material. This type is used in high-voltage applications in power-switching circuits, audio amplifiers, series and shunt regulators, drivers, and output stages, dc-to-dc converters, inverters, and solenoid (hammer)/relay driver service in military, industrial, and commercial equipment. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector to case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	140	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	140	V
Base open	V_{CEO}	120	V

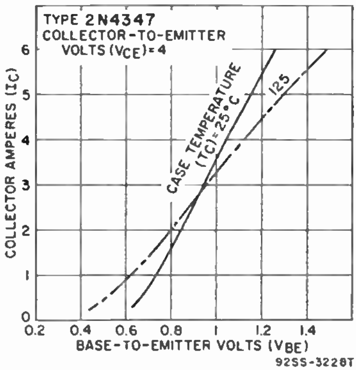
MAXIMUM RATINGS (cont'd)

Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	5	A
Peak Collector Current	i_C	10	A
Base Current	I_B	3	A
Transistor Dissipation:			
T_C up to 25°C	P_T	100	W
T_C above 25°C	P_T	See curve page 116	
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

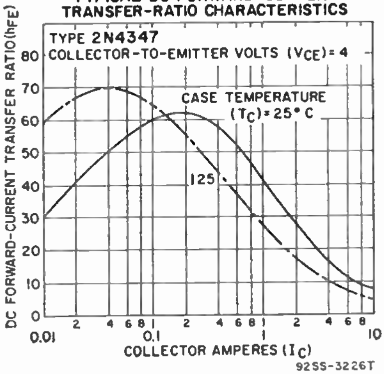
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage:			
I_C = 0.2 A to 3 A, I_B = 0	V_{CEO}(sus)	120 min	V
V_{BE} = −1.5 V, I_C = 0.1 A to 1.5 A	V_{CEV}(sus)	140 min	V
Collector-to-Emitter Saturation Voltage (I_C = 2 A, I_B = 0.2 A)	V_{CE}(sat)	1 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 2 A)	V_{BE}	2 max	V
Collector-Cutoff Current:			
V_{CE} = 120 V, V_{BE} = −1.5 V	I_{CEV}	2 max	mA
V_{CE} = 120 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	10 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 = 2 A)	h_{FE}	20 to 70	
Power Rating Test (V_{CE} = 67 V, I_C = 1.5 A, t = 1 s)		100	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.75 max	°C/W

TYPICAL TRANSFER CHARACTRISTICS



TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



2N4348 POWER TRANSISTOR

Si **n-p-n** type featuring a base comprised of a homogeneous-resistivity silicon material. This type is used in high-voltage applications in power-switching circuits, audio amplifiers, series and shunt regulators, drivers, and output stages, dc-to-dc converters, inverters, and solenoid (hammer)/relay driver service in military, industrial, and commercial equipment. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector to case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	140	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	140	V
Base open	V_{CEO}	120	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	10	A
Peak Collector Current	i_C	30	A
Base Current	I_B	4	A

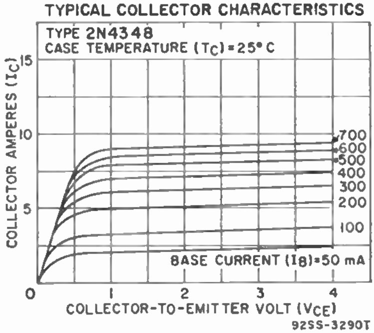
MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_C up to 25°C	P_T	120	W
T_C above 25°C	P_T	See curve page 116	
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

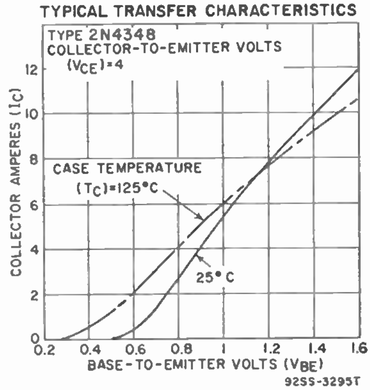
CHARACTERISTICS (At case temperature = 25°C)

Emitter-to-Base Breakdown Voltage (I_E = 5 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = 1.5 V, I_C = 0.1 A to 1.5 A	V_{CEV}(sus)	140 min	V
I_C = 0.2 A to 3 A, I_B = 0	V_{CEO}(sus)	120 min	V
Collector-to-Emitter Saturation Voltage (I_C = 5 A, I_B = 0.5 A)	V_{CE}(sat)	1 max	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 5 A)	V_{BE}	2 max	V
Collector-Cutoff Current:			
V_{CE} = 120 V, V_{BE} = −1.5 V	I_{CEV}	2 max	mA
V_{CE} = 120 V, I_B = 0, T_C = 150°C	I_{CEV}	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 = 5 A, t_p = 300 μs, f = 60 Hz)	h_{FE}(pulsed)	15 to 60	
Power Rating Test (V_{CE} = 80 V, I_C = 1.5 A, t = 1 s)		120	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.46 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



TRANSISTOR 2N4390

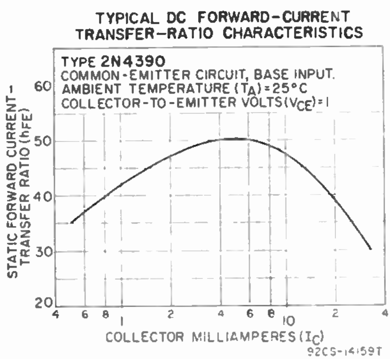
Si n-p-n type used for direct "on-off" control of high-voltage, low-power devices such as numerical display tubes and relays, and for other control applications in industrial equipment. JEDEC TO-104, Outline No.26 (3-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.

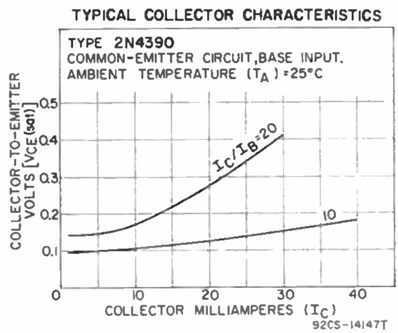
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	120	V
Emitter-to-Base Voltage	V_{EBO}	6	V
Collector-to-Emitter Voltage	V_{CEO}	120	V
Collector Current	I_C	Limited by dissipation	
Transistor Dissipation:			
T_A up to 25°C	P_T	500	mW
T_A above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	265	°C

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	120 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 1 mA, I_B = 0)	$V_{(BR)CEO}$	120 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	6 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = 20 mA, I_B = 2 mA	V_{CE}(sat)	0.3 max	V
I_C = 2 mA, I_B = 0.2 mA	V_{CE}(sat)	0.2 max	V
Base-to-Emitter Voltage:			
I_C = 20 mA, I_B = 2 mA	V_{BE}	0.85 max	V
I_C = 2 mA, I_B = 0.2 mA	V_{BE}	0.75 max	V
Collector-Cutoff Current (V_{CE} = 70 V, V_{EB} = 1 V)	I_{CEV}	1 max	µA
Base-Cutoff Current (V_{CE} = 70 V, V_{EB} = 1 V)	I_{BEV}	1 max	µA
Static Forward-Current Transfer Ratio:			
V_{CE} = 1 V, I_C = 2 mA	h_{FE}	20 min	
V_{CE} = 1 V, I_C = 20 mA	h_{FE}	20 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 20 mA, f = 4 MHz)	h_{fe}	12.5 min	
Feedback Capacitance (V_{CB} = 10 V, I_E = 0, f = 1 MHz)	C_{cb}	6 max	pF
Input Capacitance (V_{EB} = 0.5 V, I_E = 0, f = 1 MHz)	C_{ibo}	40 max	pF
Delay Time (V_{CC} = 3.4 V, V_{BE}(off) = 1.5 V, I_{B1} = 2 mA, I_{CS} = 20 mA)	t_d	150 max	ns
Rise Time (V_{CC} = 3.4 V, V_{BE}(off) = 1.5 V, I_{B1} = 2 mA, I_{CS} = 20 mA)	t_r	500 max	ns
Storage Time (V_{CC} = 3.4 V, I_{B1} = 2 mA, I_{CS} = 20 mA, I_{B2} = −2 mA)	t_s	800 max	ns
Fall Time (V_{CC} = 3.4 V, I_{B1} = 2 mA, I_{CS} = 20 mA, I_{B2} = −2 mA)	t_f	500 max	ns





2N4395 POWER TRANSISTOR

Si **n-p-n** high-current power type used in a wide variety of applications in industrial equipment such as power switching, voltage and current regulating, dc-to-dc converters, inverters, and relay drivers; and in ultrasonic oscillator and high-power af amplifiers. JEDEC TO-3, Outline No.2. Terminals: 1 - base, 2 - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

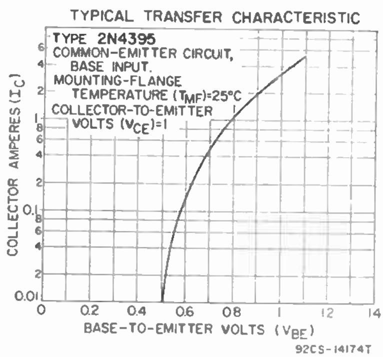
Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	5	A
Peak Collector Current	I_C	15	A
Transistor Dissipation:			
T_{MF} up to 25°C	P_T	62.5	W
T_{MF} above 25°C	P_T	See curve page 116	

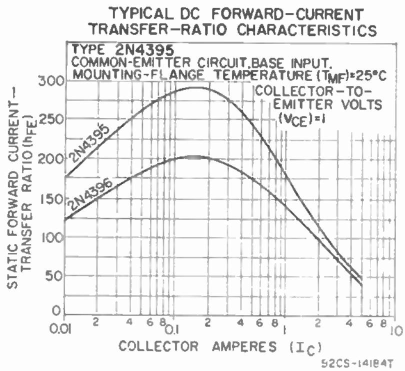
MAXIMUM RATINGS (cont'd)

Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 150	°C
Storage	T_{STG}	−65 to 150	°C
Lead-Soldering Temperature (10 s max)	T_L	265	°C

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Base-to-Emitter Breakdown Voltage (I_E = 0.01 A)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 0.1 A, I_B = 0)	$V_{(BR)CEO}$	40 min	V
Collector-to-Emitter Saturation Voltage:			
I_C = 2 A, I_B = 0.2 A	V_{CE}(sat)	0.25	V
I_C = 4 A, I_B = 0.8 A	V_{CE}(sat)	0.8 max	V
Base-to-Emitter Saturation Voltage (I_C = 4 A, I_B = 0.8 A)	V_{BE}(sat)	1.5 max	V
Collector-Cutoff Current:			
V_{CB} = 60 V, I_E = 0	I_{CBO}	0.1 max	mA
V_{CE} = 35 V, V_{BE} = −1 V, T_{MF} = 85°C	I_{CEV}	1 max	mA
V_{CE} = 35 V, V_{BE} = − 1 V, T_{MF} = 25°C	I_{CEV}	0.5 max	mA
Emitter-Cutoff Current:			
V_{BE} = −4 V, I_C = 0	I_{EBO}	10 max	mA
V_{BE} = −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}	75 min	
V_{CE} = 1 V, I_C = 2 A	h_{FE}	50 to 170	
V_{CE} = 1 V, I_C = 4 A	h_{FE}	20 min	
Magnitude of Small-Signal Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 0.5 A, f = 1 MHz	$\|h_{fe}\|$	4 min; 7 typ	
V_{CE} = 10 V, I_C = 0.5 A, f = 1 kHz	$\|h_{fe}\|$	100 min	
Second-Breakdown Collector Current (V_{CE} = 25 V)	$I_{S/b}$	4 min	A
Turn-On Time (V_{CC} = 25 V, V_{BB} = −5 V, I_C = 2 A, I_{B1} = 0.2 A, I_{B2} = −0.2 A)	$t_d + t_r$	0.8 max	μs
Turn-Off Time (V_{CC} = 25 V, V_{BB} = −5 V, I_C = 2 A, I_{B1} = 0.2 A, I_{B2} = −0.2 A)	$t_s + t_f$	1.5 max	μs





POWER TRANSISTOR 2N4396

Si n-p-n high-current power type used in a wide variety of applications in industrial equipment such as power switching, voltage and current regulating, dc-to-dc converters, inverters, and relay drivers; and in ultrasonic oscillators and high-power af amplifiers. JEDEC TO-3, **Outline** No.2. **Terminals:** 1 - base, 2 - emitter, Mounting Flange - collector and case. This type is identical with type 2N4395 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	80	V
Collector-to-Emitter Voltage	V_{CEO}	60	V

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Breakdown Voltage (I_C = 0.1 A, I_B = 0)	$V_{(BR)CEO}$	60 min	V
Collector-Cutoff Current (V_{CB} = 80 V, I_E = 0)	I_{CBO}	0.1 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = 1 V, I_C = 1 A	h_{FE}	60 min	
V_{CE} = 1 V, I_C = 2 A	h_{FE}	40 to 170	
V_{CE} = 1 V, I_C = 4 A	h_{FE}	20 min	
Turn-On Time (V_{CC} = 25 V, V_{BB} = −5 V, I_C = 2 A, I_{B1} = 0.2 A, I_{B2} = −0.2 A)	$t_d + t_r$	1 max	μs
Turn-Off Time (V_{CC} = 25 V, V_{BB} = −5 V, I_C = 2 A, I_{B1} = 0.2 A, I_{B2} = −0.2 A)	$t_s + t_f$	2 max	μs

2N4397 TRANSISTOR

Si **n-p-n epitaxial planar** type used as low-noise rf amplifier at frequencies up to 500 MHz. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No. 26 (4-lead). **Terminals:** 1 - base, 2 - emitter, 3 - collector, 4 - case. This type is identical to type 2N4081 except for the following items:

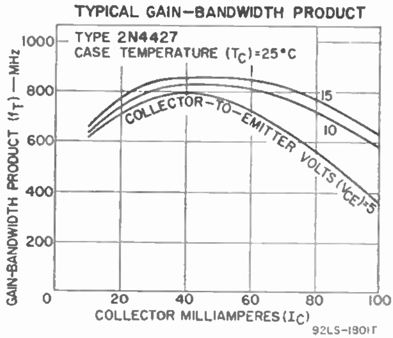
CHARACTERISTICS

Collector-to-Base Feedback Capacitance* (V_{CB} = 10 V, I_C = 0, f = 0.1 to 1 MHz)	C_{cb}	0.25 max	pF
Power Gain, Amplifier, Unneutralized■ (V_{CB} = 8 V, I_C = 2 mA, f = 450 MHz)	G_{pe}	11.5 to 16.5	dB
Power Gain, AGC■ (I_C from 2 mA to 11 mA)		20	dB
Noise Figure■ (V_{CE} = 8 V, I_C = 2 mA, R_S = 100 Ω, f = 450 MHz)	NF	5 max	dB

* Three-terminal measurement with lead No. 2 (emitter) and lead No. 4 (case) connected to guard terminal.
■ Lead No. 4 (case) grounded.

2N4427 TRANSISTOR

Si **n-p-n "overlay" epitaxial planar** type used in class A, B, or C amplifier, frequency-multiplier, or oscillator circuits; it is used in output, driver, or pre-driver stages in vhf and uhf equipment. JEDEC TO-39, Outline No.12. **Terminals:** 1 - emitter, 2 - base, 3 - collector and case.



MAXIMUM RATINGS

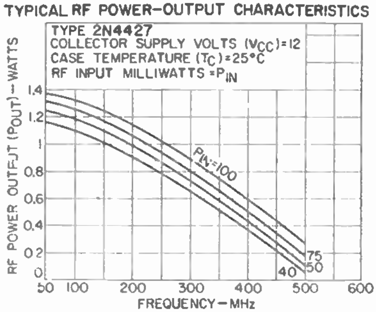
Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage	V_{CEO}	20	V
Emitter-to-Base Voltage	V_{EBO}	2	V
Collector Current	I_C	0.4	A
Transistor Dissipation:			
T_C up to 25°C	P_T	3.5	W
T_C above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C
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)	$V_{(BR)CBO}$	40 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 = 100 mA, I_B = 20 mA)	V_{CE}(sat)	0.5 max	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 5 mA, R_{BE} = 10 Ω	V_{CER}(sus)	40 min	V
I_C = 5 mA, I_B = 0	V_{CEO}(sus)	20 min	V
Collector-Cutoff Current (V_{CE} = 12 V, I_B = 0)	I_{CEO}	20 max	μA
Output Capacitance (V_{CB} = 12 V, I_E = 0, f = 1 MHz)	C_{obo}	4 max	pF
RF Power Output, Amplifier, Unneutralized (V_{CC} = 12 V, P_{IE} = 0.1 W, f = 175 MHz, R_G and R_L = 50 Ω)	P_{OE}	1* min	W

* For conditions given, minimum efficiency = 70 per cent.

TYPICAL RF POWER-OUTPUT CHARACTERISTICS



92LS-1757T

TRANSISTOR 2N4440

Si n-p-n "overlay" epitaxial planar type used in class A, B, and C amplifiers, frequency multipliers, or oscillators, for military and industrial communications. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

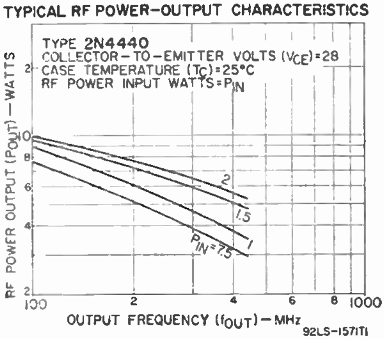
Collector-to-Emitter Voltage:			
V_{BE} = —1.5 V	V_{CEV}	65	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	1.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	11.6	W
T_C above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C
Storage	T_{STG}	—65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	230	°C

CHARACTERISTICS (At case temperature = 25°C)

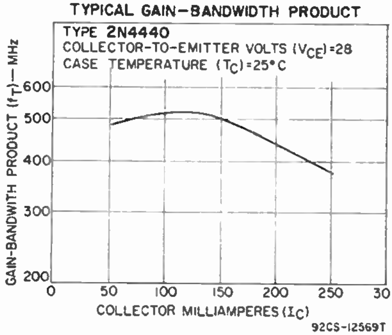
Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	65 min	V
Collector-to-Emitter Breakdown Voltage: I_B = 0, I_C = 0 to 200 mA, pulsed through inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	40 min	V
V_{BE} = −1.5 V, I_C = 0 to 200 mA, pulsed through inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	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	V
Gain-Bandwidth Product (V_{CE} = 28 V, I_C = 150 mA)	f_T	500	MHz
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{obo}	10 max	pF
Collector-to-Case Capacitance	C_c	6 max	pF
Intrinsic Base-Spreading Resistance (V_{CE} = 28 V, I_C = 250 mA)	$r_{bb'}$	10	Ω
RF Power Output, Amplifier, Unneutralized: V_{CE} = 28 V, P_{IE} = 1.7 W, R_G and R_L = 50 Ω, f = 225 MHz	P_{OE}	6.5*	W
V_{CE} = 28 V, P_{IE} = 1.7 W, R_G and R_L = 50 Ω, f = 400 MHz	P_{OE}	5 min▪	W

* For conditions given, minimum efficiency = 55 per cent.
▪ For conditions given, minimum efficiency = 45 per cent.

TYPICAL RF POWER-OUTPUT CHARACTERISTICS



TYPICAL GAIN-BANDWIDTH PRODUCT



2N4932 TRANSISTOR

Si n-p-n "overlay" epitaxial planar type used in high-power class C rf amplifiers for international vhf mobile and portable communications service. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, mounting stud, and case, 2 - base, 3 - collector.

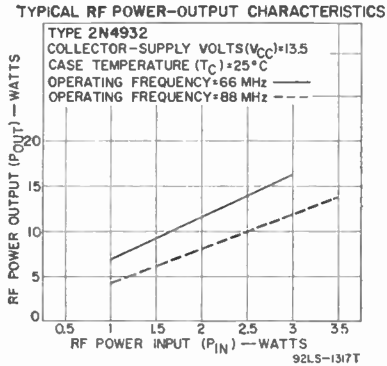
MAXIMUM RATINGS

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}	25	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	3.3	A
Peak Collector Current	i_C	10	A
Transistor Dissipation: T_C up to 25°C	P_T	70	W
T_C above 25°C	P_T	See curve page 116	
RF Input Power: At 88 MHz	P_{IE}	3.5	W
Below 88 MHz	P_{IE}	Derate linearly by 0.022 W/MHz to 3 W	
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 Breakdown Voltage:			
I_C = 200 mA, pulsed through an inductor L = 25 mH, df = 50%, I_B = 0	$V_{(BR)CEO}$(sus)	25 min	V
I_C = 200 mA, pulsed through an inductor L = 25 mH, df = 50%, V_{BE} = −1.5 V	$V_{(BR)CEV}$(sus)	50 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_{CC} = 13.5 V, P_{IE} = 3.5 W, f = 88 MHz, R_G and R_L = 50 Ω)	P_{OE}	12• min	W

• For conditions given, minimum efficiency = 70 per cent.



TRANSISTOR 2N4933

Si n-p-n "overlay" epitaxial planar type used in high-power class C rf amplifiers for international vhf mobile and portable communications service. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, mounting stud, and case, 2 - base, 3 - collector. This type is identical with type 2N4932 except for the following items:

MAXIMUM RATINGS

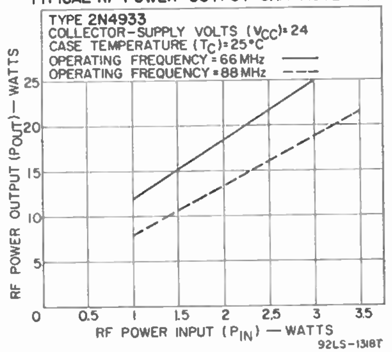
Collector-to-Base Voltage	V_{CBO}	70	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	70	V
Base open	V_{CEO}	35	V

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
I_C = 200 mA, pulsed through inductor L = 25 mA, df = 50%, I_B = 0	$V_{(BR)CEO}$(sus)	35 min	V
I_C = 200 mA, pulsed through inductor L = 25 mA, df = 50%, V_{BE} = −1.5 V	$V_{(BR)CEV}$(sus)	70 min	V
Collector-Cutoff Current:			
V_{CE} = 30 V, I_B = 0	I_{CEO}	1 max	mA
V_{CB} = 50 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_{CC} = 24 V, P_{IE} = 3.5 W, f = 88 MHz, R_G and R_L = 50 Ω)	P_{OE}	20• min	W

• For conditions given, minimum efficency = 70 per cent.

TYPICAL RF POWER—OUTPUT CHARACTERISTICS



2N4934 TRANSISTOR

Si n-p-n epitaxial planar type used in vhf-uhf applications at frequencies up to 500 MHz. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104 Outline No.26 (4-lead). Terminals: 1 - base, 2 - emitter, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

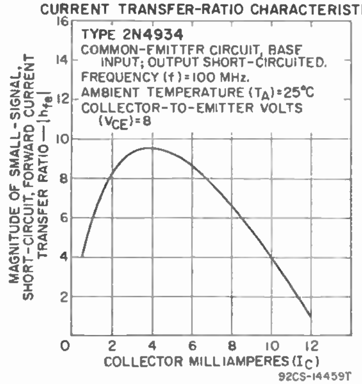
Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage	V_{CEO}	30	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	Limited by dissipation	
Transistor Dissipation:			
T_A up to 25°C	P_T	200	mW
T_A above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Lead-Soldering Temperature (10 s max)	T_L	265	°C

CHARACTERISTICS

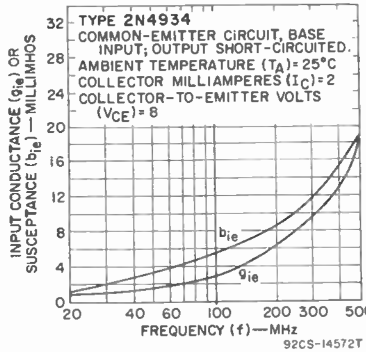
Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	40 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 1 mA, I_B = 0)	$V_{(BR)CEO}$	30 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.001 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V
Collector-Cutoff Current (V_{CB} = 15 V, I_E = 0)	I_{CBO}	10 max	nA
Static Forward-Current Transfer Ratio (V_{CE} = 8 V, I_C = 2 mA)	h_{FE}	40 to 170	
Magnitude of Small-Signal Forward-Current Transfer Ratio:*			
V_{CE} = 8 V, I_C = 2 mA, f = 1 kHz	$\|h_{fe}\|$	45 to 195	
V_{CE} = 8 V, I_C = 2 mA, f = 100 MHz	$\|h_{fe}\|$	7 to 16	
Collector-to-Base Feedback Capacitance• (V_{CB} = 8 V, I_E = 0, f = 0.1 to 1 MHz)	C_{cb}	0.2 typ; 0.25 max	pF
Collector-to-Base Time Constant* (V_{CB} = 8 V, I_E = −2 mA, f = 31.9 MHz)	$r_b'C_c$	1 to 8	ps
Small-Signal Power Gain, Amplifier, Unneutralized* (V_{CE} = 8 V, I_C = 2 mA, R_G and R_L = 50 Ω, f = 200 MHz)	G_{pe}	18 to 26	dB
Noise Figure* (V_{CE} = 8 V, I_C = 2 mA, R_S = 200 Ω, R_G and R_L = 50 Ω, f = 200 MHz)	NF	3.5 max	dB

* Lead 4 (case) grounded.
• Three-terminal measurement with lead No. 1 (emitter) and lead No. 4 (case) connected to guard terminal.

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC



TYPICAL INPUT CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



TRANSISTOR 2N4935

Si n-p-n epitaxial planar type used in vhf-uhf applications at frequencies up to 500 MHz. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.26 (4-lead). Terminals: 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. This type is identical with type 2N4934 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	50	V
Collector-to-Emitter Voltage	V_{CEO}	40	V

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.001 mA, I_E = 0)	$V_{(BR)CBO}$	50	V
Collector-to-Emitter Breakdown Voltage (I_C = 1 mA, I_B = 0)	$V_{(BR)CEO}$	40	V
Static Forward-Current Transfer Ratio (V_{CE} = 8 V, I_C = 2 mA)	h_{FE}	60 to 200	
Magnitude of Small-Signal Forward-Current Transfer Ratio* (V_{CE} = 8 V, I_C = 2 mA, f = 1 kHz)	$\|h_{fe}\|$	70 to 225	
Collector-to-Base Time Constant* (V_{CB} = 8 V, I_E = −2 mA, f = 31.9 MHz)	$r_b'C_c$	1 to 6	ps
Small-Signal Power Gain, Amplifier, Unneutralized* (V_{CE} = 8 V, I_C = 2 mA, R_G and R_L = 50 Ω, f = 200 MHz)	G_{pe}	21 to 28	dB
Noise Figure* (V_{CE} = 8 V, I_C = 2 mA, R_S = 200 Ω, R_G and R_L = 50 Ω, f = 200 MHz)	NF	3 max	dB

* Lead 4 (case) grounded.

TRANSISTOR 2N4936

Si n-p-n epitaxial planar type used in vhf-uhf applications at frequencies up to 500 MHz. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.26 (4-lead). Terminals: 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. This type is identical with type 2N4935 except for the following items:

CHARACTERISTICS

Static Forward-Current Transfer Ratio (V_{CE} = 8 V, I_C = 2 mA)	h_{FE}	60 to 250	
Magnitude of Small-Signal Forward-Current Transfer Ratio* (V_{CE} = 8 V, I_C = 2 mA, f = 1 kHz)	$\|h_{fe}\|$	70 to 280	
Small-Signal Power Gain, Amplifier, Unneutralized* (V_{CE} = 8 V, I_C = 2 mA, R_G and R_L = 50 Ω, f = 450 MHz)	G_{pe}	13 to 18	dB
Small-Signal Power Gain, Amplifier, Neutralized* (V_{CE} = 8 V, I_C = 2 mA, R_G and R_L = 50 Ω, f = 450 MHz)	G_{pe}	20	dB
Noise Figure* (V_{CE} = 8 V, I_C = 2 mA, R_S = 100 Ω, R_G and R_L = 500 Ω, f = 450 MHz)	NF	4.5 max	dB

* Lead 4 (case) grounded.

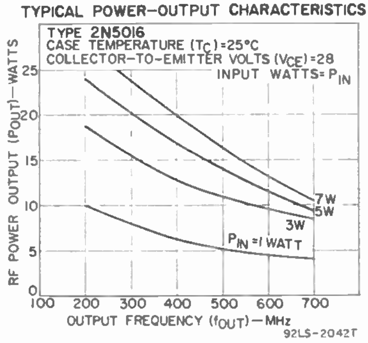
2N5016 TRANSISTOR

Si n-p-n "overlay" epitaxial planar type used in large-signal high-power class B and C rf amplifiers for military and industrial communications service (200 to 700 MHz). 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}	65	V
R_{BE} = 30 Ω	V_{CER}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	4.5	A
Transistor Dissipation:			
T_C up to 50°C	P_T	30	W
T_C above 50°C	P_T	See curve page 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C
Case-Soldering Temperature (10 s max)	T_C	230	°C

TYPICAL POWER-OUTPUT CHARACTERISTICS



CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
R_{BE} = 30 Ω, I_B = 0, I_C = 200 mA, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CER}$	40 min	V
V_{BE} = −1.5 V, I_C = 200 mA, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$(sus)	65 min	V
Emitter-to-Base Breakdown Voltage (I_E = 5 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage (I_B = 40 mA, I_C = 2000 mA)	V_{CE}(sat)	1 max	V
Collector-Cutoff Current (V_{CE} = 30 V, I_B = 0)	I_{CEO}	10 max	mA
Collector-to-Base Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{cb}	25	pF

CHARACTERISTICS (cont'd)

Gain-Bandwidth Product (V_{CE} = 15 V, I_C = 500 mA)	f_T	600	MHz
RF Power Output, Unneutralized:			
V_{CE} = 28 V, P_{IE} = 5 W, R_G and R_L = 50 Ω, f = 225 MHz	P_{OE}	23*	W
V_{CE} = 28 V, P_{IE} = 5 W, R_G and R_L = 50 Ω, f = 400 MHz	P_{OE}	15 ▪	W
Dynamic Input Impedance (V_{CE} = 28 V, P_{IE} = 5 W, R_G and R_L = 50 Ω, f = 400 MHz)		2.5 + j 5 ▪	Ω

* For conditions given, minimum efficiency = 60 per cent.
▪ For conditions given, minimum efficiency = 50 per cent.

TRANSISTOR 2N5017

Si n-p-n "overlay" epitaxial planar type used in large-signal high-power class B and C rf amplifiers for military and industrial communications service (200 to 700 MHz). Outline No.47. Terminals: 1 - emitter, 2 - collector, 3 - base, 4 - collector. This type is electrically identical with type 2N5016 except for the following item:

CHARACTERISTICS (At case temperature = 25°C)

Dynamic Input Impedance (V_{CE} = 28 V, P_{IE} = 5 W, R_G and R_L = 50 Ω, f = 400 MHz)		2 + j 2 ▪	Ω

▪ For conditions given, minimum efficiency = 50 per cent.

POWER TRANSISTOR 2N5034

Si n-p-n type featuring a base comprised of a homogeneous-resistivity silicon material and molded silicone plastic package with vertical leads. This type fits a standard TO-3 socket. It is used in a wide variety of high-power switching and amplifier applications such as series and shunt regulators, drivers, and output stages for high-fidelity amplifiers. Outline No.48. See Mounting Hardware for desired mounting arrangement. Terminals: 1 - base, 2 - emitter, mounting flange, and collector.

MAXIMUM RATINGS

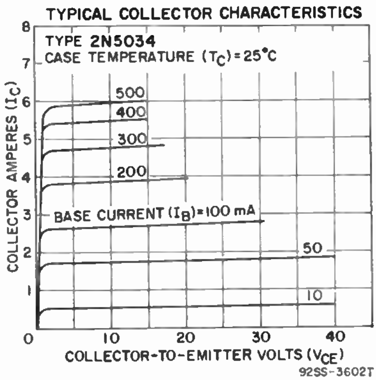
Collector-to-Base Voltage	V_{CBO}	55	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = −1.5 V	V_{CEV}(sus)	55	V
R_{BE} = 100 Ω	V_{CER}(sus)	45	V
Base open	V_{CEO}(sus)	40	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	6	A
Peak Collector Current	i_C	12	A
Base Current	I_B	6	A
Transistor Dissipation:			
T_C up to 25°C	P_T	83	W
T_C above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 150	°C
Storage	T_{STG}	−65 to 150	°C
Lead-Soldering Temperature (10 s max)	T_L	235	°C

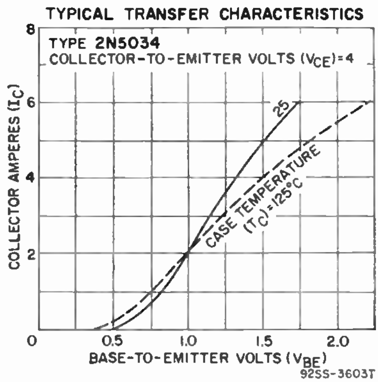
CHARACTERISTICS (At case temperature = 25°C)

Emitter-to-Base Breakdown Voltage (I_E = 5 mA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 0.2 A, I_B = 0, t_p = 300 μs, df = 1.8%	V_{CEO}(sus)	40 min	V
V_{BE} = −1.5 V, I_C = 0.1 A, t_p = 300 μs, df = 1.8%	V_{CEV}(sus)	55 min	V
R_{BE} = 100 Ω, I_C = 0.2 A, t_p = 300 μs, df = 1.8%	V_{CER}(sus)	45 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 2.5 A, t_p = 300 μs, df = 1.8%)	V_{BE}	1.7 max	V
Collector-to-Emitter Saturation Voltage (I_C = 2.5 A, I_B = 0.25 A, t_p = 300 μs, df = 1.8%)	V_{CE}(sat)	1 max	V

CHARACTERISTICS (cont'd)

Collector-Cutoff Current:			
V_{CE} = 35 V, R_{BE} = 100 Ω	I_{CER}	1 max	mA
V_{CE} = 35 V, R_{BE} = 100 Ω, T_C = 150°C	I_{CER}	5 max	mA
V_{CE} = 50 V, V_{BE} = −1.5 V	I_{CEV}	1 max	mA
V_{CE} = 50 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	5 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 = 2.5 A, t_p = 300 μs, df = 1.8%)	h_{FE}(pulsed)	20 to 70	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 0.5 A)	f_T	0.8 to 2.8	MHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W





2N5035 POWER TRANSISTOR

Si n-p-n type featuring a base comprised of a homogeneous-resistivity silicon material and molded silicone plastic package having horizontal leads for mounting on printed-circuit boards. It is used in a wide variety of high-power switching and amplifier applications such as series and shunt regulators, drivers, and output stages for high-fidelity amplifiers. **Outline No.49. Terminals:** 1 - base, 2 - emitter, mounting flange, and collector. This type is electrically identical to type 2N5034.

2N5036 POWER TRANSISTOR

Si n-p-n type featuring a base comprised of a homogeneous-resistivity silicon material and molded silicone plastic package with vertical leads. This type fits a standard TO-3 socket. It is used in a wide variety of high-power switching and amplifier applications such as series and shunt regulators, drivers, and output stages for high-fidelity amplifiers. **Outline No.48.** See **Mounting Hardware** for desired mounting arrangement. **Terminals:** 1 - base, 2 - emitter, mounting flange, and collector.

MAXIMUM RATINGS

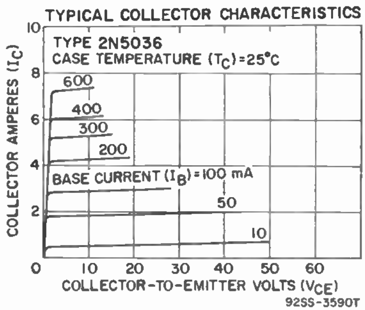
Collector-to-Base Voltage	V_{CBO}	70	V
Collector-to-Emitter Sustaining Voltage:			
V_{BE} = −1.5 V	V_{CEV}(sus)	70	V
R_{BE} = 100 Ω	V_{CER}(sus)	60	V
Base open	V_{CEO}(sus)	50	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	8	A
Peak Collector Current	i_C	12	A
Base Current	I_B	6	A

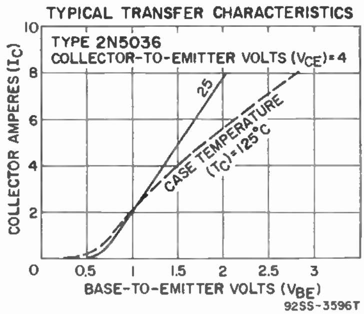
MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_C up to 25°C	P_T	83	W
T_C above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 150	°C
Storage	T_{STG}	−65 to 150	°C
Lead-Soldering Temperature (10 s max)	T_L	235	°C

CHARACTERISTICS (At case temperature = 25°C)

Emitter-to-Base Breakdown Voltage (I_E = 5 mA, I_C = 0)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 0.2 A, I_B = 0, t_p = 300 μs, df = 1.8%	V_{CEO}(sus)	50 min	V
V_{BE} = −1.5 V, I_C = 0.1 A, t_p = 300 μs, df = 1.8%	V_{CEV}(sus)	70 min	V
R_{BE} = 100 Ω, I_C = 0.2 A, t_p = 300 μs, df = 1.8%	V_{CER}(sus)	60 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 3 A, t_p = 300 μs, df = 1.8%)	V_{BE}	1.7 max	V
Collector-to-Emitter Saturation Voltage (I_C = 3 A, t_p = 300 μs, df = 1.8%, I_B = 0.3 A)	V_{CE}(sat)	1 max	V
Collector-Cutoff Current:			
V_{CE} = 50 V, R_{BE} = 100 Ω	I_{CER}	1 max	mA
V_{CE} = 50 V, R_{BE} = 100 Ω, T_C = 150°C	I_{CER}	5 max	mA
V_{CE} = 65 V, V_{BE} = −1.5 V	I_{CEV}	1 max	mA
V_{CE} = 65 V, V_{BE} = −1.5 V, T_C = 150°C	I_{CEV}	5 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 = 3 A, t_p = 300 μs, df = 1.8%)	h_{FE}(pulsed)	20 to 70	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 0.5 A)	f_T	0.8 to 2.8	MHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W





POWER TRANSISTOR 2N5037

Si **n-p-n** type featuring a base comprised of a homogeneous-resistivity silicon material and molded silicone plastic package having horizontal leads for mounting on printed-circuit boards. It is used in a wide variety of high-power switching and amplifier applications such as series and shunt regulators, drivers, and output stages for high-fidelity amplifiers. Outline No.49. **Terminals:** 1 - base, 2 - emitter, mounting flange, and collector. This type is electrically identical to type 2N5036.

TRANSISTOR 2N5070

Si **n-p-n** "overlay" epitaxial planar type used in high-power class A or B service in a 2-to-30-MHz single-sideband power amplifier operating from a 28-volt power supply. JEDEC TO-60, Outline No.20. **Terminals:** 1 - emitter, mounting stud, and case, 2 - base, 3 - collector.

MAXIMUM RATINGS

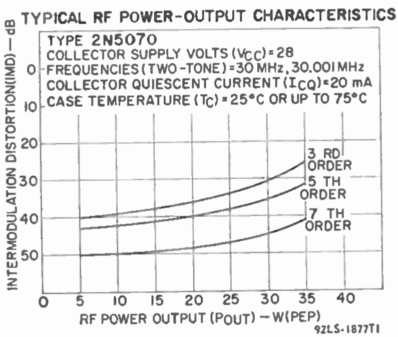
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	65	V
$R_{BE} = 5\ \Omega$	V_{CER}	40	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	3.3	A
Peak Collector Current	i_C	10	A
Transistor Dissipation:			
T_C up to 25°C	P_T	70	W
T_C above 25°C	P_T	See curve page 116	
Temperature Range:			
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)

Emitter-to-Base Breakdown Voltage (I_E = 10 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Sustaining Voltage:			
$V_{BE} = -1.5$ V, I_C = 200 mA	V_{CEV}(sus)	65 min	V
$R_{BE} = 5\ \Omega$, I_C = 200 mA	V_{CER}(sus)	40 min	V
Collector-Cutoff Current:			
V_{CE} = 30 V, I_B = 0	I_{CEO}	5 max	mA
V_{CB} = 30 V, I_E = 0	I_{CBO}	10 max	mA
Output Capacitance (V_{CB} = 1 V, I_E = 0, f = 1 MHz)	C_{obo}	85 max	pF
Thermal Resistance, Junction-to-Case	θ_{J-C}	2.5 max	°C/W

TYPICAL OPERATION IN RF-AMPLIFIER CIRCUIT

Collector Supply Voltage	28	V
Collector Base Current	20	mA
RF Power Output:		
Average	12.5 min	W
Peak Envelope	25 min	W
Intermodulation Distortion	30 max	dB
Collector Efficiency	40 min	%



2N5071 TRANSISTOR

Si n-p-n "overlay" epitaxial planar type used in high-power class A and C rf amplifiers for FM communications with a 24-volt power supply. It is used for narrowband and wideband applications in the 30-to-76-MHz frequency range. JEDEC TO-60, Outline No.20. Terminals: 1 - emitter, mounting stud, and case, 2 - base, 3 - collector. For maximum ratings, refer to type 2N5070.

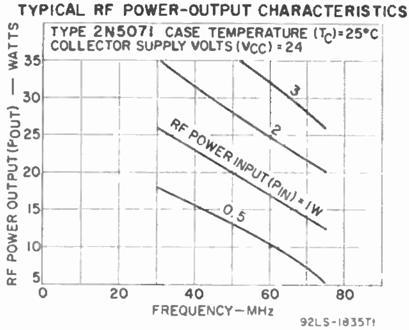
CHARACTERISTICS (At case temperature = 25°C)

Emitter-to-Base Breakdown Voltage (I_E = 10 mA, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Sustaining Voltage:			
$V_{BE} = -1.5$ V, I_C = 200 mA	V_{CEV}(sus)	65 min	V
$R_{BE} = 5\ \Omega$, I_C = 200 mA	V_{CER}	40 min	V

CHARACTERISTICS (cont'd)

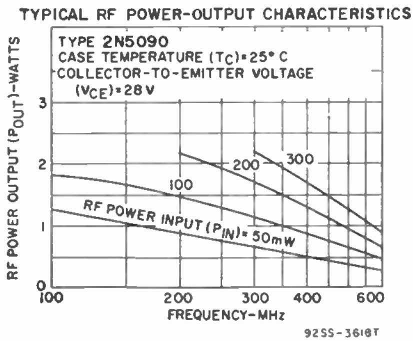
Collector-to-Emitter Cutoff Current (V_{CE} = 30 V, I_B = 0)	I_{CEO}	5 max	mA
Collector-to-Base Cutoff Current (V_{CB} = 60 V, I_E = 0)	I_{CBO}	10 max	mA
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{obo}	85 max	pF
Power Output:			
Narrowband Amplifier (V_{CE} = 24 V, P_{IE} = 3 W, R_G and R_L = 50 Ω, f = 76 MHz)	P_{OE}	24• min	W
Wideband Amplifier (V_{CE} = 24 V, P_{IE} = 3 W, R_G and R_L = 50 Ω, f = 30 to 76 MHz)	P_{OE}	15* min	W
Thermal Resistance, Junction-to-Case	θ_{J-C}	2.5	°C/W

• For conditions given, minimum efficiency = 60 per cent.
* For conditions given, minimum efficiency = 35 per cent.



POWER TRANSISTOR 2N5090

Si n-p-n "overlay" epitaxial planar type used in class A, B, or C amplifier, frequency-multiplier, or oscillator circuits; it is used in output, driver, or pre-driver stages in vhf and uhf equipment. JEDEC TO-60, Outline No. 20. Terminals: 1 - emitter, 2 - base, 3 - collector.



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 75°C	P_T	5	W
T_C above 75°C	P_T	See curve page 116	
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)

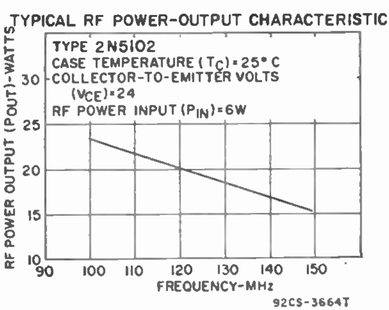
Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	55 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	3.5 min	V
Collector-to-Emitter Sustaining Voltage:			
I_C = 5 mA, R_{BE} = 10 Ω, pulsed through inductor L = 25 mH, df = 50%	V_{CER}(sus)	55 min	V
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 = 50 mA)	f_T	500 min	MHz
Collector-to-Base Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{obo}	3.5 max	pF
RF Power Output, Amplifier, Unneutralized (V_{CE} = 28 V, P_{IE} = 0.2 W, f = 400 MHz, R_G and R_L = 50 Ω)	P_{OE}	1.2* min	W

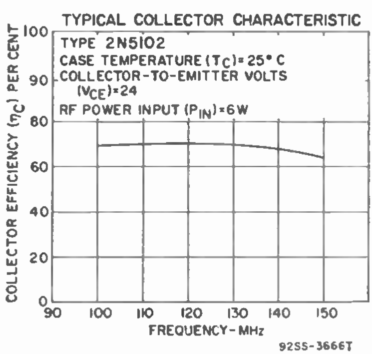
* For conditions given, minimum efficiency = 45 per cent.

2N5102

TRANSISTOR

Si n-p-n "overlay" epitaxial planar type designed to provide high power as a class C rf amplifier for vhf aircraft communications service (108 to 150 MHz) with amplitude modulation and 24-volt power supply. JEDEC TO-60, Outline No. 20. Terminals: 1 - emitter, mounting stud, and case, 2 - base, 3 - collector.





MAXIMUM RATINGS

Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	100	V
$R_{BE} = 5\ \Omega$	V_{CER}	50	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current:			
Peak	i_C	10	A
Continuous	I_C	3.3	A
Transistor Dissipation:			
T_C up to 25°C	P_T	70	W
T_C above 25°C	P_T	See curve page 116	
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)

Emitter-to-Base Breakdown Voltage (I_E = 10 V, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Sustaining Voltage:			
$V_{BE} = -1.5$ V, I_C = 600 mA, pulsed through an inductor L = 9 mH, df = 50%	V_{CEV}(sus)	100 min	V
$R_{BE} = 5\ \Omega$, I_C = 200 mA, pulsed through an inductor L = 9 mH, df = 50%	V_{CER}(sus)	50 min	V
Collector-Cutoff Current (V_{CE} = 50 V, $R_{BE} = 5\ \Omega$)	I_{CER}	10 max	mA
Collector-to-Base Capacitance (V_{CB} = 30 V, I_C = 0)	C_{cb}	85 max	pF
RF Power Output (V_{CC} = 24 V, P_{IE} = 6 W, R_G and R_L = 50 Ω, f = 136 MHz)	P_{OE}	15* min	W
Modulation● (V_{CE} = 24 V, f = 118 MHz)		80 min	%
Load Mismatch■ (V_{CE} = 24 V, f = 118 MHz)		will not be damaged	
Dynamic Input Impedance (V_{CE} = 24 V, I_C = 1100 mA, P_{OE} = 6 W, f = 150 MHz)		1.7 + j2.6	Ω

* Unmodulated carrier.

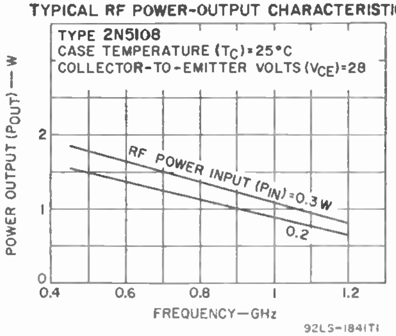
● Carrier Power, P_{CAR} = 15 W; V_{CC} modulation = 100%; $M = \frac{\sqrt{2(P_{AM} - P_{CAR})}}{P_{CAR}} \times 100\%$.

■ Under conditions of footnote (●), the transistor is subjected to all conditions of load mismatch from short circuit to open circuit.

TRANSISTOR 2N5108

Si n-p-n "overlay" epitaxial planar type used as a high-power amplifier, fundamental-frequency oscillator, and frequency multiplier. It may be used in final, driver, and pre-driver amplifier stages in uhf equipment and as a fundamental-frequency oscillator at 1.68 GHz. JEDEC TO-39, Outline No. 12. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

TYPICAL RF POWER-OUTPUT CHARACTERISTICS



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	V
Collector Current	I_C	0.4	A
Transistor Dissipation:			
T_C up to 25°C	P_T	3.5	W
T_C above 25°C	P_T	See curve page 116	
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 min	V
Collector-to-Emitter Sustaining Voltage (R_{BE} = 10 Ω, I_C = 5 mA, pulsed through an inductor L = 2.5 mH, df = 50%)	V_{CER}(sus)	55 min	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_{CE} = 15 V, I_B = 0	I_{CEO}	20 max	μA
V_{CE} = 50 V	I_{CES}	1 max	μA
Collector-to-Base Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{obo}	3 max	pF
Magnitude of Small-Signal Forward-Current Transfer Ratio (V_{CE} = 15 V, I_C = 50 mA, f = 200 MHz)	$\|h_{fe}\|$	6 min	
RF Power Output, Common Emitter Amplifier (V_{CE} = 28 V, P_{IE} = 0.316 W, f = 1 GHz)	P_{OE}	1* min	W
RF Power Output, Fundamental Frequency Oscillator (V_{CE} = 20 V, V_{EB} = 1.5 V, f = 1.68 GHz)	P_{OE}	0.3†	W

* For conditions given, minimum efficiency = 35 per cent.
† For conditions given, minimum efficiency = 15 per cent.

2N5109 TRANSISTOR

Si n-p-n "overlay" epitaxial planar type designed to provide large dynamic range, low distortion, and low noise as a wide-band amplifier into the vhf range. JEDEC TO-39, Outline No. 12. 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}	40	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	0.4	A
Transistor Dissipation:			
T_C up to 25°C	P_T	3.5	W
T_C above 25°C	P_T	See curve page 116	
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)	$V_{(BR)CBO}$	40 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V
Collector-to-Emitter Sustaining Voltage:			
R_{BE} = 10 Ω, I_C = 5 mA, pulsed through an inductor L = 2.5 mH, df = 50%	V_{CER}(sus)	40 min	V
I_C = 5 mA, I_B = 0	V_{CEO}(sus)	20 min	V
Collector-to-Emitter Saturation Voltage (I_C = 100 mA, I_B = 10 mA)	V_{CE}(sat)	0.5 max	V
Collector-Cutoff Current (I_C = 0.1 mA, I_E = 0)	I_{CEO}	20 max	μA
Collector-to-Base Capacitance (V_{CB} = 15 V, I_E = 0, f = 1 MHz)	C_{obo}	3.5 max	pF
Static Forward-Current Transfer Ratio (V_{CB} = 15 V, I_C = 50 mA)	h_{FE}	70 min; 210 typ	

CHARACTERISTICS (cont'd)

Small-Signal Forward-Current Transfer Ratio:			
V_{CB} = 15 V, I_C = 25 mA	h_{fe}	4.8 min	
V_{CB} = 15 V, I_C = 50 mA	h_{fe}	6 min	
V_{CB} = 15 V, I_C ≃ 100 mA	h_{fe}	4.8 min	
Voltage Gain, Wideband (V_{CB} = 15 V, I_C = 50 mA, f = 50 to 216 MHz)		11 min	dB
Cross Modulation at 54 dBmV● Output (V_{CB} = 15 V, I_C = 50 mA)		−57	dB
Power Gain, Narrowband (V_{CB} = 15 V, I_C = 10 mA, P_{IE} = −10 dB, f = 200 MHz)		11 min	dB
Noise Figure (V_{CB} = 15 V, I_C = 10 mA, f = 200 MHz)	NF	3	dB

● 0 dBmV = 1 millivolt.

FIELD-EFFECT TRANSISTOR 3N128

Si insulated-gate field-effect (MOS) n-channel depletion type used in amplifier and oscillator applications in commercial and industrial vhf communications equipment operating up to 250 MHz. Similar to JEDEC TO-72, Outline No.23. Terminals: 1 - drain, 2 - source, 3 - gate, 4 - substrate and case.

MAXIMUM RATINGS

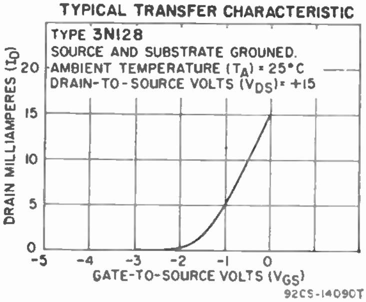
Drain-to-Source Voltage	V_{DS}	20	V
DC Gate-to-Source Voltage	V_{GS}	0 to −8	V
Peak Gate-to-Source Voltage	v_{GS}	±15	V
Drain Current	I_D	Limited by dissipation	
Transistor Dissipation (T_A up to 100°C)	P_T	100	mW
Temperature Range:			
Operating	T_A	−65 to 100	°C
Storage	T_{STG}	−65 to 125	°C
Lead-Soldering Temperature (10 s max)	T_L	265	°C

CHARACTERISTICS

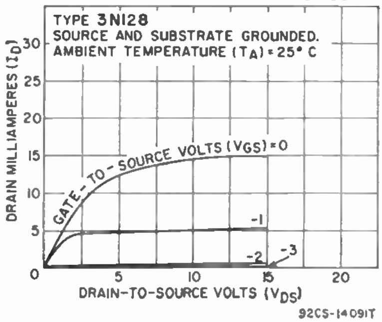
Gate Leakage Current (V_{GS} = −8 V, V_{DS} = 0)	I_{GSS}	0.1 typ; 50 max	pA
Drain Current (V_{DS} = 15 V, V_{GS} = 0, t_p = 20 ms, df ≤ 0.15%)	I_{DSS}	5 to 30	mA
Drain-to-Source ON Resistance (f = 1 kHz, V_{DS} = 0, V_{GS} = 0)	r_{DS}(ON)	200	Ω
Gate Leakage Resistance (V_{GS} = −8 V, V_{DS} = 0)	r_{GS}	10^{14}	Ω
Power Gain (V_{DS} = 15 V, I_D = 5 mA, f = 200 MHz)	G_{PS}	14.5 min; 18 typ	dB
Forward Transconductance:			
V_{DS} = 15 V, V_{GS} = 0, f = 1 kHz	Y_{fs}	10000	µmhos
V_{DS} = 15 V, I_D = 5 mA, f = 1 kHz	Y_{fs}	5000 to 12000	µmhos
Pinch-Off Voltage (I_D = 50 µA, V_{DS} = 15 V)		−3.5 typ; −8 max	V
Small-Signal Short-Circuit Input Capacitance (V_{DS} = 15 V, I_D = 5 mA, f = 0.1 to 1 MHz)	C_{iss}	5.8	pF
Small-Signal Short-Circuit Reverse Transfer Capacitance* (V_{DS} = 15 V, I_D = 5 mA, f = 0.1 to 1 MHz)	C_{rss}	0.13 typ; 0.2 max	pF
Small-Signal Short-Circuit Output Capacitance (V_{DS} = 15 V, I_D = 5 mA, f = 0.1 to 1 MHz)	C_{oss}	1.4	pF
Noise Figure (V_{DS} = 15 V, I_D = 5 mA, f = 200 MHz)	NF	4 typ; 5 max	dB

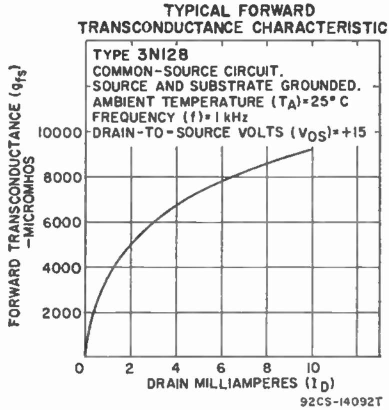
* Three-terminal measurement with source returned to guard terminal.

TYPICAL TRANSFER CHARACTERISTIC



TYPICAL DRAIN CHARACTERISTICS



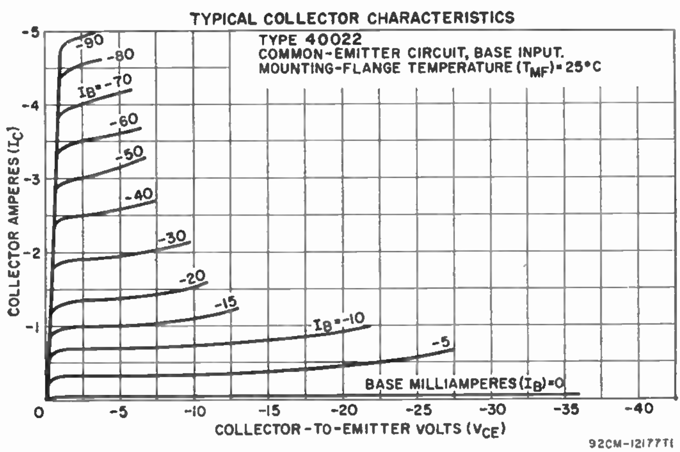


40022 POWER TRANSISTOR

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
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)

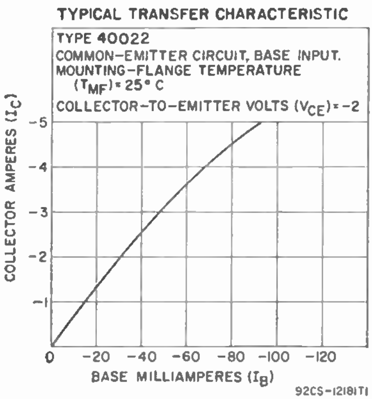
Collector-to-Base Breakdown Voltage (I_C = —0.005 A, I_E = 0)	$V_{(BR)CBO}$	—32 min	V
Collector-to-Emitter Breakdown Voltage (I_C = —0.2 A, R_{BE} = 33 Ω)	$V_{(BR)CER}$	—32 min	V
Emitter-to-Base Breakdown Voltage (I_E = —0.002 A, I_C = 0)	$V_{(BR)EBO}$	—5 min	V
Base-to-Emitter Voltage* (V_{CB} = —10 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; 70 typ	
Gain-Bandwidth Product (V_{CE} = —5 V, I_C = —0.5 A)	f_T	300	kHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

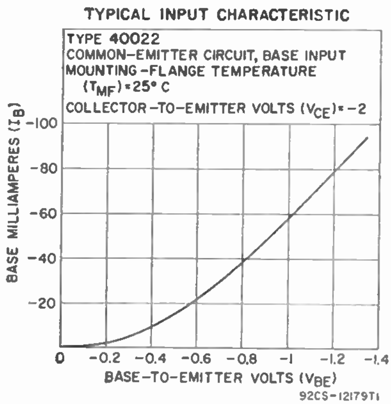
TYPICAL OPERATION IN CLASS B AF-AMPLIFIER CIRCUIT

Unless otherwise specified, values are for 2 transistors.

DC Collector-Supply Voltage	V_{CC}	—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

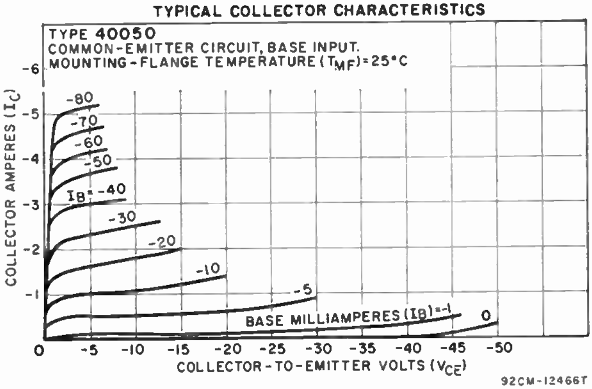
MAXIMUM RATINGS (cont'd)

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	See curve page 116	
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

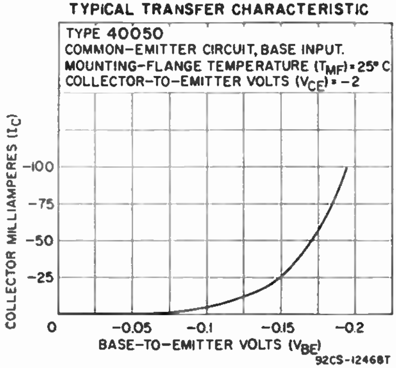
CHARACTERISTICS (At mounting-flange temperature = 25°C)

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
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	kHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

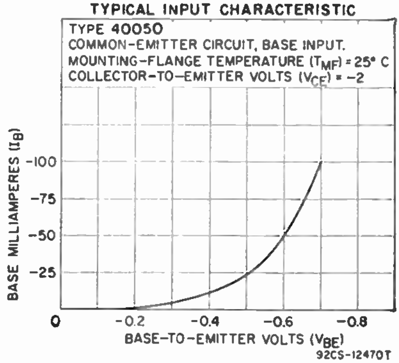
TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC



TYPICAL INPUT CHARACTERISTIC



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

POWER TRANSISTOR 40051

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
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-MHz 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 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C

CHARACTERISTICS

Collector-to-Emitter Voltage (I_C = 10 mA, I_B = 0)	V_{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 MHz)	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

40081 TRANSISTOR

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-MHz citizens-band transmitter, JEDEC TO-5, Outline No. 3. 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 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C

CHARACTERISTICS

Collector-to-Emitter Voltage (V_{BE} = −0.5 V, I_C = 100 μA)	V_{CEV}	60 min	V
Emitter-to-Base Voltage (I_E = 500 μA, I_C = 0)	V_{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 MHz)	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-MHz 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 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 200	°C

CHARACTERISTICS

Collector-to-Emitter Voltage (V_{BE} = −0.5 V, I_C = 500 μA)	V_{CEV}	60 min	V
Emitter-to-Base Voltage (I_E = 500 μA, I_C = 0) I_C = 0)	V_{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 MHz)	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

TRANSISTOR 40084

Si n-p-n triple-diffused planar type used in a wide variety of small and medium-power applications (up to 20 MHz) 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	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	1	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 116	
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	225	°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 MHz)	h_{fe}	5 min	
Noise Figure (R_G = 500 Ω, circuit bandwidth = 15 kHz, V_{CE} = 10 V, I_C = 0.3 mA, f = 1 kHz)	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

40217 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 2N706.

40218 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 2N706A.

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. JEDEC TO-104, **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

MAXIMUM RATINGS (cont'd)

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 116	
T_C up to 125°C	P_T	1	W
T_C above 125°C	P_T	See curve page 116	
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 kHz)	h_{fe}	55 to 180	
Gain-Bandwidth Product (V_{CE} = 6 V, I_C = 1 mA)	f_T	60	MHz
Intrinsic Base-Spreading Resistance (V_{CB} = 6 V, I_C = 1 mA, f = 100 MHz)	$r_{bb'}$	20	Ω
Output Capacitance (V_{CB} = 6 V, I_E = 0, f = 1 MHz)	C_{obo}	22	pF
Noise Figure (R_G = 1000 Ω, V_{CE} = 6 V, I_C = 0.1 mA, circuit bandwidth = 1 Hz, f = 10 kHz)	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. JEDEC TO-104, 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 kHz)	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. JEDEC TO-104, 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 kHz)	h_{fe}	90 to 300	
Noise Figure:			
R_G = 1000 Ω, V_{CE} = 6 V, I_C = 0.1 mA, circuit bandwidth = 1 Hz, f = 10 kHz	NF	2	dB
R_G = 1000 Ω, V_{CE} = 6 V, I_C = 0.5 mA, circuit bandwidth = 1 Hz, f = 1 kHz	NF	6 max	dB

40234 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. JEDEC TO-104, **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:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 55°C	P_T	0.4	W
T_A above 55°C	P_T	See curve page 116	
T_A up to 125°C	P_T	1	W
T_C above 125°C	P_T	See curve page 116	

CHARACTERISTICS

Collector-to-Emitter Saturation Voltage (I_C = 50 mA, I_B = 5 mA)	V_{CE}(sat)	0.2	V
Small-Signal Forward-Current Transfer Ratio (I_C = 2 mA, V_{CE} = 10 V, f = 1 kHz)	h_{fe}	35 to 180	

40235 TRANSISTOR

Si **n-p-n** type used as rf amplifier in television tuners covering channels 2 through 13. JEDEC TO-104, **Outline** No.26 (4-lead). **Terminals**: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

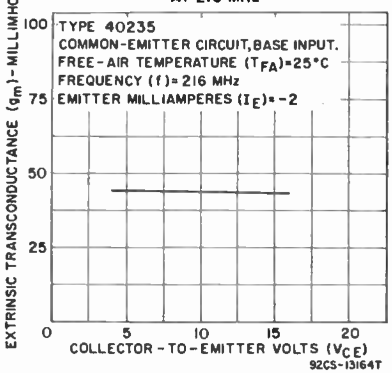
MAXIMUM RATINGS

Collector-to-Base Voltage:			
V_{EB} = 1 V	V_{CBO}	45	V
Emitter open	V_{CBO}	45	V
Emitter-to-Base Voltage	V_{EBO}	4.5	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 116	
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 175	°C
Lead Soldering Temperature (10 s max)	T_L	255	°C

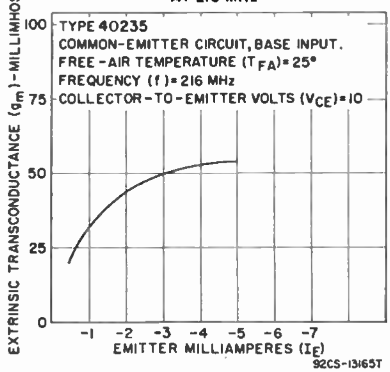
CHARACTERISTICS

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} = 4.5 V, I_C = 0)	I_{EBO}	1 max	µA

TYPICAL EXTRINSIC TRANSCONDUCTANCE AT 216 MHz



TYPICAL EXTRINSIC TRANSCONDUCTANCE AT 216 MHz



CHARACTERISTICS (cont'd)

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 = −2 mA, f = 100 MHz)	f_T	1000	MHz
Collector-to-Base Feedback Capacitance (V_{CE} = 10 V, I_E = −2 mA, f = 216 MHz)	C_{cb}	0.65 max	pF
Input Resistance (V_{CE} = 10 V, I_E = −2 mA, f = 216 MHz)	R_{ie}	190	Ω
Output Resistance (V_{CE} = 10 V, I_E = −2 mA, f = 216 MHz)	R_{oe}	8.9	kΩ
Extrinsic Transconductance (V_{CE} = 10 V, I_E = −2 mA, f = 216 MHz)	g_m	43.7	mmhos
Noise Figure (V_{CE} = 10 V, I_E = −2 mA, R_G and R_L = 50 Ω, f = 216 MHz)	NF	3.3	dB
Maximum Available Amplifier Gain (V_{CE} = 10 V, I_E = −2 mA, f = 216 MHz)	MAG	29.1	dB
Maximum Usable Amplifier Gain, Neutralized (V_{CE} = 10 V, I_E = −2 mA, R_G and R_L = 50 Ω, f = 216 MHz)	MUG	18.1	dB

TRANSISTOR 40236

Si **n-p-n** type used as rf mixer in television tuners covering channels 2 through 13. JEDEC TO-104, **Outline** No.26 (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
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 MHz)	f_T	1000	MHz
Collector-to-Base Feedback Capacitance (V_{CE} = 12 V, I_E = 1.5 mA, f = 216 MHz)	C_{cb}	0.65 max	pF
Input Resistance (V_{CE} = 12 V, I_E = −1.5 mA, f = 216 MHz)	R_{ie}	230	Ω
Output Resistance (V_{CE} = 12 V, I_E = −1.5 mA, f = 45 MHz)	R_{oe}	65	kΩ
Maximum Available Conversion Gain (V_{CE} = 12 V, I_E = −1.5 mA, f = 216 to 45 MHz)	MAG_c	19	dB

TRANSISTOR 40237

Si **n-p-n** type used as rf local oscillator in television tuners covering channels 2 through 13. JEDEC TO-104, **Outline** No.26 (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
Collector-to-Base Feedback Capacitance (V_{CE} = 12 V, I_E = 1.5 mA, f = 216 MHz)	C_{cb}	0.8 max	pF
Output Capacitance (V_{CB} = 12 V, I_C = −2.5 mA, f = 257 MHz)	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 MHz)	f_T	1000	MHz

40238 TRANSISTOR

Si n-p-n type use as 45-MHz if amplifier in television receivers. JEDEC TO-104, Outline No.26 (4-lead). Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

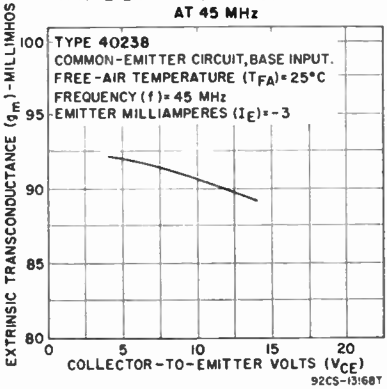
MAXIMUM RATINGS

Collector-to-Base Voltage:			
V_{BE} = −1 V	V_{CBV}	45	V
Emitter open	V_{CBO}	45	V
Emitter-to-Base Voltage	V_{EBO}	4.5	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 116	
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

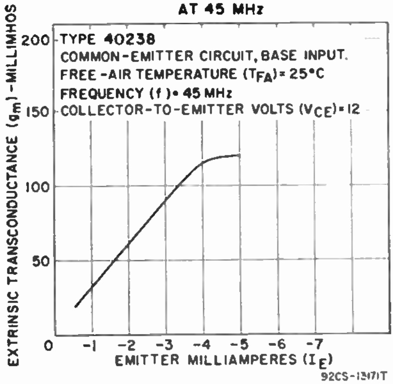
CHARACTERISTICS

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_{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 = −2 mA, f = 100 MHz)	f_T	800	MHz
Collector-to-Base Feedback Capacitance (V_{CE} = 12 V, I_E = −3 mA, f = 216 MHz)	C_{cb}	0.65 max	pF
Input Resistance (V_{CE} = 12 V, I_E = −3 mA, f = 45 MHz)	R_{ie}	480	Ω
Output Resistance (V_{CE} = 12 V, I_E = −3 mA, f = 45 MHz)	R_{oe}	35	kΩ
Extrinsic Transconductance (V_{CE} = 12 V, I_E = −3 mA, f = 45 MHz)	g_m	90	mmhos
Maximum Available Amplifier Gain For 1, 2, or 3 Stages (V_{CE} = 12 V, I_E = −3 mA, f = 45 MHz)	MAG	45.3	dB
Maximum Usable Amplifier Gain, Unneutralized (V_{CE} = 12 V, I_E = −3 mA, f = 45 MHz):			
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 MHz):			
For 1 stage	MUG	28	dB
For 2 stages	MUG	25.8	dB
For 3 stages	MUG	24.1	dB

TYPICAL EXTRINSIC TRANSCONDUCTANCE AT 45 MHz



TYPICAL EXTRINSIC TRANSCONDUCTANCE AT 45 MHz



TRANSISTOR 40239

Si n-p-n type used as 45-MHz if amplifier in television receivers. JEDEC TO-104, Outline No.26 (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

TRANSISTOR 40240

Si n-p-n type used as 45-MHz if amplifier in television receivers. JEDEC TO-104, Outline No.26 (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

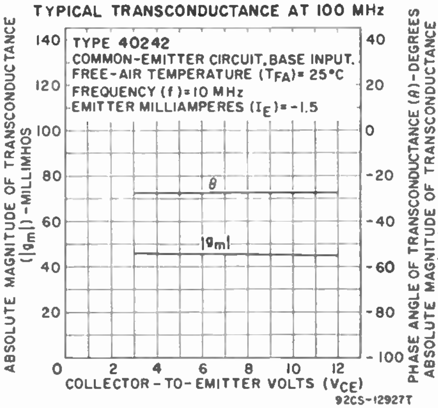
Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	27 to 275

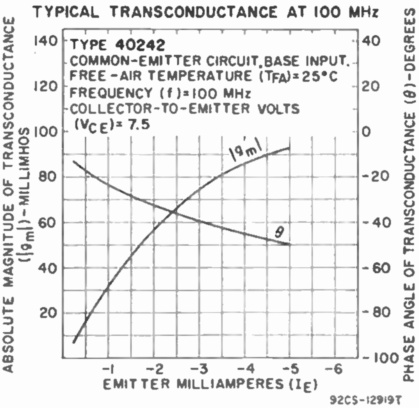
TRANSISTOR 40242

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. JEDEC TO-104, Outline No.26 (4-lead). Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

Collector-to-Base Voltage:			
Emitter open	V_{CBO}	45	V
V_{EB} = −1 V	V_{CBV}	45	V
Collector-to-Emitter Voltage	V_{CEV}	45	V
Emitter-to-Base Voltage	V_{EBO}	4.5	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 116	
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C



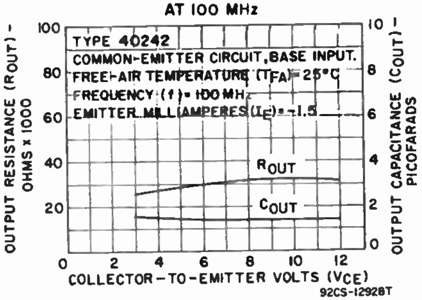


CHARACTERISTICS

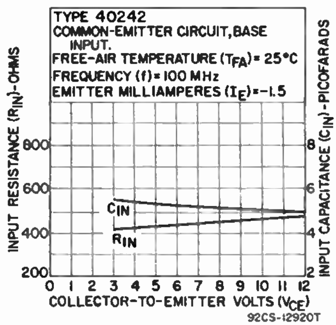
Collector-to-Base Breakdown Voltage: I_C = 0.001 mA, I_E = 0	$V_{(BR)CBO}$	45 min	V
V_{EB} = −1 V, I_C = 0.001 mA	$V_{(BR)CBV}$	45 min	V
Collector-to-Emitter Breakdown Voltage (I_E = 0.5 mA, I_B = 0)	$V_{(BR)CEO}$	45 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.001 mA, I_C = 0)	$V_{(BR)EBO}$	4.5 min	V
Collector-Cutoff Current (V_{CE} = 1 V, I_E = 0)	I_{CBO}	0.02 max	μA
Emitter-Cutoff Current (V_{CE} = 1.5 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 MHz)	g_m	45	mmhos
Maximum Available Amplifier Gain* (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	MAG	38.3	dB
Maximum Usable Amplifier Gain*: Neutralized—V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz	MUG	21.5	dB
Unneutralized—V_{CC} = 15 V, f = 100 MHz	MUG	16.4	dB
Input Capacitance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	C_{ie}	5.2	pF
Feedback Capacitance (V_{CE} = 8 V, I_E = 0, f = 1 MHz)	C_{cb}	0.65 max	pF
Input Resistance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	R_{ie}	450	Ω
Output Resistance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	R_{oe}	30	kΩ
Output Capacitance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	C_{oe}	1.35	pF
Noise Figure* (V_{CC} = 15 V, R_G = 50 Ω, f = 100 MHz)	NF	2.5	dB

* This characteristic applies only to type 40242.

TYPICAL OUTPUT CHARACTERISTICS AT 100 MHz



TYPICAL INPUT CHARACTERISTICS AT 100 MHz



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. JEDEC TO-104, **Outline** No.26 (4-lead). **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - case. This type is identical with type 40242 except for the following items:

CHARACTERISTICS

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	
Extrinsic Transconductance (V_{CE} = 7.5 V, I_E = −1 mA, f = 100 MHz)	g_m	32	mmhos
Maximum Available Conversion Gain (V_{CE} = 7.5 V, I_E = −1 mA, f = 10.7 to 100 MHz)	MAG_c	37.64	dB
Input Capacitance (V_{CE} = 7.5 V, I_E = −1 mA, f = 100 MHz)	C_{ie}	4.5	pF
Input Resistance (V_{CE} = 7.5 V, I_E = −1 mA, f = 100 MHz)	R_{ie}	650	Ω

CHARACTERISTICS (cont'd)

Output Resistance (V_{CE} = 7.5 V, I_E = −1 mA, f = 100 MHz)	R_{oe}	30	kΩ
Output Capacitance (V_{CE} = 7.5 V, I_E = −1 mA, f = 100 MHz)	C_{oe}	1.35	pF

TRANSISTOR 40244

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. JEDEC TO-104, Outline No.26 (4-lead). Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

Collector-to-Base Voltage:			
Emitter open	V_{CBO}	45	V
V_{EB} = −1 V	V_{CBV}	45	V
Collector-to-Emitter Voltage	V_{CEO}	45	V
Emitter-to Base Voltage	V_{EBO}	4.5	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 116	
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	$V_{(BR)CBO}$	45 min	V
V_{BE} = −1 V, I_C = 0.001 mA	$V_{(BR)CBV}$	45 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
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 MHz)	V_{ob}	55	mV
Feedback Capacitance (V_{CE} = 8 V, I_E = 0, f = 1 MHz)	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 rceivers. JEDEC TO-104, Outline No.26 (4-lead). Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

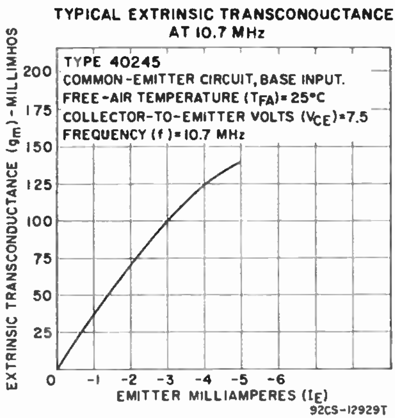
Collector-to-Base Voltage:			
Emitter open	V_{CBO}	45	V
V_{EB} = −1 V	V_{CBV}	45	V
Collector-to-Emitter Voltage	V_{CEO}	45	V
Emitter-to-Base Voltage	V_{EBO}	4.5	V
Collector Current	I_C	50	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	180	mW
T_A above 25°C	P_T	See curve page 116	
Temperature Range:			
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	$V_{(BR)CBO}$	45 min	V
V_{BE} = −1 V, I_C = 0.001 mA	$V_{(BR)CBV}$	45 min	V

CHARACTERISTICS (cont'd)

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 275	
Feedback Capacitance (V_{CE} = 8 V, I_E = 0, f = 1 MHz)	C_{cb}	0.65 max	pF
Extrinsic Transconductance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	g_m	70	mmhos
Maximum Available Amplifier Gain (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	MAG	51.4	dB
Maximum Usable Amplifier Gain:			
Neutralized—V_{CC} = 12 V, f = 10.7 MHz	MUG	33.2	dB
Unneutralized—V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz	MUG	28.1	dB
Input Capacitance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	C_{ie}	8.2	pF
Input Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	R_{ie}	1500	Ω
Output Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	R_{oe}	80	kΩ
Output Capacitance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	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. JEDEC TO-104, Outline No.26 (4-lead). Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case. This type is identical with type 40245 except for the following items:

CHARACTERISTICS

Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	27 to 90	
Maximum Available Amplifier Gain (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	MAG	51.2	dB
Input Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	R_{ie}	1200	Ω
Output Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	R_{oe}	90	kΩ

POWER TRANSISTOR 40250

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.

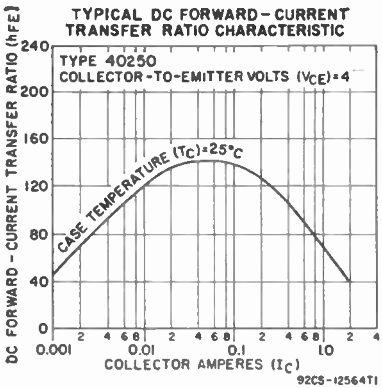
MAXIMUM RATINGS

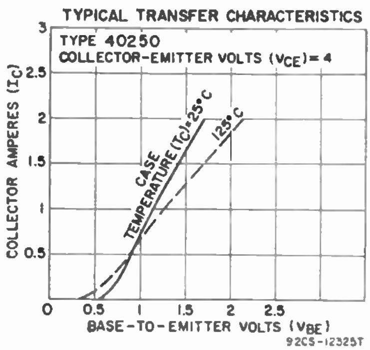
Collector-to-Base Voltage	V_{CBO}	50	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	50	V
Base open	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	4	A
Base Current	I_B	2	A
Transistor Dissipation:			
T_C up to 25°C	P_T	29*	W
T_C above 25°C	P_T	See curve page 116	
Temperature 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.





40250V1 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. This type has an attached heat radiator for mounting on printed-circuit-board applications. JEDEC TO-66 (with heat radiator), **Outline** No.22A. **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)

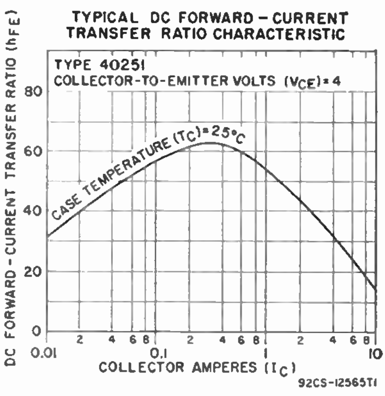
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	30 max	°C/W

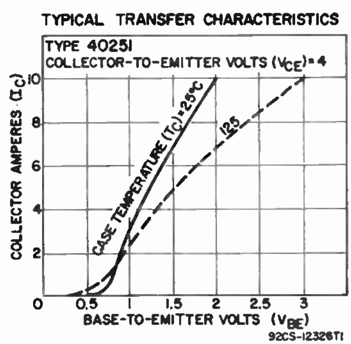
40251 POWER TRANSISTOR

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-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 116	
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	
Power Rating Test (V_{CE} = 39 V, I_C = 3 mA)		1	s
Thermal Resistance, Junction-to-Case	Θ_{J-C}	1.5 max	°C/W

TRANSISTOR 40253

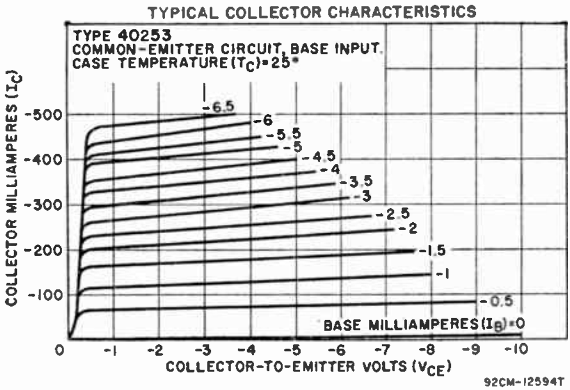
Ge p-n-p alloy-junction type used in class B audio amplifier applications in consumer product and industrial equipment. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

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
Transistor Dissipation:			
T_A up to 55°C	P_T	125	mW
T_A above 55°C	P_T	See curve page 116	
T_C up to 64°C	P_T	650	mW
T_C above 64°C	P_T	See curve page 116	
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)

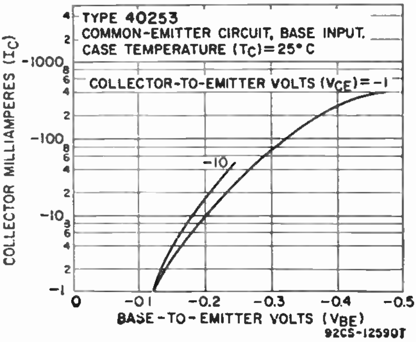
Collector-to-Base Breakdown Voltage (I_C = −0.05 mA, I_E = 0)	$V_{(BR)CBO}$	−25 min	V
Collector-to-Emitter Breakdown Voltage (I_C = −2 mA, I_B = 0)	$V_{(BR)CEO}$	−25 min	V



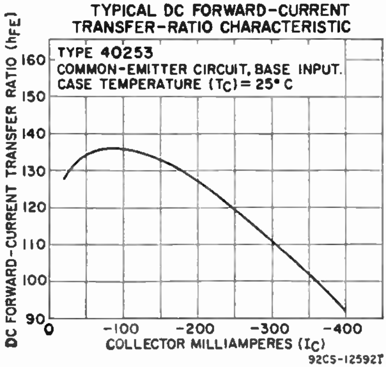
CHARACTERISTICS (cont'd)

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 (V_{CE} = −6 V, I_C = −1 mA)	f_T	1	MHz
Thermal Resistance, Junction-to-Case (T_C = 64°C)	θ_{J-C}	40 max	°C/W

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

40261 TRANSISTOR

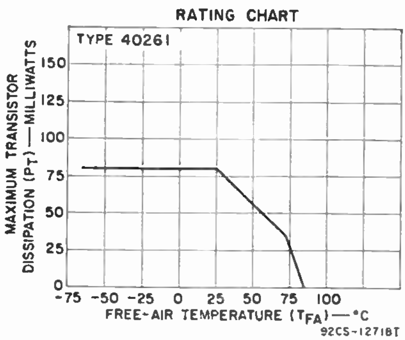
Ge p-n-p drift-field type used in converter service in conjunction with types 40262 (if amplifier), 40263 (af amplifier and driver), 40424 (power output), and 40265 (line rectifier) to provide a complement for line-operated AM broadcast-band receivers and phonographs in entertainment equipment. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

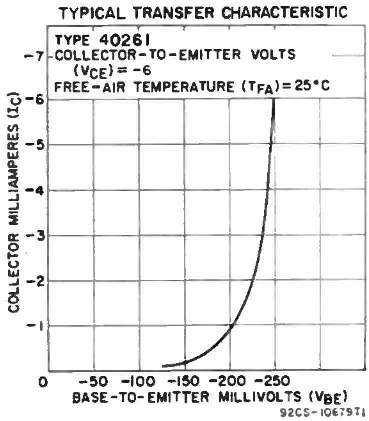
MAXIMUM RATINGS

Collector-to-Base Voltage:			
Emitter open	V_{CBO}	−50	V
V_{BE} = 0.5 V, I_C = −50 μA	V_{CBV}	−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 up to 25°C	P_T	80	mW
T_A above 25°C	P_T	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	$V_{(BR)CBO}$	−50	V
V_{BE} = 0.5 V, I_C = −0.05 mA	$V_{(BR)CBV}$	−34	V
Emitter-to-Base Breakdown Voltage (I_E = −0.012 mA, I_C = 0)	$V_{(BR)EBO}$	−1.5 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 MHz)	r_{bb}'	25	Ω
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	27 to 170	
Gain-Bandwidth Product (V_{CE} = −12 V, I_C = −1 mA)	f_T	40	MHz
Collector-to-Base Feedback Capacitance (V_{CB} = −12 V, I_E = 0)	C_{cb}	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), 40424 (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

Emitter-to-Base Breakdown Voltage (I_E = −0.012 mA, I_C = 0)	$V_{(BR)EBO}$	−0.5 min	V
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	82 to 350	
Gain-Bandwidth Product (V_{CE} = −12 V, I_C = −1 mA)	f_T	30	MHz
Collector-to-Base Capacitance (V_{CB} = −12 V, I_E = 0)	C_{cb}	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), 40424 (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_{EBO}	−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 116	
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 = −5 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	MHz
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	100 to 325	
Intrinsic Base-Spreading Resistance (V_{CE} = −6 V, I_C = −1 mA, f = 100 MHz)	r_{bb}'	200	Ω

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 116	
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)	$V_{(BR)CBO}$	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
V_{BE} = −1.5 V, I_C = 0 to 200 mA, pulsed through inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	65 min	V

CHARACTERISTICS (cont'd)

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)	C_{obo}	10 max	pF
RF Power Output, Unneutralized Amplifier:			
V_{CE} = 28 V, P_{IE} = 1 W, R_G and R_L = 50 Ω, f = 100 MHz	P_{OE}	7.5* min	W
V_{CE} = 28 V, P_{IE} = 1 W, R_G and R_L = 50 Ω, f = 400 MHz	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.

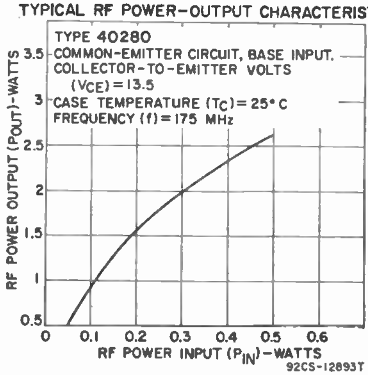
MAXIMUM RATINGS

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 116	
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

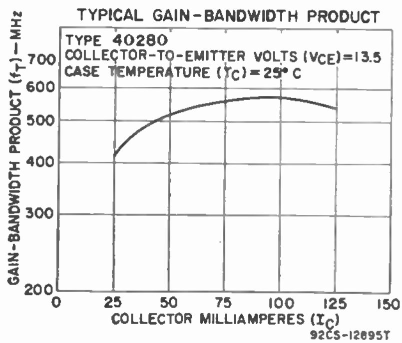
CHARACTERISTICS (At case temperature = 25°C)

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

TYPICAL RF POWER-OUTPUT CHARACTERISTIC



TYPICAL GAIN-BANDWIDTH PRODUCT



CHARACTERISTICS (cont'd)

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	MHz
Output Capacitance (V_{CB} = 13.5 V, I_E = 0, f = 1 MHz)	C_{obo}	15 max	pF
Input Resistance, Real Part (V_{CE} = 13.5 V, I_C = 100 mA, f = 175 MHz)	$R_e(h_{ie})$	10	Ω
Power Output, Class C Amplifier, Unneutralized (V_{CE} = 13.5 V, P_{IE} = 0.125 W, f = 175 MHz, R_G and 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.

40281 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

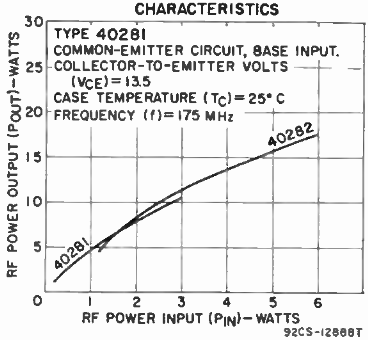
Collector Current	I_C	1	A
Transistor Dissipation: T_C up to 25°C	P_T	11.6	W

CHARACTERISTICS (At case temperature = 25°C)

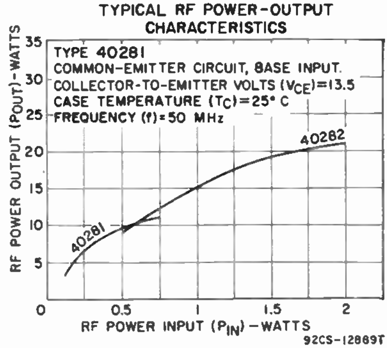
Gain-Bandwidth Product (V_{CE} = 13.5 V, I_C = 400 mA)	f_T	400	MHz
Output Capacitance (V_{CB} = 13.5 V, I_E = 0, f = 1 MHz)	C_{obo}	22 max	pF
Collector-to-Case Capacitance	C_c	5 max	pF
Input Resistance, Real Part (V_{CE} = 13.5 V, I_C = 400 mA, f = 175 MHz)	$R_e(h_{ie})$	7	Ω
Power Output, Class C Amplifier, Unneutralized (V_{CE} = 13.5 V, P_{IE} = 1 W, f = 175 MHz, R_G and 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.

TYPICAL RF POWER-OUTPUT CHARACTERISTICS



TYPICAL RF POWER-OUTPUT CHARACTERISTICS



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:			
T_C 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	MHz
Output Capacitance (V_{CB} = 13.5 V, I_E = 0, f = 1 MHz)	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 MHz)	$R_e(h_{ie})$	5	Ω
Power Output, Class C Amplifier, Unneutralized (V_{CE} = 13.5 V, P_{IE} = 4 W, f = 175 MHz, R_G and 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 116	
Lead-Soldering Temperature (10 s max)	T_L	265	°C

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 MHz	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 116	
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%	$V_{(BR)CEV}$	50 min	V
I_C = 50 mA, V_{BE} = −2 V, f ≦ 100 MHz	$V_{(BR)CES}$(RF)	90 min	V

CHARACTERISTICS (cont'd)

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	MHz
Output Capacitance (V_{CB} = 12.5 V, I_E = 0, f = 1 MHz)	C_{obo}	17 max	pF
Input Resistance, Real Part (V_{CE} = 12.5 V, I_C = 100 mA, f = 135 MHz)	$R_e(h_{ie})$	12	Ω
Power Output, Class C Amplifier, Unneutralized (V_{CE} = 12.5 V, P_{IE} = 0.5 W, f = 135 MHz, R_G and 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.

40291 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. 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 MHz	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 116	
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 Ω, pulsed through inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	50 min	V
I_C = 50 mA, V_{BE} = 0, f ≦ 100 MHz	$V_{(BR)CES}$(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	MHz
Collector-to-Case Capacitance	C_c	6 max	pF
Output Capacitance (V_{CB} = 12.5 V, I_E = 0, f = 1 MHz)	C_{obo}	30 max	pF
Input Resistance, Real Part (V_{CE} = 12.5 V, I_C = 400 mA, f = 135 MHz)	$R_e(h_{ie})$	6.5	Ω

CHARACTERISTICS (cont'd)

Power Output, Class C Amplifier, Unneutralized (V_{CE} = 12.5 V, P_{IE} = 2 W, f = 135 MHz, R_G and R_L = 50 Ω)	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.

TRANSISTOR 40294

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 40295

and oscillator applications. This type 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. This type is identical to type 2N2708 except for the following item:

MAXIMUM RATINGS

Collector Current	I_C	40	mA

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 116	
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 MHz)	C_{obo}	10 max	pF
RF Power Output, Amplifier, Unneutralized: (V_{CE} = 28 V, P_{IE} = 0.25 W, f = 175 MHz, R_G and R_L = 50 Ω)	P_{OE}	2.5† min	W

* For type 40306 this value is maximum Pin-Soldering Temperature.
† For conditions given, minimum efficiency = 50 per cent.

40306 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. 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 MHz, R_G and R_L = 50 Ω	P_{OE}	7.5* min	W
V_{CE} = 28 V, P_{IE} = 1 W, f = 400 MHz, R_G and 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

MAXIMUM RATINGS (cont'd)

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 116	
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 = 300 mA)	h_{FE}	10 min	
Output Capacitance (V_{CB} = 30 V, I_E = 0, f = 1 MHz)	C_{obo}	20 max	pF
RF Power Output, Amplifier, Unneutralized: (V_{CE} = 28 V, P_{IE} = 3.5 W, f = 175 MHz, R_G and R_L = 50 Ω)	P_{OE}	13.5† min	W

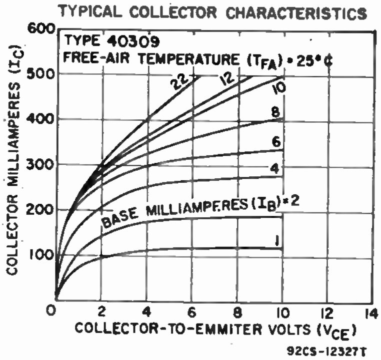
† For conditions given, minimum efficiency = 70 per cent.

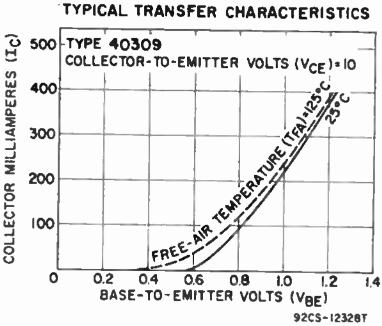
POWER TRANSISTOR 40309

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 116	
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	MHz
Thermal Resistance, Junction-to-Case	Θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	Θ_{J-A}	175 max	°C/W

40310 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-66, **Outline** No.22. **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

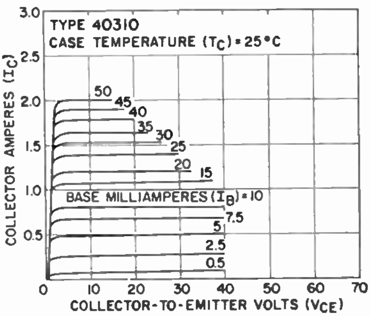
MAXIMUM RATINGS

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 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

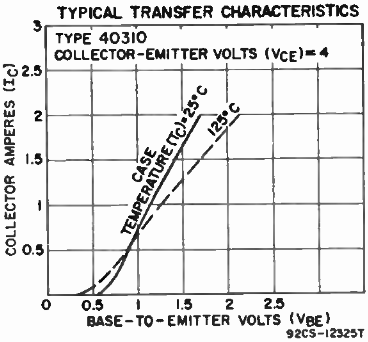
CHARACTERISTICS (At case temperature = 25°C)

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	kHz
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 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	—65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

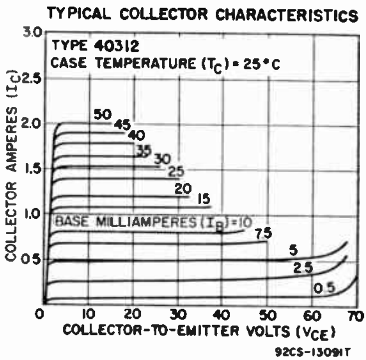
Collector-to-Emitter Sustaining Voltage (I_C = 100 mA, I_B = 0, t_p = 300 μs, df ≦ 2%)	V_{CEO}(sus)	30 min	V
Base-to-Emitter Voltage (V_{CE} = 4 V, I_C = 50 mA)	V_{BE}	1 max	V
Collector-Cutoff Current:			
V_{CB} = 15 V, I_E = 0, T_C = 25°C	I_{CBO}	0.25 max	μA
V_{CB} = 15 V, I_E = 0, T_C = 150°C	I_{CBO}	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	MHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

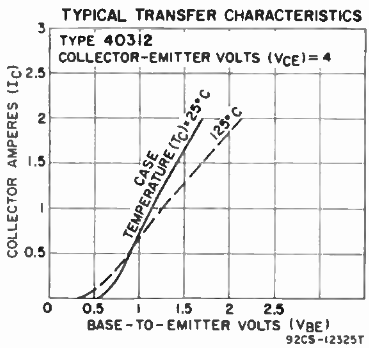
POWER TRANSISTOR 40312

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_{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 116	
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, tp = 300 μs, df = 2%)	V_{CER}(sus)	60 min	V

CHARACTERISTICS (cont'd)

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	kHz
Thermal Resistance, Junction-to-Case	Θ_{J-C}	6 max	°C/W

40313 POWER TRANSISTOR

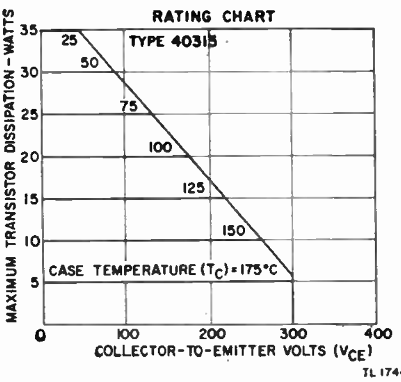
Si n-p-n high-voltage type for direct 117-volt line operation in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

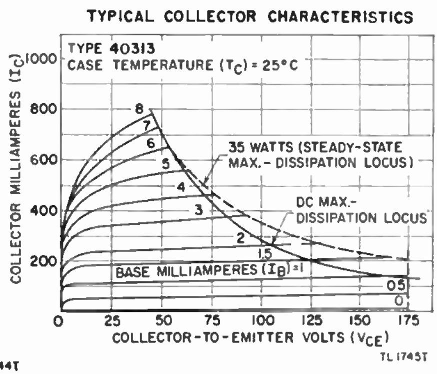
MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 500 Ω)	V_{CER}(sus)	300	V
Emitter-to-Base Voltage	V_{EBO}	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
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





POWER TRANSISTOR 40314

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 116	
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}	35 to 150	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 50 mA)	f_T	100	MHz
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 40315

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 116	
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	MHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

40316 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)	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 116	
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	kHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	6 max	°C/W

40317 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 116	
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

POWER TRANSISTOR 40318

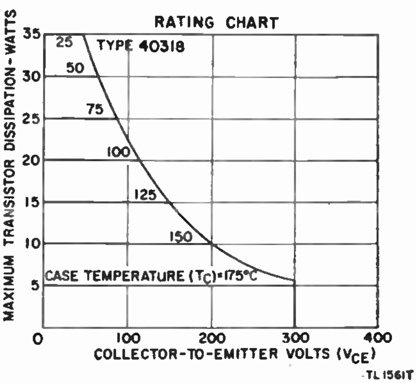
Si **n-p-n** high-voltage type for direct 117-volt line operation in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-66, Outline No.22. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

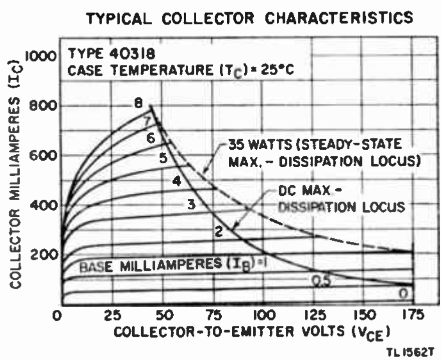
MAXIMUM RATINGS

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

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 = 0.5 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 Ω, L = 100 μH)	$E_{S/b}$	50 min	μJ
Thermal Resistance, Junction-to-Case	Θ_{J-C}	5 max	°C/W



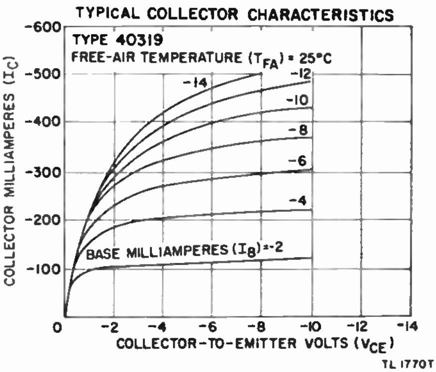


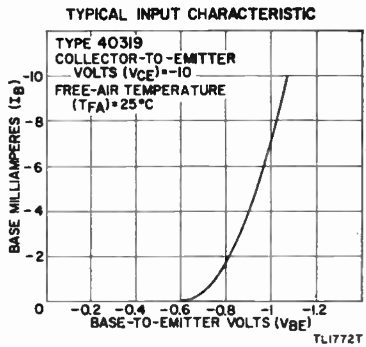
POWER TRANSISTOR 40319

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 116	
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}	35 to 200	
Gain-Bandwidth Product (V_{CE} = −4 V, I_C = −50 mA)	f_T	100	MHz
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 116	
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

CHARACTERISTICS (cont'd)

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

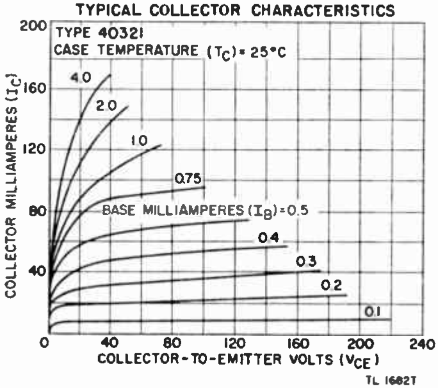
POWER TRANSISTOR 40321

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.

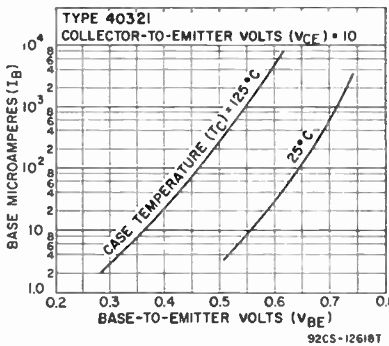
MAXIMUM RATINGS

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 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 300	°C

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL INPUT CHARACTERISTICS



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, I_E = 0, T_C = 150°C	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}	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 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} = 200 Ω, 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 Ω, L = 100 μH)	$E_{S/b}$	50 min	μJ
Thermal Resistance, Junction-to-Case	θ_{J-C}	5 max	°C/W

40323 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)	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 116	
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	MHz
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 40324

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 116	
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	kHz
Thermal Resistance, Junction-to-Case	Θ_{J-C}	6 max	°C/W

POWER TRANSISTOR 40325

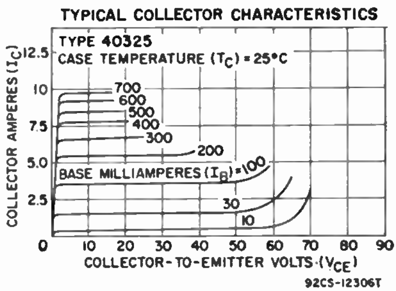
Si **n-p-n** type used in audio-amplifier output stages for economical high-quality performance. Designed to assure freedom from second breakdown in the operating region. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

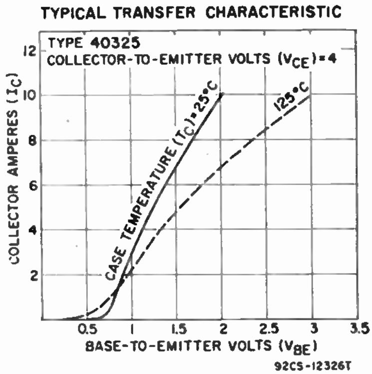
MAXIMUM RATINGS

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 116	
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	
V_{CB} = 30 V, I_E = 0, T_C = 150°C	I_{CBO}	10 max	
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	10 max	°C/W
Static Forward-Current Transfer Ratio			mA
(V_{CE} = 4 V, I_C = 8 A)	h_{FE}	12 to 60	mA
Thermal Resistance, Junction-to-Case	Θ_{J-C}	1.5 max	mA





40326 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 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 116	
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_{CB} = 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

40327 POWER TRANSISTOR

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

MAXIMUM RATINGS (cont'd)

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 116	
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

POWER TRANSISTOR 40328

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

TRANSISTOR 40329

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} ≦ 4700 Ω)	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

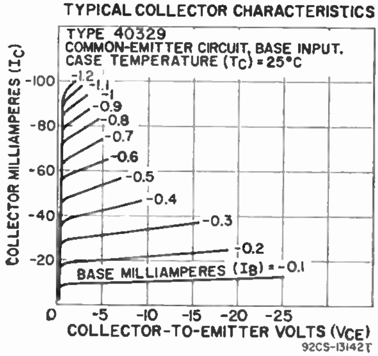
MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_A up to 55°C (With infinite heat sink)	P_T	375	mW
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 116	
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

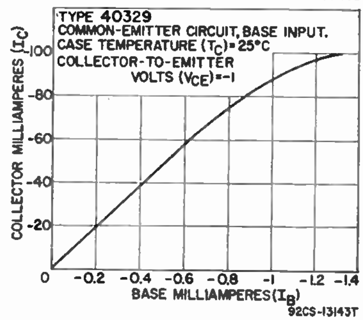
CHARACTERISTICS (At case temperature = 25°C)

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 kHz	h_{fe}	75 to 300	
V_{CE} = − V, I_C = −1 mA, f = 1 kHz	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	MHz
Output Capacitance (V_{CB} = −6 V, f = 1 kHz)	C_{obo}	35	pF
Small-Signal Input Impedance (V_{CE} = −10 V, I_C = −10 mA, f = 1 kHz)	h_{ie}	400	Ω
Small-Signal Output Admittance (V_{CE} = −10 V, I_C = −10 mA, f = 1 kHz)	h_{oe}	175	μmhos
Small-Signal Reverse Voltage-Transfer Ratio (V_{CE} = −10 V, I_C = −10 mA, f = 1 kHz)	h_{re}	300 x 10^{-6}	
Equivalent RMS Noise Input Current (V_{CE} = −6 V, I_C = −0.5 mA, f = 20 Hz to 20 kHz)		0.02 max	μA
Intrinsic Base-Spreading Resistance (V_{CE} = −6 V, I_C = −1 mA, f = 20 MHz)	$r_{bb'}$	100	Ω

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC



40340 TRANSISTOR

Si n-p-n "overlay" epitaxial planar type used in high-power class C amplifier applications at frequencies to 100 MHz. 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

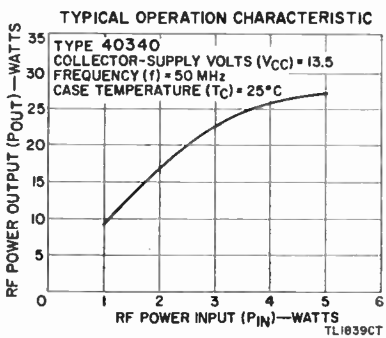
MAXIMUM RATINGS (cont'd)

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 mH, df = 50%	$V_{(BR)CEV}$	60 min	V
I_C = 200 mA, I_B = 0, pulsed through an inductor L = 25 mH, 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 MHz, R_G and 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.



TRANSISTOR 40341

Si n-p-n "overlay" epitaxial planar type used in high-power class C amplifier applications at frequencies to 100 MHz. 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}	70	V
Collector-to-Emitter Voltage:			
V_{BE} = −1.5 V	V_{CEV}	70	V
Base open	V_{CEO}	35	V

CHARACTERISTICS (At case temperature = 25°C)

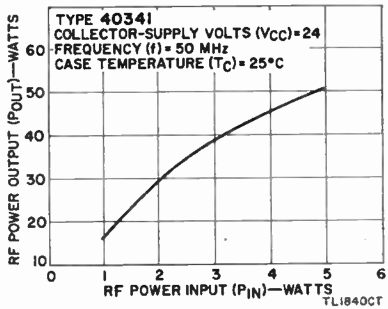
Collector-to-Emitter Breakdown Voltage:			
I_C = 200 mA, V_{BE} = −1.5 V, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEV}$	70 min	V
I_C = 200 mA, I_B = 0, pulsed through an inductor L = 25 mH, df = 50%	$V_{(BR)CEO}$	35 min	V
Collector-Cutoff Current:			
V_{CE} = 30 V, I_B = 0	I_{CEO}	1 max	mA
V_{CB} = 50 V, I_E = 0	I_{CBO}	10 max	mA

CHARACTERISTICS (cont'd)

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 MHz. R_G and R_L = 50 Ω)	P_{OE}	30* min	W

* For conditions given, minimum efficiency = 60 per cent.

TYPICAL OPERATION CHARACTERISTIC



40346

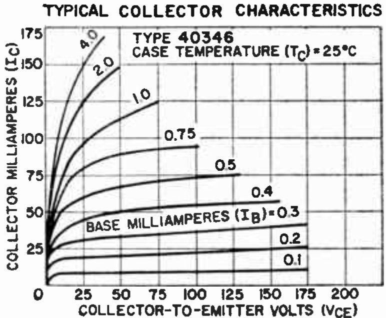
POWER TRANSISTOR

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.

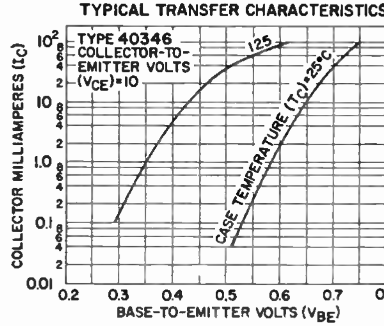
MAXIMUM RATINGS

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 25°C	P_T	10*	W
T_A and T_C above 50°C	P_T	See curve page 116	
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 MHz)	h_{fe}	2 min	
Thermal Resistance, Junction-to-Case	θ_{J-C}	15* max	°C/W

* This value does not apply to type 40346V1.

TRANSISTOR 40346V1

Si n-p-n triple-diffused type used in high-voltage switching and linear-amplifier applications in military and commercial applications. This type is particularly useful in neon-indicator driver circuits and in differential and operational 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 to type 40346 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	4	W

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	45 max	°C/W

TRANSISTOR 40346V2

Si n-p-n triple-diffused type used in high-voltage switching and linear-amplifier applications in military and commercial applications. This type is particularly useful in neon-indicator driver circuits and in differential and operational amplifiers. 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 40346.

POWER TRANSISTOR 40347

Si n-p-n single-diffused type featuring a base comprised of a homogeneous-resistivity silicon material. This type is used in a wide variety of low- and medum-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	1.5	A
Peak Collector Current	i_C	3	A
Base Current	I_B	0.5	A

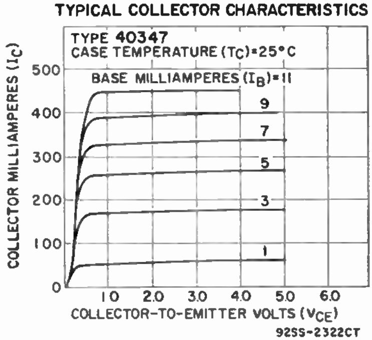
MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_C up to 25°C	P_T	8.75	W
T_A and T_C above 25°C	P_T	See curve page 116	
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

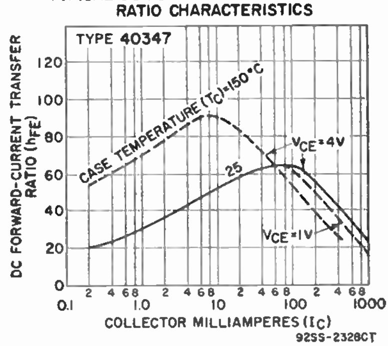
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter 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 = 450 mA)	V_{BE}	1.5 max	V
Collector-Cutoff Current:			
V_{CE} = 30 V, R_{BE} = 1 kΩ, T_C = 25°C	I_{CER}	1 max	μA
V_{CE} = 30 V, R_{BE} = 1 kΩ, T_C = 150°C	I_{CER}	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 = 450 mA)	h_{FE}	20 to 80	
Thermal Resistance, Junction-to-Case	θ_{J-C}	20 max	°C/W

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL DC FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTICS



40347V1 POWER TRANSISTOR

Si n-p-n single-diffused type featuring a base comprised of a homogeneous-resistivity silicon material. This type has 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	4.4	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	40 max	°C/W

POWER TRANSISTOR 40347V2

Si n-p-n single-diffused type featuring a base comprised of a homogeneous-resistivity silicon material. This type is 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	11.7	W
T_C above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

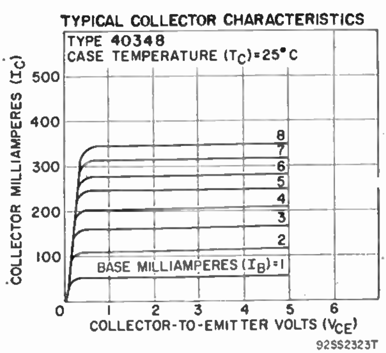
Thermal Resistance, Junction-to-Case	θ_{J-C}	15 max	°C/W

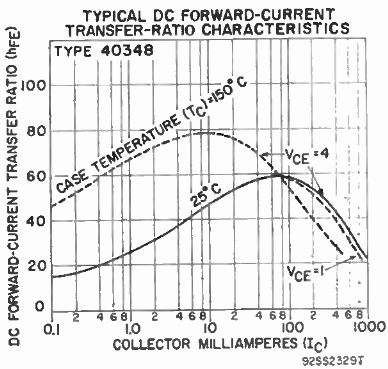
POWER TRANSISTOR 40348

Si n-p-n single-diffused type featuring a base comprised of a homogeneous-resistivity silicon material. This type is used in a wide varety of low- and medium-power applications where medium- and high-voltage power transstors 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
Peak Collector Current	i_C	3	A
Collector Current	I_C	1.5	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	8.75	W
T_A and T_C above 25°C	P_T	See curve page 116	
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 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, R_{BE} = 1 kΩ, T_C = 25°C	I_{CER}	1 max	μA
V_{CE} = 60 V, R_{BE} = 1 kΩ, T_C = 150°C	I_{CER}	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 = 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 featuring a base comprised of a homogeneous-resistivity silicon material. This type has 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	4.4	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	40 max	°C/W

40348V2 POWER TRANSISTOR

Si n-p-n single-diffused type featuring a base comprised of a homogeneous-resistivity silicon material. This type is used in a wide varety of low- and medum-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	11.7	W
T_C above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Thermal Resistance, Junction-to-Case	θ_{J-C}	15 max	°C/W

40349 POWER TRANSISTOR

Si n-p-n single-diffused type featuring a base comprised of a homogeneous-resistivity silicon material. This type is used in a wide varety of low- and medum-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.

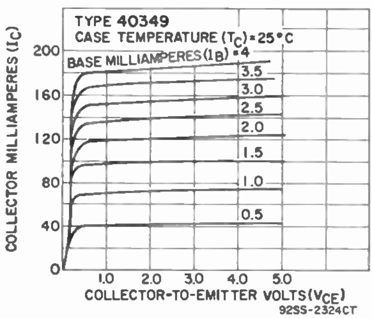
MAXIMUM RATINGS

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	1.5	A
Peak Collector Current	i_C	3	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	8.75	W
T_A and T_C above 25°C	P_T	See curve page 116	
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

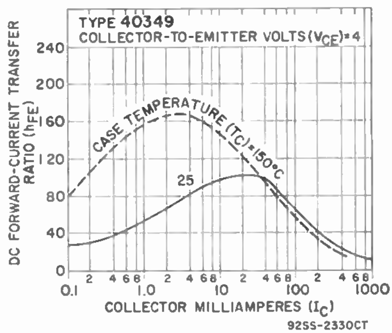
CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage:			
V_{BE} = −1.5 V, I_C = 50 mA, tp = 300 μs, df = 1.8%	V_{CEV}(sus)	160 min	V
I_C = 50 mA, I_B = 0, tp = 300 μs, df = 1.8%	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} = 90 V, R_{BE} = 1 kΩ, T_C = 25°C	I_{CER}	1 max	μA
V_{CE} = 90 V, R_{BE} = 1 kΩ, T_C = 150°C	I_{CEO}	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



POWER TRANSISTOR 40349V1

Si n-p-n single-diffused type featuring a base comprised of a homogeneous-resistivity silicon material. This type has 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	4.4	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	40 max	°C/W

40349V2 POWER TRANSISTOR

Si n-p-n single-diffused type featuring a base comprised of a homogeneous-resistivity silicon material. This type is 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	11.7	W
T_C above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Case	θ_{J-C}	15 max	°C/W

40354 TRANSISTOR

Si n-p-n type used in video-output amplifier stages of black-and-white television receivers. JEDEC TO-104, Outline No.26 (3-lead). 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 116	
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	MHz
V_{CE} = 140 V, I_C = 2 mA	f_T	50 min	MHz
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. JEDEC TO-104, Outline No.27 (3-lead with heat sink). Terminals: 1 - emitter, 2 - base, 3 - collector and case (with heat sink). 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

TRANSISTOR 40359

Ge p-n-p alloy-junction type used in af-amplifier applications in consumer product and industrial equipment. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

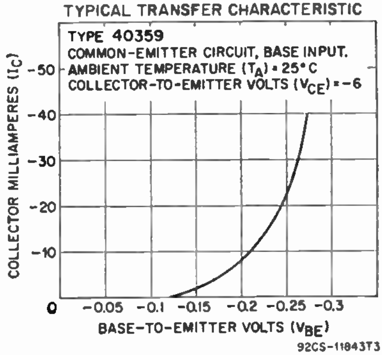
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−20	V
Collector-to-Emitter Voltage ($R_{BE} \leq 10000\ \Omega$)	V_{CER}	−18	V
Emitter-to-Base Voltage	V_{EBO}	−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 116	
Temperature Range:			
Operating	T_A	−65 to 100	°C
Storage	T_{STG}	−65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

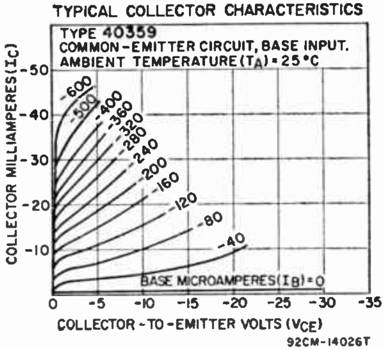
CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage (R_{BE} = 10 kΩ, I_C = −1 mA)	$V_{(BR)CER}$	−18 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.05 mA, I_C = 0)	$V_{(BR)EBO}$	2.5 min	V

TYPICAL TRANSFER CHARACTERISTIC



TYPICAL COLLECTOR CHARACTERISTICS



CHARACTERISTICS (cont'd)

Collector-Cutoff Current (V_{CB} = −15 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 (V_{CE} = −6 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	40 to 165	
Small-Signal Forward-Current Transfer-Ratio Cutoff Frequency (V_{CE} = −6 V, I_C = −1 mA)	f_{hfb}	10	MHz
Intrinsic Base-Spreading Resistance (V_{CE} = −6 V, I_C = −1 mA, f = 100 MHz)	$r_{bb'}$	200	Ω

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 116	
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	MHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	35 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	175 max	°C/W

40361 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 (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 116	
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	MHz
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
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 116	
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}	35 to 200	
Gain-Bandwidth Product (V_{CE} = −4 V, I_C = −50 mA)	f_T	100	MHz
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 40363

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

MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_C up to 25°C	P_T	115	W
T_C above 25°C	P_T	See curve page 116	
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	kHz
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.

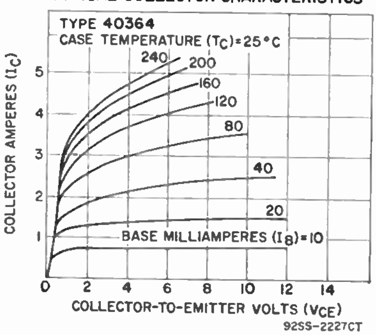
MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 150 Ω)	V_{CER}(sus)	60	V
Emitter-to-Base Voltage	V_{EBO}	4	V
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 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

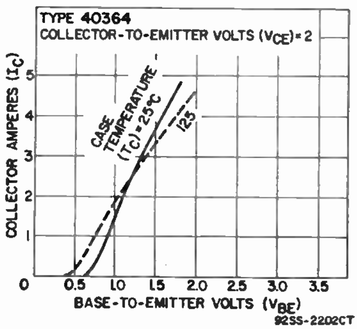
CHARACTERISTICS (At case temperature = 25°C)

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

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



CHARACTERISTICS (cont'd)

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	MHz
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

POWER TRANSISTOR 40366

Si n-p-n **triple-diffused** planar type 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.

MAXIMUM RATINGS

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_C up to 25°C	P_T	5	A
T_A above 25°C	P_T	1	A
T_C and T_A above 25°C	P_T	See curve page 116	
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			
(V_{EB} = 1.5 V, I_C = 0.1 mA)	$V_{(BR)CEV}$	120 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Sustaining Voltage:			
R_{BE} = 10 Ω, I_C = 100 mA, tp = 300 μs, df = 1.8%	V_{CER}(sus)	80 min	V
I_C = 100 mA, I_B = 0, tp = 300 μs, df = 1.8%	V_{CEO}(sus)	65 min	V
Collector-to-Emitter Saturation Voltage			
(I_C = 150 mA, I_B = 15 mA, tp = 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, tp = 300 μs, df = 1.8%)	V_{BE}(sat)	1.1 max	V
Collector-Cutoff Current (V_{CB} = 60 V, I_E = 0)	I_{CBO}	2 max	nA
Emitter-Cutoff Current (V_{EB} = 5 V, I_C = 0)	I_{EBO}	5 max	nA
Static Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 0.01 mA	h_{FE}	10 min	
V_{CE} = 10 V, I_C = 0.1 mA	h_{FE}	20 min	
Pulsed Forward-Current Transfer Ratio:			
V_{CE} = 10 V, I_C = 150 mA, tp = 300 μs, df = 1.8%	h_{FE}(pulsed)	40 to 120	
V_{CE} = 10 V, I_C = 500 mA, tp = 300 μs, df = 1.8%	h_{FE}(pulsed)	25 min	
V_{CE} = 10 V, I_C = 1000 mA, tp = 300 μs, df = 1.8%	h_{FE}(pulsed)	10 min	

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 116	
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 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:			
T_C up to 25°C	P_T	25	W
T_C above 25°C	P_T	See curve page 116	
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 116	
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 featuring a base comprised of a homogeneous-resistivity silicon material. This type has 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.22A. **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_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	30 max	°C/W

POWER TRANSISTOR 40373

Si **n-p-n diffused** type features a base comprised of a homogeneous-resistivity silicon material. This type has 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.22A. **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_A above 25°C	P_T	See curve page 116

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	30 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.22A. **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 item:

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	30 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.22A. **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 116

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	30 max °C/W

40385 POWER TRANSISTOR

Si **n-p-n triple-diffused** type subjected to special preconditioning and reliability tests for high-reliability operation in 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 2N3439.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	450	V
Collector-to-Emitter Voltage	V_{CEO}	350	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 116	
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	

POWER TRANSISTOR 40389

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 MHz) 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 116	

CHARACTERISTICS (At case temperature = 25°C)

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	3.5	W
T_A above 25°C	P_T	See curve page 116	

40391 POWER TRANSISTOR

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	3.5	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	50 max	°C/W

40392 POWER TRANSISTOR

Si n-p-n triple-diffused planar type features a base comprised of a homogeneous-resistivity silicon material. This type is used in a wide variety of small-signal, medium-power applications at frequencies up to 20 MHz. 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 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Case	θ_{J-C}	25 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 identical with type 2N4037 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	See curve page 116	

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 116	

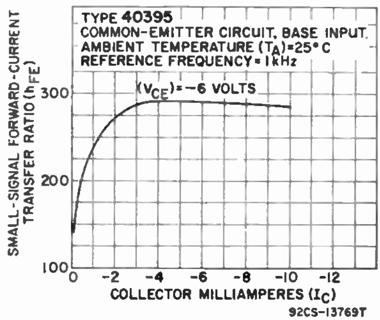
MAXIMUM RATINGS (cont'd)

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-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 kHz)		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	MHz

TYPICAL SMALL-SIGNAL FORWARD-CURRENT TRANSFER-RATIO CHARACTERISTIC



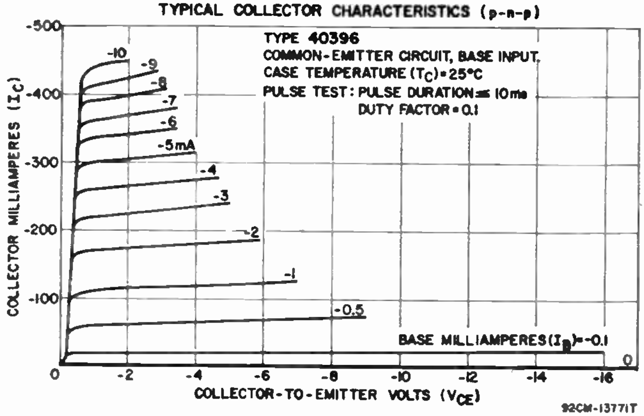
POWER TRANSISTORS (Matched Pair) — 40396

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} ≦ 4.7 kΩ)	V_{CER}	−18	18	V
Emitter-to-Base Voltage	V_{EBO}	−2.5	2.5	V

TYPICAL COLLECTOR CHARACTERISTICS (p-n-p)



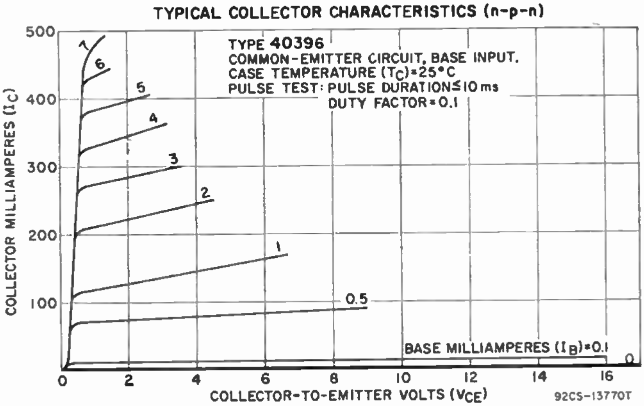
MAXIMUM RATINGS (cont'd)

		p-n-p	n-p-n	
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 116		
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

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)	−0.5 max		V
I_C = 250 mA, I_B = 25 mA	V_{CE}(sat)		0.5 max	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
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 = −50 mA	h_{FE}	50 min	50 min	
V_{CE} = 1 V, I_C = 50 mA	h_{FE}			
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_{CE} = −6 V, I_C = −1 mA	f_{hfb}	1.5		MHz
V_{CE} = 6 V, I_C = 1 mA	f_{hfb}		2	MHz

TYPICAL COLLECTOR CHARACTERISTICS (n-p-n)



40397 TRANSISTOR

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier service in commercial and industrial equipment. JEDEC TO-104, Outline No.27 (3-lead). Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

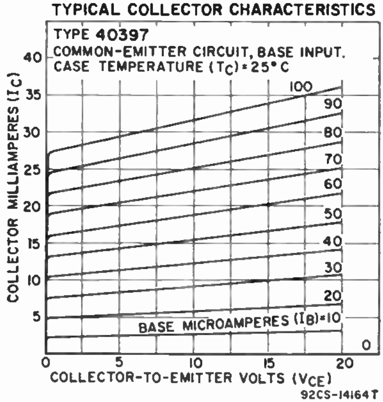
Collector-to-Emitter Voltage:			
Base open	V_{CEO}	25	V
V_{BE} = −1 V	V_{CEV}	25	V
Emitter-to-Base Voltage	V_{EBO}	7.5	V
Collector Current	I_C	200	mA
Emitter Current	I_E	−200	mA

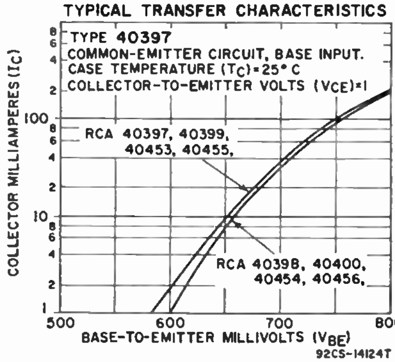
MAXIMUM RATINGS (cont'd)

Base Current	I_B	25	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_C up to 75°C	P_T	2	W
T_A or T_C above 25°C	P_T	See curve page 116	
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 (At case temperature = 25°C)

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 = 0.05 mA, I_C = 0)	$V_{(BR)EBO}$	7.5 min	V
Collector-to-Emitter Saturation Voltage (I_C = 200 mA, I_B = 10 mA)	V_{CE}(sat)	0.15 typ; 0.25 max	V
Base-to-Emitter Saturation Voltage (I_C = 200 mA, I_B = 10 mA)	V_{BE}(sat)	0.8 typ; 1.3 max	V
Collector-Cutoff Current:			
V_{CB} = 25 V, I_E = 0	I_{CBO}	100 max	nA
V_{CB} = 25 V, I_E = 0, T_C = 85°C	I_{CBO}	5 max	μA
V_{CE} = 25 V, V_{BE} = −1 V	I_{CEV}	10 max	μA
Emitter-Cutoff Current (V_{BE} = −2.5 V, I_C = 0)	I_{EBO}	100 max	nA
Static Forward-Current Transfer Ratio:			
V_{CE} = 6 V, I_C = 0.5 mA	h_{FE}	20 min; 175 typ	
V_{CE} = 10 V, I_C = 10 mA	h_{FE}	165 to 600	
V_{CE} = 1 V, I_C = 100 mA	h_{FE}	100 min; 245 typ	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{fe}	165 min; 375 typ	
Gain-Bandwidth Product (V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	f_T	50 min; 80 typ	MHz
Intrinsic Base-Spreading Resistance (V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	$r_{bb'}$	20 typ; 40 max	Ω
Output Capacitance (V_{CB} = 6 V, I_E = 0, f = 1 MHz)	C_{obo}	12 typ; 20 max	pF
Small-Signal Input Impedance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{ie}	1200	Ω
Small-Signal Output Admittance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{oe}	120	μmhos
Small-Signal Reverse-Voltage Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{re}	250×10^{-6}	
Thermal Resistance, Junction-to-Case	θ_{J-C}	50 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	300 max	°C/W



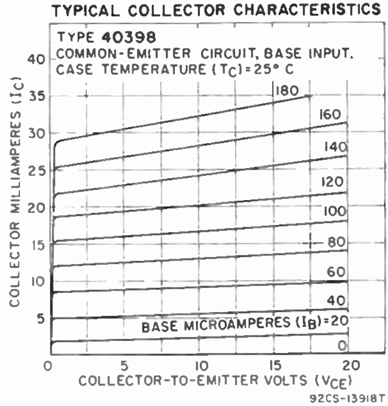


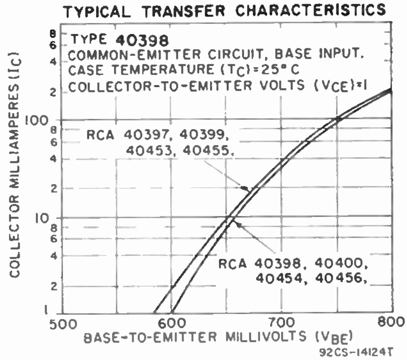
TRANSISTOR 40398

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier service in commercial and industrial equipment. JEDEC TO-104, Outline No.27 (3-lead). Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 40397 except for the following items:

CHARACTERISTICS (At case temperature = 25°C)

Static Forward-Current Transfer Ratio:			
V_{CE} = 6 V, I_C = 0.5 mA	h_{FE}	20 min; 75 typ	
V_{CE} = 10 V, I_C = 10 mA	h_{FE}	75 to 300	
V_{CE} = 1 V, I_C = 100 mA	h_{FE}	50 min; 140 typ	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{fe}	75 min; 200 typ	
Small-Signal Input Impedance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{ie}	600	Ω
Small-Signal Output Admittance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{oe}	75	μmhos
Small-Signal Reverse-Voltage Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{re}	125×10^{-6}	





40399 TRANSISTOR

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier service in commercial and industrial equipment. JEDEC TO-104, Outline No.27 (3-lead). Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

Collector-to-Emitter Voltage:			
Base open	V_{CEO}	18	V
V_{BE} = −1 V	V_{CEV}	18	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	200	mA
Emitter Current	I_E	−200	mA
Base Current	I_B	25	mA
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_C up to 75°C	P_T	2	W
T_A or T_C above 25°C	P_T	See curve page 116	
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

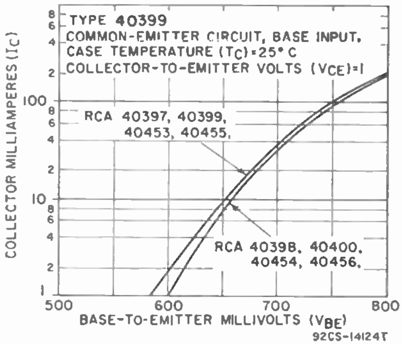
CHARACTERISTICS (At case temperature = 25°C)

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 = 0.05 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Saturation Voltage (I_C = 100 mA, I_B = 5 mA)	V_{CE}(sat)	0.1 typ; 0.2 max	V
Base-to-Emitter Saturation Voltage (I_C = 100 mA, I_B = 5 mA)	V_{BE}(sat)	0.75 typ; 1.3 max	V
Collector-Cutoff Current:			
V_{CB} = 12 V, I_E = 0	I_{CBO}	500 max	nA
V_{CB} = 12 V, I_E = 0, T_C = 85°C	I_{CBO}	10 max	μA

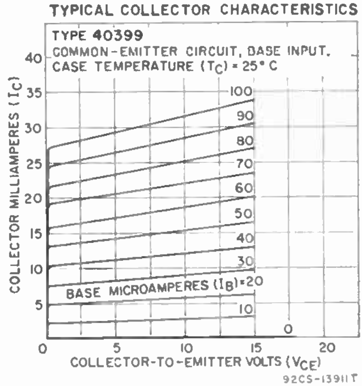
CHARACTERISTICS (cont'd)

Emitter-Cutoff Current (V_{BE} = −2.5 V, I_C = 0)	I_{EBO}	500 max	nA
Static Forward-Current Transfer Ratio:			
V_{CE} = 6 V, I_C = 0.5 mA	h_{FE}	175	
V_{CE} = 10 V, I_C = 10 mA	h_{FE}	165 to 600	
V_{CE} = 1 V, I_C = 100 mA	h_{FE}	100 min; 245 typ	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{fe}	165 min; 375 typ	
Gain-Bandwidth Product (V_{CE} = 6V, I_C = 1 mA, f = 100 MHz)	f_T	50 typ; 80 max	MHz
Intrinsic Base-Spreading Resistance (V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	$r_{bb'}$	20 typ; 40 max	Ω
Output Capacitance (V_{CB} = 6 V, I_E = 0, f = 1 MHz)	C_{obo}	12 typ; 20 max	pF
Small-Signal Input Impedance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{ie}	1200	Ω
Small-Signal Output Admittance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{oe}	120	μmhos
Small-Signal Reverse-Voltage Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{re}	250×10^{-6}	
Thermal Resistance, Junction-to-Case	θ_{J-C}	50 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	300 max	°C/W

TYPICAL TRANSFER CHARACTERISTICS



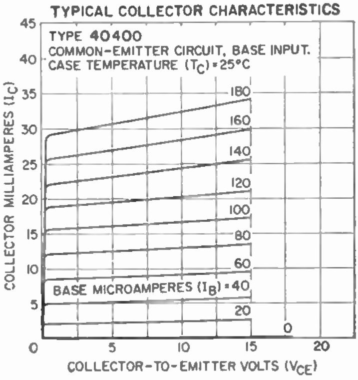
TYPICAL COLLECTOR CHARACTERISTICS



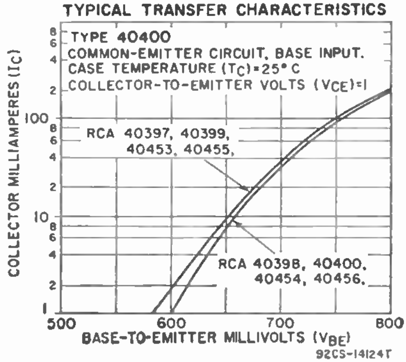
TRANSISTOR 40400

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier service in commercial and industrial equipment. JEDEC TO-104, Outline No.27 (3-lead). Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 40399 except for the following items:

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTICS



CHARACTERISTICS (At case temperature = 25°C)

Static Forward-Current Transfer Ratio:			
V_{CE} = 6 V, I_C = 0.5 mA	h_{FE}	75	
V_{CE} = 10 V, I_C = 10 mA	h_{FE}	75 to 300	
V_{CE} = 1 V, I_C = 100 mA	h_{FE}	50 min; 140 typ	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{fe}	75 min; 200 typ	
Small-Signal Input Impedance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{ie}	600	Ω
Small-Signal Output Admittance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{oe}	75	μmhos
Small-Signal Reverse-Voltage Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{re}	125×10^{-6}	

40403 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 2N396A except for the following item:

CHARACTERISTICS

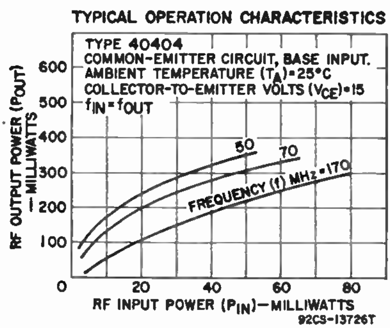
Collector-Cutoff Current (V_{CE} = −20 V, base reverse-biased, V_{BB} = 2 V, R_{BE} = 10000 Ω)	I_{CEX}	−6 max	μA

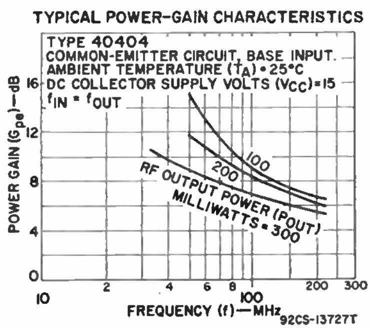
40404 TRANSISTOR

Si **n-p-n** epitaxial planar type used in vhf low-level class C rf amplifiers and frequency multipliers at frequencies to 170 MHz 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 116	
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, $t_p \leq$ 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 MHz)	C_{obo}	4 max	pF
RF Power Output, Frequency-Doubler (V_{CC} = 12 V, P_{ie} = 5 mW, f(in) = 43 MHz, f(out) = 86 MHz)	P_{oe}	50* min	mW

* For conditions given, minimum efficiency = 35 per cent.

TRANSISTOR 40405

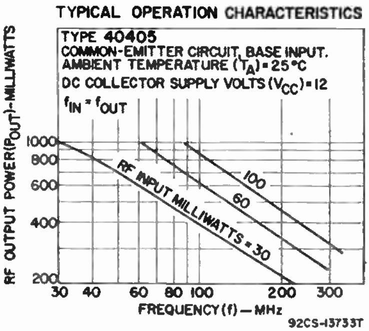
Si n-p-n epitaxial planar type used in class C rf power amplifiers, drivers, and frequency multipliers at frequencies to 400 MHz in battery-operated communications equipment. JEDEC TO-52, Outline No.18. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

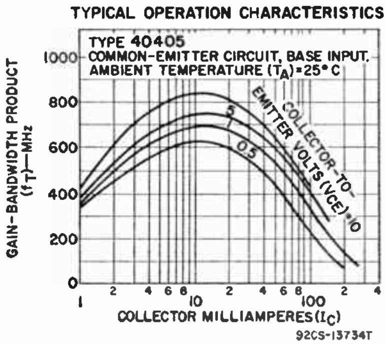
MAXIMUM RATINGS

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 116	
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, t_p = 100 μs, df = 2%	$V_{(BR)CEO}$	16 min	V
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 MHz)	h_{fe}	3 min	





CHARACTERISTICS (cont'd)

Gain Bandwidth Product (I_C = 100 mA, V_{CE} = 1 V)	f_T	300 min	MHz
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 0.1 to 1 MHz)	C_{obo}	3.5 max	pF
RF Power Output, Frequency-Doubler (V_{CC} = 15 V, P_{IE} = 30 mW, f(in) = 86 MHz, f(out) = 172 MHz	P_{oe}	200* min	mW

* For conditions given, minimum efficiency = 35 per cent.

40406 TRANSISTOR

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 116	
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}	30 to 200	
Gain-Bandwidth Product (V_{CE} = −4 V, I_C = −50 mA)	f_T	100	MHz
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. For collector-characteristics and transfer-characteristics curves, refer to type 40309. This type is identical with type 40406 except for reversal of all polarity signs and the following items:

CHARACTERISTICS (At case temperature = 25°C)

Base-to-Emitter Voltage (V_{CE} = 10 V, I_C = 1 mA)	V_{BE}	0.8 max	V
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 1 mA)	h_{FE}	40 to 200	

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 116	
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	MHz
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 Hz. 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} ≦ 10 Ω)	$V_{CER}(sus)$	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 116	
Temperature Range:			
Operating (Junction)	$T_J(opr)$	−65 to 200	°C

CHARACTERISTICS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 100 Ω, 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 max	V
Collector-Cutoff Current:			
V_{CE} = 80 V, R_{BE} = 100 Ω, T_C = 25°C	I_{CER}	1 max	μA
V_{CE} = 80 V, R_{BE} = 100 Ω, 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	MHz
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 Hz. 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.

40411 POWER TRANSISTOR

Si **n-p-n** type features a base comprised of a homogeneous-resistivity silicon material. This type is 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 Hz. JEDEC TO-3, Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

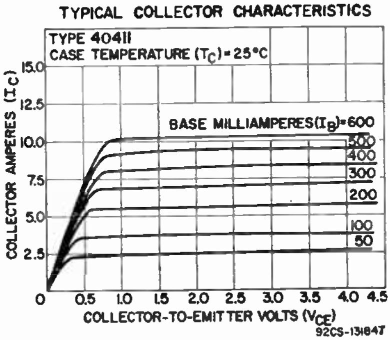
MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage ($R_{BE} \leq 100\ \Omega$)	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 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

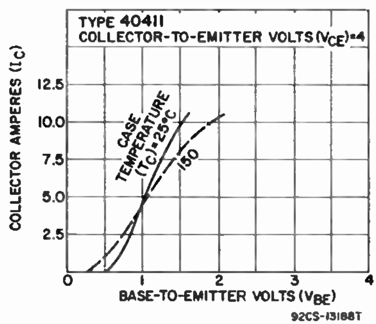
CHARACTERISTICS (At case temperature = 25°C)

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)	0.8 max	V
Base-to-Emitter Voltage ($V_{CE} = 4$ V, $I_C = 4$ A)	V_{BE}	1.2 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	kHz
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



TRANSISTOR 40412

Si n-p-n triple-diffused type used in high-voltage switching and linear-amplifier applications in military and commercial applications. This type is particularly useful in neon-indicator driver circuits and in differential and operational amplifiers. JEDEC TO-5, Outline No.3. Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

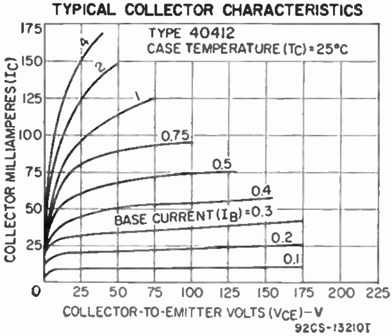
Collector-to-Emitter Sustaining Voltage (R_{BE} = 10000 Ω)	V_{CER}(sus)	250	V
Collector Current	I_C	1	A
Base Current	I_B	0.5	A
Transistor Dissipation:			
T_C up to 25°C	P_T	10 *	W
T_A up to 50°C	P_T	1 ▪	W
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 200	°C

CHARACTERISTICS (At case temperature = 25°C)

Collector-to-Emitter Sustaining Voltage (R_{BE} = 10000 Ω, I_C = 50 mA)	V_{CER}(sus)	250 min	V
Collector-Cutoff Current:			
R_{BE} = 10000 Ω, V_{CE} = 100 V	I_{CER}	1 max	mA
V_{CE} = 150 V, V_{EB} = 1.5 V, T_C = 150°C	I_{CEV}	2 max	mA
Emitter-Cutoff Current (V_{EB} = 3 V, I_C = 0)	I_{EBO}	100 max	µA
Static Forward-Current Transfer Ratio (V_{CE} = 20 V, I_C = 30 mA)	h_{FE}	40 min	
Small-Signal Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 10 mA, f = 5 MHz)	h_{fe}	2 min	
Output Capacitance (V_{CB} = 10 V, I_E = 0, f = 1 MHz)	C_{obo}	10 max	pF
Second-Breakdown Collector Current (V_{CE} = 200 V)	$I_{S/b}$	50 min	mA
Thermal Resistance, Junction-to-Case	θ_{J-C}	15 * max	°C/W

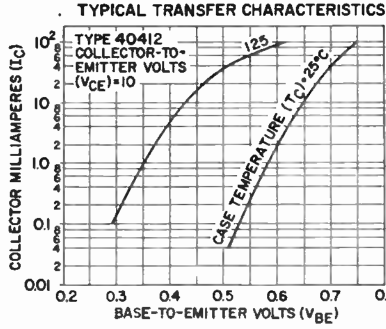
* This value does not apply to type 40412V1.
▪ This value applies only for type 40412.

TYPICAL COLLECTOR CHARACTERISTICS



92CS-13210T

TYPICAL TRANSFER CHARACTERISTICS



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TRANSISTOR 40412V1

Si n-p-n triple-diffused type used in high-voltage switching and linear-amplifier applications in military and commercial applications. This type is particularly useful in neon-indicator driver circuits and in differential and operational 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 electrically identical with type 40412 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation (T_A up to 25°C)	P_T	4	W

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	45 max	°C/W

40412V2 TRANSISTOR

Si n-p-n triple-diffused type used in high-voltage switching and linear-amplifier applications in military and commercial applications. This type is particularly useful in neon-indicator driver circuits and in differential and operational amplifiers. 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 40412.

40413 TRANSISTOR

Si n-p-n double-diffused epitaxial planar type used in rf amplifier and mixer applications up to 200 MHz, and in oscillator applications up to 500 MHz. JEDEC TO-72, Outline No.23. **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case. This type is electrically and mechanically similar to type 2N2708, but each shipment of type 40413 is accompanied by a certified summary of electrical and environmental tests. For typical characteristics curves, refer to type 2N2857.

40414 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 MHz in a common-emitter circuit and 1200 MHz in a common-base circuit. JEDEC TO-72, Outline No.23. **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case. This type is electrically and mechanically similar to type 2N2857, but each shipment of type 40414 is accompanied by a certified summary of electrical and environmental tests. For typical characteristics curves, refer to type 2N2857.

40421 POWER TRANSISTOR

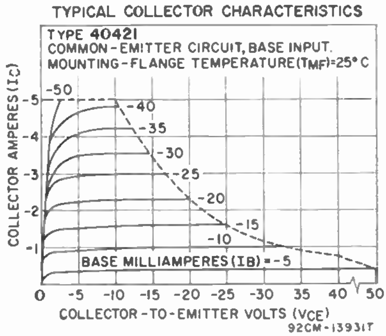
Ge p-n-p drift-field type used in high-fidelity af amplifier applications. JEDEC TO-3, Outline No.2. **Terminals:** 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

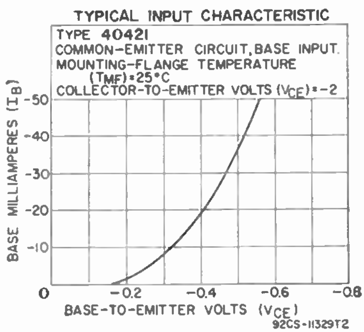
MAXIMUM RATINGS

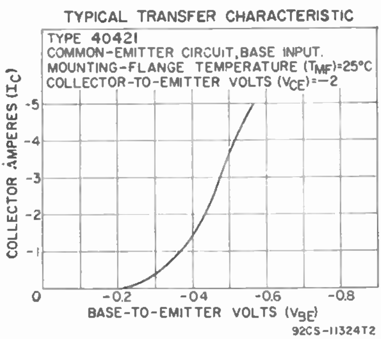
Collector-to-Base Voltage	V_{CBO}	−75	V
Collector-to-Emitter Voltage	V_{CEO}	−50	V
Emitter-to-Base Voltage	V_{EBO}	−1.5	V
Collector Current	I_C	−5	A
Base Current	I_B	−1	A
Emitter Current	I_E	5	A
Transistor Dissipation:			
T_{MF} up to 81°C	P_T	12.5	W
T_{MF} above 81°C	P_T	See curve page 116	
Temperature 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, t_p ≧ 300 μs, df = 0.01%)	$V_{(BR)CBO}$	−75	V
Collector-to-Emitter Sustaining Voltage (I_C = −100 mA, I_B = 0)	V_{CEO}(sus)	−50	V
Base-to-Emitter Voltage:			
V_{CE} = −10 V, I_C = −50 mA	V_{BE}	0.21 to 0.28	V
V_{CE} = −2 V, I_C = −1 mA	V_{BE}	0.5 max	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_{BE} = 1.5 V, I_C = 0)	I_{EBO}	−2.5 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = −2 V, I_C = −1000 V	h_{FE}	62 to 175	
V_{CE} = −2 V, I_C = −4000 V	h_{FE}	40 min	
Gain-Bandwidth Product (V_{CE} = −5 V, I_C = −500 mA)	f_T	2 min; 4 typ	MHz
Thermal Resistance, Junction-to-Mounting Flange	θ_{J-MF}	1.5 max	°C/W







POWER TRANSISTOR 40422

Si **n-p-n** type used in class A amplifiers in line-operated radios, phonographs, television receivers, and other entertainment-type electronic equipment. JEDEC TO-66, Outline No.22. **Terminals:** 1 (E) - emitter, 2 (B) - base, Mounting Flange - collector and case.

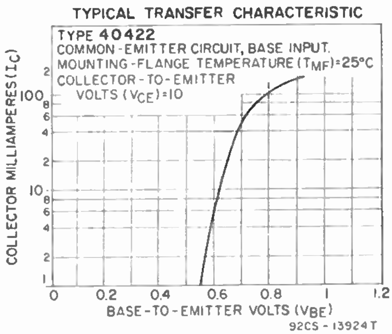
MAXIMUM RATINGS

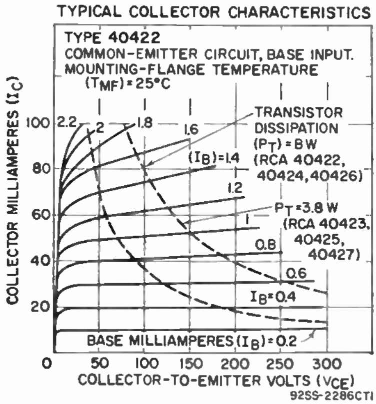
Collector-to-Base Voltage	V_{CBO}	300	V
Collector-to-Emitter Voltage (I_C = 5 mA, I_B = 5 μA)	V_{CEX}(sus)	300	V
Emitter-to-Base Voltage	V_{EBO}	2	V
Collector Current	I_C	150	mA
Base Current	I_B	150	mA
Emitter Current	I_E	150	mA
Transistor Dissipation:			
T_{MF} up to 70°C	P_T	8*	W
T_{MF} above 70°C	P_T	See curve page 116	
Temperature Range:			
Operating (T_A —T_{MF})		−65 to 150	°C
Storage	T_{STG}	−65 to 150	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	2 min	V
Collector-Cutoff Current:			
V_{CB} = 300, I_E = 0	I_{CBO}	100 max	μA
V_{CE} = 300 V, I_B = 5 mA	I_{CEX}	5 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA)	h_{FE}	50 to 250	
Gain-Bandwidth Product (V_{CE} = 50 V, I_C = 20 mA)	f_T	25	MHz
Output Capacitance (V_{CB} = 50 V, I_E = 0)	C_{obo}	5	pF
Intrinsic Base-Spreading Resistance (V_{CE} = 50 V, I_C = 20 mA, f = 100 MHz)	$r_{bb'}$	20	Ω
Thermal Resistance, Junction-to-Mounting Flange	θ_{J-MF}	8* typ; 10* max	°C/W

* This value does not apply to types 40423, 40425, 40427.





40423 POWER TRANSISTOR

Si n-p-n type used in class A af power-amplifier service in line-operated radios, phonographs, television receivers, and other entertainment-type electronic equipment. JEDEC TO-66 (with heat radiator), Outline No.22B. Terminals: 1 (E) - emitter, 2 (B) - base, Mounting Flange - collector and case (with heat radiator). This type is identical with type 40422 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 55°C	P_T	3.8	W
T_A above 55°C	P_T	See curve page 116	

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	25 max	°C/W

POWER TRANSISTOR 40424

Si n-p-n type used in class A output amplifier service. This type is used in conjunction with types 40261 (converter), 40262 (if amplifier), 40263 (af amplifier and driver), 40425 (power output), and 40265 (line rectifier) to provide a complement for line-operated AM broadcast-band receivers and phonographs in entertainment equipment. JEDEC TO-66, Outline No.22. Terminals: 1 (E) - emitter, 2 (B) - base, Mounting Flange - collector and case. For collector-characteristics and transfer-characteristics curves, refer to type 40422.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	300	V
Collector-to-Emitter Voltage (I_C = 5 mA, I_B = 5 μA)	V_{CEX}	300	V
Emitter-to-Base Voltage	V_{EBO}	2	V
Collector Current	I_C	150	mA
Base Current	I_B	150	mA
Emitter Current	I_E	−150	mA
Transistor Dissipation:			
T_{MF} up to 70°C	P_T	8 *	W
T_{MF} above 70°C	P_T	See curve page 116	
Temperature Range:			
Operating (T_A —T_{MF})		−65 to 150	°C
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)	$V_{(BR)EBO}$	2 min	V
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}	5 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA)	h_{FE}	30 to 150	
Gain-Bandwidth Product (V_{CE} = 50 V, I_C = 20 mA)	f_T	25	MHz
Intrinsic Base-Spreading Resistance (V_{CE} = 50 V, I_C = 20 mA, f = 100 MHz)	$r_{bb'}$	20	Ω
Feedback Capacitance (V_{CB} = 50 V, I_E = 0)	C_{cb}	5	pF
Thermal Resistance, Junction-to-Mounting Flange	θ_{J-MF}	8* typ; 10* max	°C/W

* This value does not apply to type 40425.

POWER TRANSISTOR 40425

Si n-p-n type used in class A output amplifier service. This type is used in conjunction with types 40261 (converter), 40262 (if amplifier), 40263 (af amplifier and driver), 40424 (power output), and 40265 (line rectifier) to provide a complement for line-operated AM broadcast-band receivers and phonographs in entertainment equipment. JEDEC TO-66 (with heat radiator), Outline No.22B. Terminals: 1 (E) - emitter, 2 (B) - base, Mounting Flange - collector and case (with heat radiator). This type is identical with type 40424 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 55°C	P_T	3.8	W
T_A above 55°C	P_T	See curve page 116	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	25 max	°C/W

40426 POWER TRANSISTOR

Si n-p-n type used in class A af power-amplifier service in line-operated radios, phonographs, television receivers, and other entertainment-type electronic equipment. JEDEC TO-66, Outline No.22. Terminals: 1 (E) - emitter, 2 (B) - base, Mounting Flange - collector and case. This type is identical with type 40422 except for the following item:

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA)	h_{FE}	20 to 100	

40427 POWER TRANSISTOR

Si n-p-n type used in class A af power-amplifier service in line-operated radios, phonographs, television receivers, and other entertainment-type electronic equipment. JEDEC TO-66 (with heat radiator), Outline No.22B. Terminals: 1 (E) - emitter, 2 (B) - base, Mounting Flange - collector and case (with heat radiator). This type is identical with type 40423 except for the following item:

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA)	h_{FE}	20 to 100	

40439 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), 2N3731 and 40440 (horizontal output), 2N3732 (horizontal driver), and 1N4785 and 40442 (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. This type is identical with type 2N3731 except for the following item:

CHARACTERISTICS

Turn-Off Time	$t_s + t_f$	0.75 max	μs

40440 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), 2N3731 and 40439 (horizontal output), 2N3732 (horizontal driver), and 1N4785 and 40442 (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. This type is identical with type 2N3731 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage: Peak	V_{CBO}	−200	V

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage (I_C = −0.025 mA, V_{EB} = 0)	$V_{(BR)CES}$	−200	V
Collector-to-Emitter Saturation Voltage: I_C = −6 A, I_B = −0.4 A	V_{CE}(sat)	−0.75 max	V
I_C = −3 A, I_B = −0.2 A	V_{CE}(sat)	−0.75 max	V
Base-to-Emitter Voltage (I_C = −6 A, I_B = −0.4 A)	V_{BE}	−1	V

TRANSISTOR 40444

Si n-p-n "overlay" epitaxial planar type used as high-power class B and C rf amplifier for marine communications service (2 to 3 MHz) with amplitude modulation and 13-volt power supply. JEDEC TO-3 Outline No.2. Terminals: 1 (B) - base, 2 (E) - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

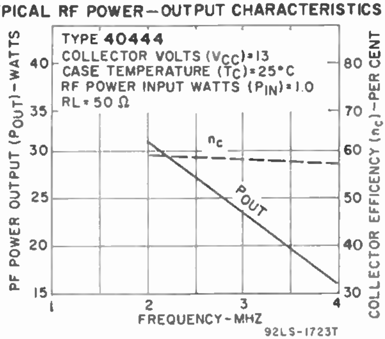
Collector-to-Base Voltage	V_{CBO}	120	V
Collector-to-Emitter Voltage:			
$V_{BE} = -1.5$ V	V_{CEV}	120	V
$R_{BE} = 50$	V_{CER}(sus)	80	V
Base open	V_{CEO}	60	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	20	A
Base Current	I_B	10	A
Transistor Dissipation:			
T_C up to 25°C	P_T	140	W
T_C above 25°C	P_T	See curve page 116	
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)

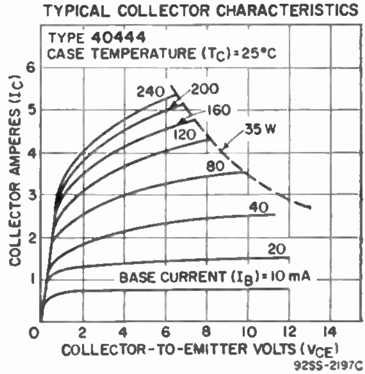
Collector-to-Emitter Sustaining Voltage:			
$I_C = 0.2$ A, $I_B = 0$	V_{CEO}(sus)	60 min	V
$V_{BE} = -1.5$ V, $I_C = 0.2$ A, $I_B = 0$	V_{CEV}(sus)	120 min	V
Collector-to-Emitter Saturation Voltage ($I_C = 10$ A, $I_B = 1$ A, $t_p \leq 350$ µs, df = 2%)	V_{CE}(sat)	1 max	V
Base-to-Emitter Voltage ($V_{CE} = 5$ V, $I_C = 10$ A, $t_p \leq 350$ µs, df = 2%)	V_{BE}	1.8 max	V
Emitter-to-Base Voltage ($I_E = 0.05$ A, $I_C = 0$)	V_{EBO}	7 min	V
Collector-Cutoff Current:			
$V_{CE} = 40$ V, $I_B = 0$	I_{CEO}	20 max	mA
$V_{CE} = 80$ V, $V_{BE} = -1.5$ V	I_{CEV}	20 max	mA
$V_{CE} = 80$ V, $V_{BE} = -1.5$ V, $T_C = 150$°C	I_{CEV}	20 max	mA
Emitter-Cutoff Current ($V_{EB} = 5$ V, $I_C = 0$)	I_{EBO}	15 max	mA
Pulsed Static Forward-Current Transfer Ratio:			
$V_{CE} = 5$ V, $I_C = 2$ A, $t_p \leq 350$ µs, df = 2%	h_{FE}(pulsed)	30 to 150	
$V_{CE} = 5$ V, $I_C = 10$ A, $t_p \leq 350$ µs, df = 2%	h_{FE}(pulsed)	20 min	
Gain Bandwidth Product ($V_{CE} = 10$ V, $I_C = 2$ A, f = 5 MHz)	f_T	60 min	MHz
Output Capacitance ($V_{CB} = 10$ V, $I_C = 0$, f = 1 MHz)	C_{obo}	500 max	pF
Second-Breakdown Collector Current:			
$V_{CE} = 30$ V, base forward-biased	$I_{S/b}$	2 min	A
$V_{CE} = 45$ V, base forward-biased	$I_{S/b}$	0.5 min	A
RF Power Output, AM Carrier ($V_{CE} = 13$ V, $P_{IE} = 1$ W, f = 2.5 MHz)	P_{OE}	20* min	W

* For conditions given, minimum efficiency = 55 per cent.

TYPICAL RF POWER—OUTPUT CHARACTERISTICS



TYPICAL COLLECTOR CHARACTERISTICS



40446 TRANSISTOR

Si n-p-n triple-diffused planar type used in power-amplifier applications, in conjunction with types 40080 (oscillator), 40081 (driver), and 40082 (power amplifier), in a 5-watt-input, 27 - MHz citizens-band transmitter. 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 40082 except for the following item:

MAXIMUM RATINGS

Transistor Dissipation:			
T_C up to 25°C	P_T	10	W

40450 TRANSISTOR

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier and switching service in commercial, industrial, and computer equipment. JEDEC TO-104, Outline No.27 (3-lead with heat sink). Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N3241A except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	150 max	°C/W

40451 TRANSISTOR

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier and switching service in commercial, industrial, and computer equipment. JEDEC TO-104, Outline No.27 (3-lead with heat sink). Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N3242A except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	150 max	°C/W

40452 TRANSISTOR

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier service in commercial and industrial equipment. JEDEC TO-104, Outline No.27 (3-lead with heat sink). Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 2N4074 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	150 max	°C/W

TRANSISTOR 40453

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier service in commercial and industrial equipment. JEDEC TO-104, Outline No.27 (3-lead with heat sink). Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 40397 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	150 max	°C/W

TRANSISTOR 40454

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier service in commercial and industrial equipment. JEDEC TO-104, Outline No.27 (3-lead with heat sink). Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 40398 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	150 max	°C/W

TRANSISTOR 40455

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier service in commercial and industrial equipment. JEDEC TO-104, Outline No.27 (3-lead with heat sink). Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 40399 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	150 max	°C/W

TRANSISTOR 40456

Si n-p-n epitaxial planar type used in high-voltage, high-current audio and video amplifier service in commercial and industrial equipment. JEDEC TO-104, Outline No.27 (3-lead with heat sink). Terminals: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 40400 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	See curve page 116	

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	150 max	°C/W

40457 TRANSISTOR

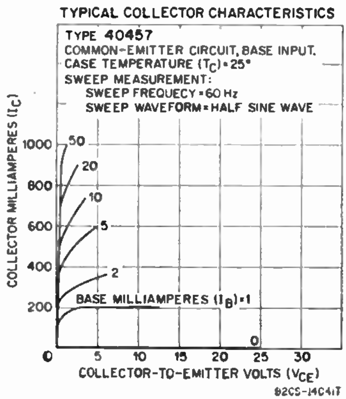
Si n-p-n epitaxial planar type used in class B af amplifier applications in consumer-product and industrial equipment. JEDEC TO-104, Outline No.26 (3-lead). Terminals: 1 - emitter, 2- base, 3 - collector and case.

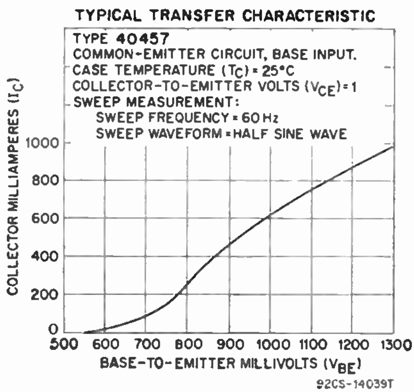
MAXIMUM RATINGS

Collector-to-Emitter Voltage			
$V_{BE} = -1$ V	V_{CEV}	25	V
Base open	V_{CEO}	25	V
Emitter-to-Base Voltage	V_{EBO}	7	V
Collector Current	I_C	1	A
Emitter Current	I_E	1	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_A above 25°C	P_T	See curve page 116	
T_C up to 75°C	P_T	2	W
T_C above 75°C	P_T	See curve page 116	
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 (At case temperature = 25°C)

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 = 0.05 mA, I_C = 0)	$V_{(BR)EBO}$	7 min	V
Collector-to-Emitter Saturation Voltage			
(I_C = 600 mA, I_B = 20 mA)	V_{CE}(sat)	1 max	V
Base-to-Emitter Saturation Voltage			
(I_C = 600 mA, I_B = 20 mA)	V_{BE}(sat)	1	V
Collector-Cutoff Current:			
V_{CB} = 25 V, I_E = 0	I_{CBO}	500 max	nA
V_{CB} = 25 V, I_E = 0, T_C = 85°C	I_{CBO}	10 max	μA
V_{CE} = 25 V, V_{BE} = −1 V	I_{CEV}	20 max	μA
Emitter-Cutoff Current			
(V_{BE} = −2.5 V, I_C = 0)	I_{EBO}	500 max	nA
Static Forward Current Transfer Ratio			
(V_{CE} = 1 V, I_C = 600 mA)	h_{FE}	30 min; 60 typ	
Gain-Bandwidth Product			
(V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	f_T	50 min; 80 typ	MHz
Output Capacitance			
(V_{CB} = 6 V, I_E = 0, f = 1 MHz)	C_{obo}	12 typ; 20 max	pF
Intrinsic Base-Spreading Resistance			
(V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	$r_{bb'}$	20 typ; 40 max	Ω
Thermal Resistance, Junction-to-Case	θ_{J-C}	50 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	300 max	°C/W





TRANSISTOR 40458

Si n-p-n double-diffused epitaxial planar type used in high-peak-current audio and video amplifier applications in commercial and industrial equipment and high-current switching and driver service in computer equipment. JEDEC TO-104, Outline No.27 (3-lead). Terminals: 1 - emitter, 2 - base, 3 - collector and case.

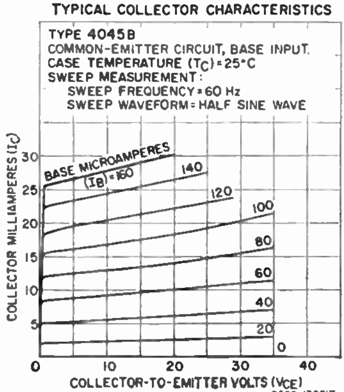
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	60	V
Collector-to-Emitter Voltage	V_{CEO}	40	V
Emitter-to-Base Voltage	V_{EBO}	8	V
Collector Current	I_C	1	A
Transistor Dissipation:			
T_A up to 25°C	P_T	0.5	W
T_A above 25°C	P_T	Derate linearly 3.3	mW/°C
T_C up to 75°C	P_T	2	W
T_C above 75°C	P_T	Derate linearly 20	mW/°C
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	265	°C

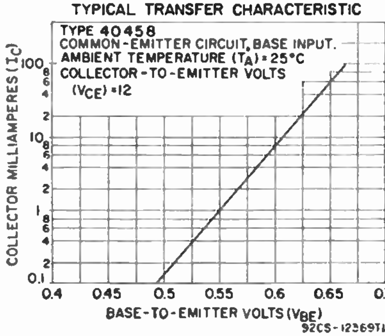
CHARACTERISTICS

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 = 0.05 mA, I_C = 0)	$V_{(BR)EBO}$	8 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 100 mA, I_B = 0, t_p = 300 μs, df = 0.018%)	$V_{(BR)CEO}$(sus)	40 min	V
Collector-to-Emitter Saturation Voltage (I_C = 300 mA, I_B = 15 mA)	V_{CE}(sat)	0.24 typ; 0.3 max	V
Base-to-Emitter Saturation Voltage (I_C = 300 mA, I_B = 15 mA)	V_{BE}(sat)	0.93 typ; 1.5 max	V
Collector-Cutoff Current:			
V_{CB} = 25 V, I_E = 0	I_{CBO}	10 max	nA
V_{CB} = 25 V, I_E = 0, T_A = 85°C	I_{CBO}	1 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} = 10 V, I_C = 10 mA	h_{FE}	100 to 300	
V_{CE} = 10 V, I_C = 150 mA	h_{FE}	150	
V_{CE} = 1 V, I_C = 300 mA	h_{FE}	50 min; 75 typ	
Small-Signal Forward-Current Transfer Ratio V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{fe}	75 min; 175 typ	
Gain-Bandwidth Product (V_{CE} = 1 V, I_C = 50 mA, f = 50 MHz)	f_T	150 min; 200 typ	MHz
Feedback Capacitance* (V_{CB} = 6 V, I_E = 0, f = 1 MHz)	C_{cb}	20 max	pF
Small-Signal Input Impedance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{ie}	600	Ω
Small-Signal Output Impedance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{oe}	75	mmhos

TYPICAL COLLECTOR CHARACTERISTICS



TYPICAL TRANSFER CHARACTERISTIC



CHARACTERISTICS (cont'd)

Small-Signal Reverse-Voltage Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{re}	125 × 10^{-6}	
Intrinsic Base-Spreading Resistance (V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	$r_{bb'}$	20	Ω
Thermal Resistance, Junction-to-Case	θ_{J-C}	50 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	300 max	°C/W

* Three-terminal measurement with lead No. 1 (emitter) guarded.

40459 TRANSISTOR

Si n-p-n **double-diffused epitaxial planar** type used in high-peak-current audio and video amplifier applications in commercial and industrial equipment and high-current switching and driver service in computer equipment. JEDEC TO-104, **Outline** No.27 (3-lead with heat sink). **Terminals**: 1 - emitter, 2 - base, 3 - collector and case. This type is identical with type 40458 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W
T_A above 25°C	P_T	Derate linearly 6.6	mW°C

CHARACTERISTICS

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	150 max	°C/W

40460 FIELD-EFFECT TRANSISTOR

Si **insulated-gate field-effect** (MOS) **n-channel depletion** type for critical chopper applications and multiplex service up to 60 MHz. The insulated gate provides a very high input resistance (10^{14} Ω typ) which is relatively insensitive to temperature and is independent of gate-bias conditions (positive, negative, or zero bias). JEDEC TO-72, **Outline** No.23. **Terminals**: 1 - source, 2 - gate, 3 - drain, 4 - substrate and case.

MAXIMUM RATINGS

Drain-to-Source Voltage	V_{DS}	±25	V
DC Gate-to-Source Voltage	V_{GS}	±10	V
Peak Gate-to-Source Voltage	v_{GS}	±25	V
Drain-to-Substrate Voltage	V_{DB}	−0.3 to 25	V
Source-to-Substrate Voltage	V_{SB}	−0.3 to 25	V
Drain Current	I_D	Limited by dissipation	
Transistor Dissipation (T_A = −65 to 125°C)	P_T	150	mW
Ambient-Temperature Range:			
Operating	T_A	−65 to 125	°C
Storage	T_{STG}	−65 to 150	°C
Lead-Soldering Temperature (10 s max)	T_L	265	°C

CHARACTERISTICS

Gate-Leakage Current:			
V_{GS} = ±10 V, V_{DS} = 0	I_{GSS}	0.1 typ; 10 max	pA
V_{GS} = ±10 V, V_{DS} = 0, T_A = 125°C	I_{GSS}	20 typ; 200 max	pA
Drain-to-Source OFF Current:			
V_{DS} = 1 V, V_{GS} = −10 V	$I_{DS}(OFF)$	0.1 typ; 0.5 max	nA
V_{DS} = 1 V, V_{GS} = −10 V, T_A = 125°C	$I_{DS}(OFF)$	0.1 typ; 0.5 max	μA
Drain Current (V_{DS} = 12 V, V_{GS} = 0)	I_D	9	mA
Drain-to-Source ON Resistance:			
V_{GS} = 10 V, V_{DS} = 0, f = 1 kHz	$r_{DS}(ON)$	90	Ω
V_{DS} = 0, V_{GS} = 0, f = 1 kHz, T_A = 125°C	$r_{DS}(ON)$	350	Ω
Forward Transconductance (V_{DS} = 12 V, V_{GS} = 0, f = 1 kHz)	Y_{fs}	3500	μmhos
Small-Signal Reverse Transfer Capacitance (V_{GS} = −6 V, V_{DS} = 0, f = 0.1 to 1 MHz)	C_{rss}	0.75 typ; 1.2 max	pF
Small-Signal Input Capacitance (V_{GS} = −6 V, V_{DS} = 0, f = 0.1 to 1 MHz)	C_{iss}	4 typ; 5 max	pF
Offset Voltage (V_{GS} = ±10 V, V_{DS} = 0)		0	V

FIELD-EFFECT TRANSISTOR 40461

Si insulated-gate field-effect (MOS) n-channel depletion type for audio, wideband, and tuned amplifier application up to 60 MHz. The insulated gate provides a very high input resistance (10^{14} Ω typ) which is relatively insensitive to temperature and is independent of gate-bias conditions (positive, negative, or zero bias). JEDEC TO-72, Outline No.23. Terminals: 1 - source, 2 - gate, 3 - drain, 4 - substrate and case. Maximum ratings for this type are identical with those for type 40460 except that the maximum drain-to-source voltage is 25 V.

CHARACTERISTICS

Gate-to-Source Cutoff Voltage (V_{DS} = 12 V, I_D = 50 μA)	V_{GS}(OFF)	−4.5 typ; −6 max	V
Gate Leakage Current:			
V_{GS} = ±10 V, V_{DS} = 0	I_{GSS}	0.1 typ; 10 max	pA
V_{GS} = ±10 V, V_{DS} = 0, T_A = 125°C	I_{GSS}	20 typ; 200 max	pA
Drain Current (V_{DS} = 12 V, V_{GS} = 0)	I_D	4 to 14	mA
Forward Transconductance:			
V_{DS} = 12 V, V_{GS} = 0	Y_{fs}	3500	μmhos
V_{DS} = 12 V, I_D = 4 mA, f = 1 kHz	Y_{fs}	1600 min; 2500 typ	μmhos
Small-Signal Reverse Transfer Capacitance (V_{DS} = 12 V, V_{GS} = 0, f = 0.1 to 1 MHz)	C_{rss}	0.9 typ; 1.2 max	pF
Small-Signal Input Capacitance (V_{DS} = 12 V, V_{GS} = 0, f = 0.1 to 1 MHz)	C_{iss}	4 typ; 5 max	pF
Output Resistance (V_{DS} = 12 V, I_D = 4 mA, f = 1 kHz)	r_d	9000 min; 13000 typ	Ω
Power Gain (V_{DS} = 12 V, I_D = 4 mA, f = 60 MHz, BW = 1.5 MHz)	G_{ps}	14	dB
Noise Figure:			
V_{DS} = 12 V, I_D = 4 mA, f = 60 MHz, BW = 1.5 MHz	NF	5.9	dB
V_{DS} = 12 V, I_D = 4 mA, R_G = 1 MΩ, f = 1 kHz	NF	4	dB
Equivalent Input Noise Voltage (V_{DS} = 12 V, I_D = 4 mA, R_G = 0, f = 1 kHz)		0.16 typ; 0.25 max	$\mu V\sqrt{f(Hz)}$

POWER TRANSISTOR 40462

Ge p-n-p alloy-junction type used in high-fidelity class B af amplifier service in push-pull and "single-ended push-pull" circuits. 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	See curve page 116	
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)	$V_{(BR)CBO}$	-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
Collector-to-Emitter Saturation Voltage (I_C = 5 A, I_B = −0.5 A)	V_{CE}(sat)	1 max	V
Base-to-Emitter Voltage (V_{CE} = −10 V, I_C = −0.05 A)	V_{BE}	−0.19	V

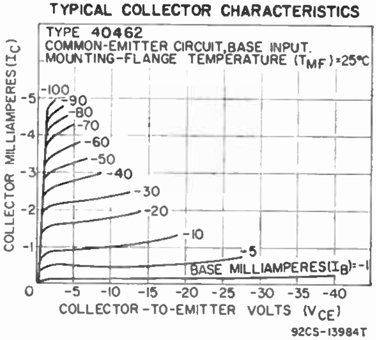
CHARACTERISTICS (cont'd)

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 min; 90 typ	
Gain-Bandwidth Product (V_{CE} = 5 V, I_C = −0.5 A)	f_T	600	kHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

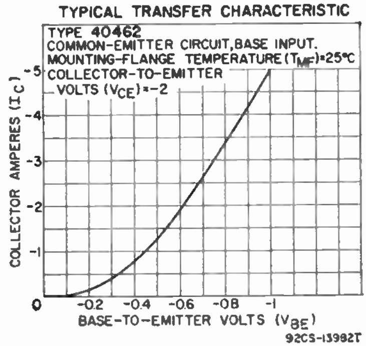
TYPICAL OPERATION IN "SINGLE-ENDED PUSH-PULL" CLASS B AF-AMPLIFIER CIRCUIT (At mounting-flange temperature = 25°C)

DC Collector Supply Voltage	V_{CC}	18	V
Zero-Signal DC Collector Current	I_C	−12	mA
Zero-Signal Base-Bias Voltage		−0.15	V
Peak Collector Current	I_{CM}	−2.8	A
Maximum-Signal DC Collector Current	I_C	−1	A
Input Impedance of Stage (per base)		32	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	G_{PE}	25	dB
Maximum-Signal Power Output	P_{OE}	15	W
Total Harmonic Distortion at Maximum-Signal Power Output		5	%

TYPICAL COLLECTOR CHARACTERISTICS



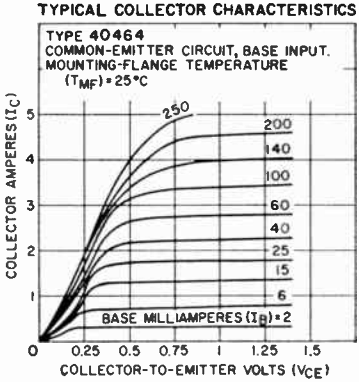
TYPICAL TRANSFER CHARACTERISTIC



40464 POWER TRANSISTOR

Si n-p-n epitaxial type used in high-fidelity af power-amplifier service when 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.

TYPICAL COLLECTOR CHARACTERISTICS

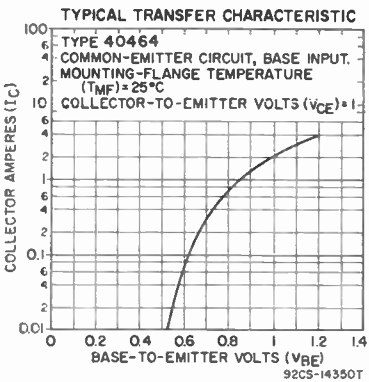


MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	35	V
Collector-to-Emitter Voltage	V_{CEO}	35	V
Emitter-to-Base Voltage	V_{EBO}	4	V
Collector Current	I_C	5	A
Transistor Dissipation:			
T_{MF} up to 70°C	P_T	40	W
T_{MF} above 70°C	P_T	See curve page 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 150	°C
Storage	T_{STG}	−65 to 150	°C
Lead-Soldering Temperature (10 s max)	T_L	265	°C

CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Breakdown Voltage (I_C = 0.1 A, I_B = 0)	$V_{(BR)CEO}$	35 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.01 A, I_C = 0)	$V_{(BR)EBO}$	4 min	V
Collector-to-Emitter Saturation Voltage (I_C = 2 A, I_B = 0.2 A)	V_{CE}(sat)	0.25	V
Collector-to-Emitter Sustaining Voltage (R_{BE} = 33 Ω, I_C = 1.5 A)	V_{CER}(sus)	35 min	V
Base-to-Emitter Voltage:			
V_{CE} = 1 V, I_C = 2 A	V_{BE}	0.9	V
V_{CE} = 10 V, I_C = 0.05 A	V_{BE}	0.55	V
Collector-Cutoff Current (V_{CB} = 35 V, I_E = 0)	I_{CBO}	0.25 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} = 1 V, I_C = 1 A	h_{FE}	40 min; 80 typ	
V_{CE} = 1 V, I_C = 2 A	h_{FE}	30 to 170	
Gain-Bandwidth Product (V_{CE} = 6 V, I_C = 0.5 A)	f_T	2 min; 5 typ	MHz
Second-Breakdown Collector Current (V_{CE} = 25 V)	$I_{S/b}$	2.5 min	A

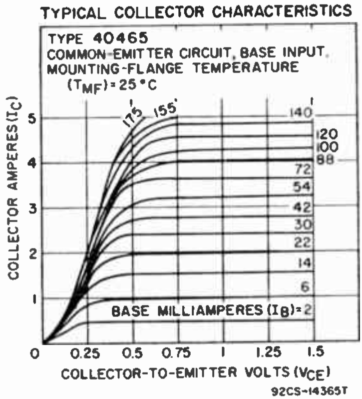


POWER TRANSISTOR 40465

Si n-p-n epitaxial type used in high-fidelity af power-amplifier service when 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 40464 except for the following items:

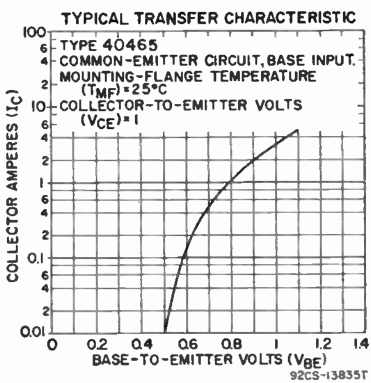
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	40	V
Collector-to-Emitter Voltage	V_{CEO}	40	V



CHARACTERISTICS (At mounting-flange temperature = 25°C)

Collector-to-Emitter Breakdown Voltage (I_C = 0.1 A, I_B = 0)	$V_{(BR)CEO}$	40 min	V
Collector-to-Emitter Sustaining Voltage (R_{BE} = 33 Ω, I_C = 1.5 A)	V_{CER}(sus)	40 min	V
Collector-Cutoff Current (V_{CB} = 40 V, I_C = 0)	I_{CBO}	0.1 max	mA
Static Forward-Current Transfer Ratio:			
V_{CE} = 1 V, I_C = 1 A	h_{FE}	70 min; 150 typ	
V_{CE} = 1 V, I_C = 2 A	h_{FE}	50 to 170	
Gain-Bandwidth Product (V_{CE} = 6 V, I_C = 0.5 A)	f_T	3 min; 5 typ	MHz
Second-Breakdown Collector Current (V_{CE} = 25 V)	$I_{S/b}$	4 min	A



40466 POWER TRANSISTOR

Si n-p-n epitaxial type used in high-fidelity af power-amplifier service when 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 40465 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-Emitter Breakdown Voltage (I_C = 0.1 A, I_B = 0)	$V_{(BR)CEO}$	50 min	V
Collector-to-Emitter Sustaining Voltage (R_{BE} = 33 Ω, I_C = 1.5 A)	V_{CER}(sus)	50 min	V
Collector-Cutoff Current (V_{CB} = 50 V, I_E = 0)	I_{CBO}	0.1 max	mA

FIELD-EFFECT TRANSISTOR 40467

Si insulated-gate field-effect (MOS) n-channel depletion type for vhf tuners and other vhf-amplifier applications in entertainment-type electronic equipment. JEDEC TO-104, Outline No. 26 (4-lead). Terminals: 1 - drain, 2 - source, 3 - insulated gate, 4 - substrate and case.

MAXIMUM RATINGS

Drain-to-Source Voltage	V_{DS}	0 to 20	V
Gate-to-Source Voltage:			
Continuous (dc)	V_{GS}	0 to −8	V
Instantaneous (ac)	V_{GS}	0.5 to −8	V
Drain Current	I_D	Limited by dissipation	
Transistor Dissipation:			
T_A up to 100°C	P_T	100	mW
T_A from 100°C to 125°C	P_T	Derate at 4 mW/°C	
Temperature Range:			
Operating (T_A) and Storage (T_{STG})		−65 to 125	°C
Lead-Soldering Temperature (10 s max)	T_L	265	°C

CHARACTERISTICS

Gate-to-Source Voltage (V_{DS} = 12 V, I_D = 0.1 mA)	V_{GS}(off)	−5 typ; −8 max	V
Gate Leakage Current (V_{GS} = −8 V, V_{DS} = 0)	I_{GSS}	200 max	pA
Drain Current (V_{DD} = 20 V, R_S = 240 Ω, R_D = 620 Ω)	I_D	5	mA
Small-Signal Short-Circuit Reverse Transfer Capacitance (V_{DS} = 15 V, I_D = 5 mA, f = 1 MHz)	C_{rss}	0.05 to 0.2	pF
Input Resistance (V_{DS} = 15 V, I_D = 5 mA, f = 200 MHz)		2	kΩ
Output Resistance (V_{DS} = 15 V, I_D = 5 mA, f = 200 MHz)		3.6	kΩ
Magnitude of Forward Transadmittance (V_{DS} = 15 V, I_D = 5 mA, f = 200 MHz)	$\|Y_{fs}\|$	7.4	mmhos
Maximum Available Power Gain (V_{DS} = 15 V, I_D = 5 mA, f = 200 MHz)	MAG	19.9	dB
Maximum Usable Power Gain, Unneutralized (V_{DS} = 15 V, I_D = 5 mA, f = 200 MHz)	MUG	12.6	dB
Maximum Usable Power Gain, Neutralized (V_{DS} = 15 V, I_D = 5 mA, f = 200 MHz)	MUG	16.3	dB
Noise Figure (V_{DS} = 15 V, I_D = 5 mA, f = 200 MHz)	NF	4.5 typ; 6 max	dB

FIELD-EFFECT TRANSISTOR 40468

Si insulated-gate field-effect (MOS) n-channel depletion type used as an rf amplifier in FM receivers covering the 88-to-108-MHz band and for general amplifier applications at frequencies up to 125 MHz. JEDEC TO-104, Outline No.27 (4-lead). Terminals: 1 - drain, 2 - source, 3 - insulated gate, 4 - substrate and case.

MAXIMUM RATINGS

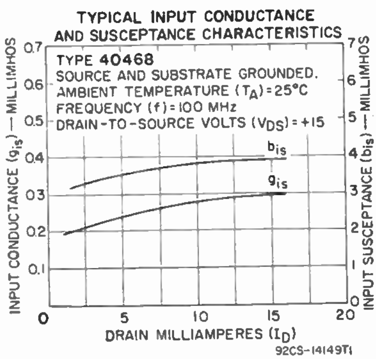
Drain-to-Source Voltage	V_{DS}	20	V
Gate-to-Source Voltage	V_{GS}	0 to −8	V

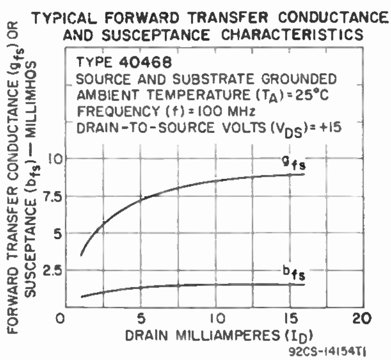
MAXIMUM RATINGS

Peak Gate-to-Source Voltage	V_{GS}	±15	V
Drain Current	I_D	20	mA
Transistor Dissipation:			
T_A up to 85°C	P_T	100	mW
T_A above 85°C	P_T	See curve page 116	
Temperature Range:			
Operating	T_A	−65 to 100	°C
Storage	T_{STG}	−65 to 100	°C
Lead-Soldering Temperature (10 s max)	T_L	265	°C

CHARACTERISTICS

Gate-to-Source Cutoff Voltage (V_{DS} = 20 V, I_D = 0.1 mA)	V_{GS}(OFF)	−5 min; −8 max	V
Gate Leakage Current (V_{GS} = −8 V, V_{DS} = 0)	I_{GSS}	200 max	pA
Drain Current (V_{DD} = 20 V, R_S = 240 Ω, R_D = 620 Ω, t_p = 20 ms, df ≤ 0.15%)	I_D(pulsed)	5	mA
Magnitude of Forward Transadmittance (V_{DS} = 15 V, I_D = 5 mA, f = 100 MHz)	$\|Y_{fs}\|$	7.5	mmhos
Small-Signal Reverse Transfer Capacitance (V_{DS} = 15 V, I_D = 5 mA, f = 1 MHz)	C_{rss}	0.1 to 0.2	pF
Small-Signal Input Capacitance (V_{DS} = 15 V, I_D = 5 mA, f = 100 MHz)	C_{iss}	5.5	pF
Small-Signal Output Capacitance (V_{DS} = 15 V, I_D = 5 mA, f = 100 MHz)	C_{oss}	1.4	pF
Input Resistance (V_{DS} = 15 V, I_D = 5 mA, f = 100 MHz)	R_{ie}	4.5	kΩ
Output Resistance (V_{DS} = 15 V, I_D = 5 mA, f = 100 MHz)	R_{oe}	4.2	kΩ
Maximum Available Power Gain (V_{DS} = 15 V, I_D = 5 mA, f = 100 MHz)	MAG	24	dB
Maximum Usable Amplifier Gain, Neutralized (V_{DS} = 15 V, I_D = 5 mA, f = 100 MHz)	MUG	17	dB
Maximum Usable Amplifier Gain, Unneutralized (V_{DS} = 15 V, I_D = 5 mA, f = 100 MHz)	MUG	14	dB
Noise Figure (V_{DS} = 15 V, I_D = 5 mA, f = 100 MHz)	NF	4 typ; 5 max	dB





40469 TRANSISTOR

Si n-p-n type used as rf amplifier in television tuners covering channels 2 through 13. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). Terminals: 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. For maximum ratings, refer to type 40472.

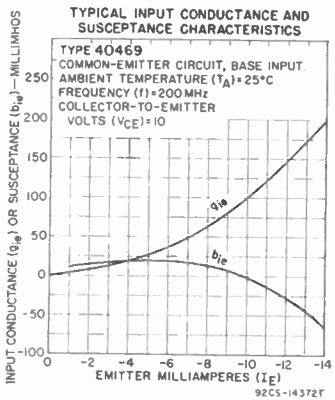
CHARACTERISTICS

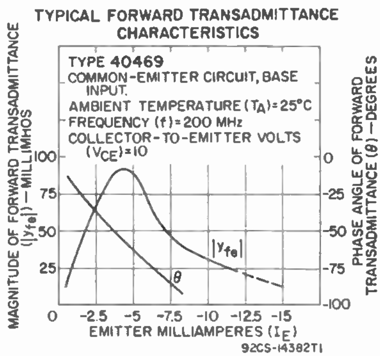
Collector-Cutoff Current:			
V_{CB} = 1 V, I_E = 0	I_{CBO}	0.02 max	µA
V_{CB} = 45 V, I_E = 0	I_{CBO}	1 max	µA

CHARACTERISTICS (cont'd)

Emitter-Cutoff Current (V_{EB} = 3 V, I_C = 0)	I_{EBO}	1 max	μA
Static Forward-Current Transfer Ratio (V_{CB} = 6 V, I_E = −1 mA)	h_{FE}	40 to 70	
Gain-Bandwidth Product (V_{CE} = 6 V, I_E = −2 mA, f = 100 MHz)	f_T	800	MHz
Collector-to-Base Feedback Capacitance (V_{CB} = 10 V, I_E = −3 mA, f = 200 MHz)	C_{cb}	0.19	pF
Input Resistance (V_{CE} = 10 V, I_E = −3 mA, f = 200 MHz)	R_{ie}	75	Ω
Output Resistance (V_{CE} = 10 V, I_E = −3 mA, f = 200 MHz)	R_{oe}	6	kΩ
Magnitude of Forward Transadmittance (V_{CB} = 10 V, I_E = −3 mA, f = 200 MHz)	$\|Y_{fe}\|$	75	mmhos
Noise Figure (V_{CE} = 10 V, I_E = −3 mA, R_S = 90 Ω, f = 200 MHz)	NF	3.3	dB
Maximum Available Amplifier Gain (V_{CE} = 10 V, I_E = −3 mA, f = 200 MHz)	MAG	28	dB
Maximum Usable Amplifier Gain, Unneutralized (V_{CE} = 10 V, I_E = −3 V, f = 200 MHz)	MUG	24.8	dB
Maximum Usable Amplifier Gain, Neutralized* (V_{CE} = 10 V, I_E = −3 mA, f = 200 MHz)	MUG	28	dB
Emitter Current for 30-db Gain Reduction (f = 200 MHz)		−9	mA

* Device is capable of achieving MAG.





TRANSISTOR 40470

Si n-p-n type used as 45-MHz if amplifier in television receivers. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). Terminals: 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. For maximum ratings, refer to type 40472.

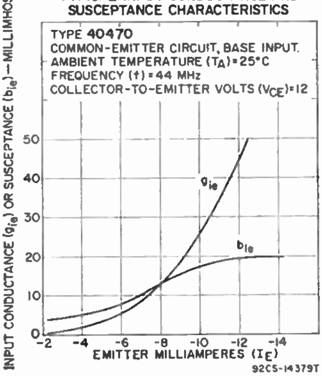
CHARACTERISTICS

Collector-Cutoff Current:			
V_{CB} = 1 V, I_E = 0	I_{CBO}	0.02 max	μA
V_{CB} = 45 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_{CB} = 6. V, I_E = −1 mA)	h_{FE}	40 to 170	
Gain Bandwidth Product (V_{CB} = 6 V, I_E = −2 mA, f = 100 MHz)	f_T	700	MHz
Collector-to-Base Feedback Capacitance (V_{CB} = 12 V, I_E = −4 mA, f = 44 MHz)	C_{cb}	0.18	pF
Input Resistance (V_{CE} = 12 V, I_E = −4 mA, f = 44 MHz)	R_{ie}	500	Ω

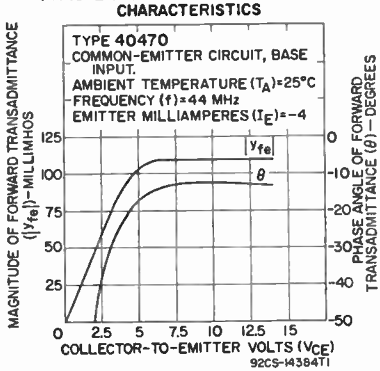
CHARACTERISTICS (cont'd)

Output Resistance (V_{CE} = 12 V, I_E = –4 mA, f = 44 MHz)	R_{oe}	25	kΩ
Magnitude of Forward Transadmittance (V_{CE} = 12 V, I_E = –4 mA, f = 44 MHz)	$\|Y_{fe}\|$	110	mmhos
Maximum Available Amplifier Gain (V_{CE} = 12 V, I_E = –4 mA, f = 44 MHz)	MAG	45.8	dB
Maximum Usable Amplifier Gain Per Stage, Unneutralized (V_{CE} = 12 V, I_E = –4 mA, f = 44 MHz):			
For 1 stage	MUG	29.3	dB
For 2 stages	MUG	27.1	dB
For 3 stages	MUG	25.3	dB
Maximum Usable Amplifier Gain Per Stage, Neutralized (V_{CE} = 12 V, I_E = –4 mA, f = 44 MHz):			
For 1 stage	MUG	34.2	dB
For 2 stages	MUG	32	dB
For 3 stages	MUG	30.2	dB
Emitter Current for 30-db Gain Reduction (f = 44 MHz)		–10	mA

TYPICAL INPUT CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



TYPICAL FORWARD TRANSADMITTANCE CHARACTERISTICS



40471 TRANSISTOR

Si n-p-n type used as 45-MHz if amplifier in television receivers. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). Terminals: 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. This type is identical with type 40470 except for the following item:

CHARACTERISTICS

Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = –1 mA)	h_{FE}	27 to 100

40472 TRANSISTOR

Si n-p-n type used as rf amplifier in television tuners covering channels 2 through 13. The terminals arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). Terminals: 1 - base, 2 - emitter, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

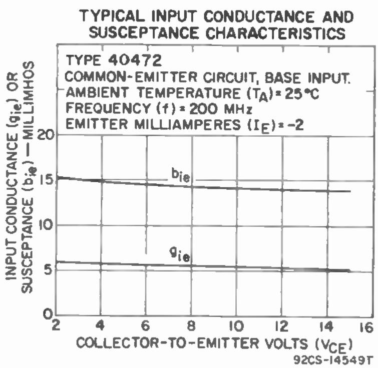
Collector-to-Base Voltage	V_{CBO}	45	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	50	mA

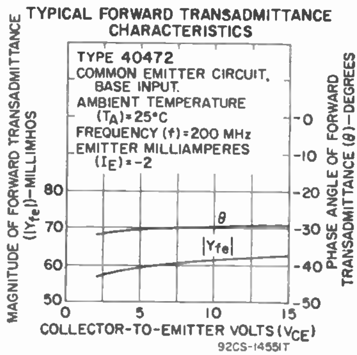
CHARACTERISTICS (cont'd)

Transistor Dissipation:			
T_A up to 25°C	P_T	180	mW
T_A above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating	T_A	—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} = 45 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 = —2 mA, f = 100 MHz)	f_T	900	MHz
Feedback Capacitance (V_{CE} = 10 V, I_E = —2 mA, f = 200 MHz)	C_{cb}	0.19	pF
Input Resistance (V_{CE} = 10 V, I_E = —2 mA, f = 200 MHz)	R_{ie}	180	Ω
Output Resistance (V_{CE} = 10 V, I_E = —2 mA, f = 200 MHz)	R_{oe}	5.5	kΩ
Magnitude of Forward Transadmittance (V_{CE} = 10 V, I_E = —2 mA, f = 200 MHz)	Y_{fe}	61	mmhos
Noise Figure (V_{CE} = 10 V, I_E = —2 mA, R_S = 90 Ω, f = 200 MHz)	NF	3.3	dB
Maximum Available Amplifier Gain (V_{CE} = 10 V, I_E = —2 mA, f = 200 MHz)	MAG	29.6	dB
Maximum Usable Amplifier Gain, Unneutralized V_{CE} = 10 V, I_E = —2 mA, f = 200 MHz)	MUG	21.8	dB
Maximum Usable Amplifier Gain, Neutralized (V_{CE} = 10 V, I_E = —2 mA, f = 200 MHz)	MUG	26.9	dB





TRANSISTOR 40473

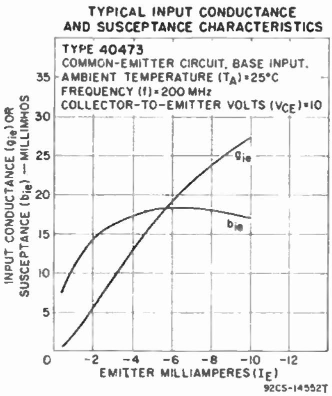
Si n-p-n type used as rf mixer in television tuners covering channels 2 through 13. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). Terminals: 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. For maximum ratings, refer to type 40472.

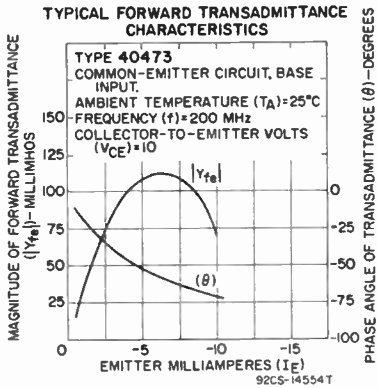
CHARACTERISTICS

Collector-Cutoff Current:			
V_{CB} = 1 V, I_E = 0	I_{CBO}	0.02 max	μA
V_{CB} = 45 V, I_E = 0	I_{CBO}	1 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}	40 to 275	
Gain-Bandwidth Product (V_{CE} = 6 V, I_E = −2 mA, f = 100 MHz)	f_T	900	MHz
Feedback Capacitance (V_{CE} = 12 V, I_E = −1.5 mA, f = 200 MHz)	C_{cb}	0.19	pF
Input Resistance (V_{CE} = 12 V, I_E = −1.5 mA, f = 44 MHz)	R_{ie}	270	Ω
Output Resistance (V_{CE} = 12 V, I_E = −1.5 mA, f = 44 MHz)	R_{oe}	4.6	kΩ
Maximum Available Conversion Gain (V_{CE} = 12 V, I_E = −1.5 mA, f = 200 to 44 MHz)	MAG_c	22.7	dB





40474 TRANSISTOR

Si **n-p-n** type used as rf oscillator in television tuners covering channels 2 through 13. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). **Terminals:** 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. For maximum ratings, refer to type 40472.

CHARACTERISTICS

Collector-Cutoff Current:			
V_{CB} = 1 V, I_E = 0	I_{CBO}	0.02 max	μA
V_{CB} = 45 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}	27 to 275	
Gain-Bandwidth Product (V_{CE} = 6 V, I_E = −2 mA, f = 100 MHz)	f_T	900	MHz

40475 TRANSISTOR

Si **n-p-n** type used as 45-MHz if amplifier in television receivers. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). **Terminals:** 1 - base, 2 - emitter, 3 - collector, 4 - connected to case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	45	V
Emitter-to-Base Voltage	V_{EBO}	3	V
Collector Current	I_C	50	mA

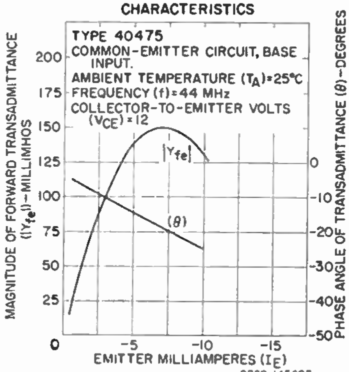
MAXIMUM RATINGS (cont'd)

Transistor Dissipation:			
T_A up to 25°C	P_T	180	mW
T_A above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating	T_A	−65 to 175	°C
Storage	T_{STG}	−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

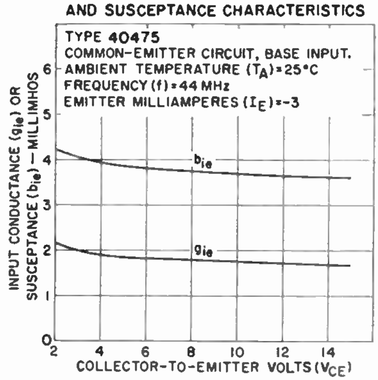
Collector-Cutoff Current:			
V_{CB} = 1 V, I_E = 0	I_{CBO}	0.02 max	μA
V_{CB} = 45 V, I_E = 0	I_{CBO}	1 max	μA
Emitter-Cutoff Current (V_{EB} = 3 V, I_C = 0)	I_{EBO}	1 max	μA
Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = 1 mA)	h_{FE}	40 to 170	
Gain-Bandwidth Product (V_{CE} = 6 V, I_E = −2 mA, f = 100 MHz)	f_T	800	MHz
Feedback Capacitance (V_{CE} = 12 V, I_E = −3 mA, f = 44 MHz)	C_{cb}	0.18	pF
Input Resistance (V_{CE} = 12 V, I_E = −3 mA, f = 44 MHz)	R_{ie}	575	Ω
Output Resistance (V_{CE} = 12 V, I_E = −3 mA, f = 44 MHz)	R_{oe}	25	kΩ
Magnitude of Forward Transadmittance (V_{CE} = 12 V, I_E = −3 mA, f = 44 MHz)	$\|Y_{fe}\|$	100	mmhos
Maximum Available Amplifier Gain (V_{CE} = 12 V, I_E = −3 mA, f = 44 MHz)	MAG	45.6	dB
Maximum Usable Amplifier Gain Per Stage, Unneutralized (V_{CE} = 12 V, I_E = −3 mA, f = 44 MHz):			
For 1 stage	MUG	28.5	dB
For 2 stages	MUG	26.2	dB
For 3 stages	MUG	24.8	dB
Maximum Usable Amplifier Gain Per Stage, Neutralized (V_{CE} = 12 V, I_E = −3 mA, f = 44 MHz):			
For 1 stage	MUG	33.5	dB
For 2 stages	MUG	31.3	dB
For 3 stages	MUG	29.5	dB

TYPICAL FORWARD TRANSADMITTANCE CHARACTERISTICS



92CS-14560T

TYPICAL INPUT CONDUCTANCE AND SUSCEPTANCE CHARACTERISTICS



92CS-14555T

TRANSISTOR 40476

Si n-p-n type used as 45-MHz if amplifier in television receivers. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). **Terminals:** 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. This type is identical with 40475 except for the following item:

CHARACTERISTICS

Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	27 to 100

40477 TRANSISTOR

Si n-p-n type used as 45-MHz if amplifier in television receivers. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). **Terminals:** 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. This type is identical with 40475 except for the following item:

CHARACTERISTICS

Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	27 to 275

40478 TRANSISTOR

Si n-p-n type used in rf - amplifier applications in conjunction with types 40479 (mixer), 40480 (rf oscillator), and 40481 and 40482 (if amplifiers) to make up a "front-end" and if complement for FM and AM/FM receivers. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). **Terminals:** 1 - base, 2 - emitter, 3 - collector, 4 - connected to case.

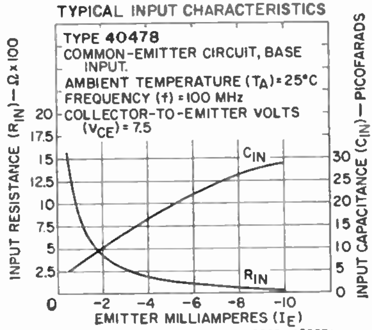
MAXIMUM RATINGS

Collector-to-Base Voltage:			
Emitter open	V_{CBO}	45	V
V_{EB} = −1 V	V_{CBV}	45	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 116	
Temperature Range:			
Operating	T_A	−65 to 175	°C
Storage	T_{STG}	−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

CHARACTERISTICS

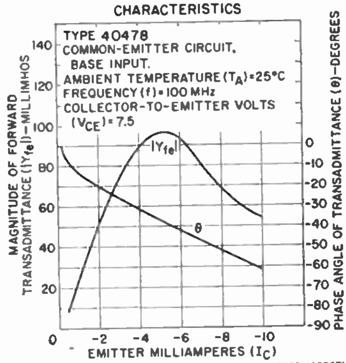
Collector-to-Base Breakdown Voltage:			
I_C = 0.001 mA	$V_{(BR)CBO}$	45 min	V
V_{EB} = −1 V	$V_{(BR)CBV}$	45 min	V
Collector-to-Emitter Breakdown Voltage (I_E = −0.5 mA, I_B = 0)	$V_{(BR)CEO}$	45 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.001 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V

TYPICAL INPUT CHARACTERISTICS



92CS-14032T1

TYPICAL FORWARD TRANSADMITTANCE CHARACTERISTICS



92CS-14036T1

CHARACTERISTICS (cont'd)

Collector-Cutoff Current (V_{CE} = 1 V, I_E = 0)	I_{CBO}	0.02 max	μA
Emitter-Cutoff Current (V_{CE} = 3 V, I_C = 0)	I_{EBO}	1 max	μA
Static Forward-Current Transfer Ratio (V_{CB} = 6 V, I_E = −1 mA)	h_{FB}	40 to 170	
Gain-Bandwidth Product (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	f_T	800	MHz
Feedback Capacitance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	C_{cb}	0.2	pF
Input Resistance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	R_{ie}	550	Ω
Output Resistance (V_{CE} = 7.5 V, I_E = 1.5 mA, f = 100 MHz)	R_{oe}	24	kΩ
Input Capacitance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	C_{ie}	8.5	pF
Output Capacitance (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	C_{oe}	1.4	pF
Magnitude of Forward Transadmittance* (V_{CB} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	$\|Y_{fe}\|$	38	mmhos
Noise Figure* (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	NF	2.5	dB
Maximum Available Amplifier Gain* (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	MAG	37	dB
Maximum Usable Gain*:			
Unneutralized—V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz	MUG	20	dB
Neutralized—V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz	MUG	25	dB

* This characteristic applies only to type 40478.

TRANSISTOR 40479

Si n-p-n type used in mixer applications in conjunction with types 40478 (rf amplifier), 40480 (rf oscillator), and 40481 and 40482 (if amplifiers) to make up a "front-end" and if complement for FM and AM/FM receivers. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). Terminals: 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. This type is identical with type 40478 except for the following item:

CHARACTERISTICS

Maximum Available Conversion Gain (V_{CE} = 7.5 V, I_E = −1.5 mA, f = 100 MHz)	MAG_c	35	dB

TRANSISTOR 40480

Si n-p-n type used in rf-oscillator applications in conjunction with types 40478 (rf amplifier), 40479 (mixer), and 40481 and 40482 (if amplifiers) to make up a "front-end" and if complement for FM and AM/FM receivers. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). Terminals: 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. For maximum ratings, refer to type 40478.

CHARACTERISTICS

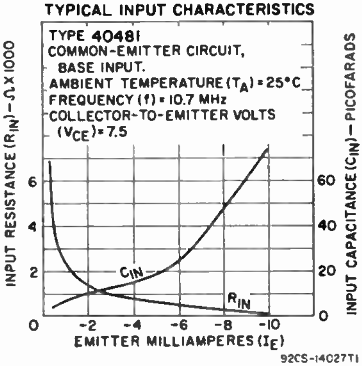
Collector-to-Base Breakdown Voltage:			
I_C = 0.001 mA, I_E = 0	$V_{(BR)CBO}$	45 min	V
V_{EB} = −1 V	$V_{(BR)CBV}$	45 min	V
Collector-to-Emitter Breakdown Voltage (I_E = −0.5 mA, I_B = 0)	$V_{(BR)CEO}$	45 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.001 mA, I_C = 0)	$V_{(BR)EBO}$	3 min	V
Collector-Cutoff Current (V_{CE} = 1 V, I_E = 0)	I_{CBO}	0.02 max	μA
Emitter-Cutoff Current (V_{CE} = 3 V, I_C = 0)	I_{EBO}	1 max	μA
Static Forward-Current Transfer Ratio (V_{CB} = 6 V, I_E = −1 mA)	h_{FB}	27 to 275	

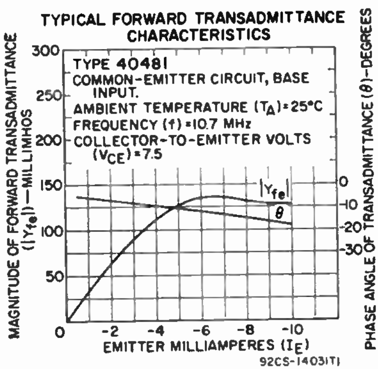
40481 TRANSISTOR

Si **n-p-n** type used in if-amplifier applications in conjunction with types 40478 (rf amplifier), 40479 mixer, 40480 (rf oscillator), and 40482 (if amplifier) to make up a "front-end" and if complement for FM and AM/FM receivers. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC TO-104, Outline No.27 (4-lead). **Terminals:** 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. For maximum ratings, refer to type 40478.

CHARACTERISTICS

Collector-to-Base Breakdown Voltage:			
I_C = 0.001 mA, I_E = 0	$V_{(BR)CBO}$	45 min	V
V_{EB} = −1 V	$V_{(BR)CBV}$	45 min	V
Collector-to-Emitter Breakdown Voltage (I_E = −0.5 mA, I_B = 0)	$V_{(BR)CEO}$	45 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_{CE} = 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 275	
Gain-Bandwidth Product (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	f_T	860	MHz
Feedback Capacitance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	C_{cb}	0.2	pF
Input Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	R_{ie}	1500	Ω
Output Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	R_{oe}	85	kΩ
Input Capacitance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	C_{ie}	11	pF
Output Capacitance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	C_{oe}	1.35	pF
Magnitude of Forward Transadmittance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	$\|Y_{fe}\|$	64	mmhos
Maximum Available Amplifier Gain (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	MAG	51	dB
Maximum Usable Gain Per Stage, Unneutralized (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz):			
For 1 stage	MUG	32	dB
For 2 stages	MUG	28	dB
For 3 stages	MUG	27.5	dB
For 4 stages	MUG	26	dB
Maximum Usable Gain Per Stage, Neutralized (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz):			
For 1 stage	MUG	37	dB
For 2 stages	MUG	35	dB
For 3 stages	MUG	33	dB
For 4 stages	MUG	32	dB





TRANSISTOR 40482

Si n-p-n type used in if-amplifier applications in conjunction with types 40478 (rf amplifier), 40479 (mixer), 40480 (rf oscillator), and 40481 (if amplifier) to make up a "front-end" and if complement for FM and AM/FM receivers. The terminal arrangement permits shielding between input and output terminals for superior high-frequency performance and greater circuit stability, particularly on printed-circuit boards. JEDEC-TO-104, Outline No.27 (4-lead). **Terminals:** 1 - base, 2 - emitter, 3 - collector, 4 - connected to case. This type is identical to type 40481 except for the following items:

CHARACTERISTICS

Static Forward-Current Transfer Ratio (V_{CE} = 6 V, I_E = −1 mA)	h_{FE}	27 to 90	
Input Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	R_{ie}	1300	Ω
Output Resistance (V_{CE} = 7.5 V, I_E = −2 mA, f = 10.7 MHz)	R_{oe}	100	kΩ

TRANSISTOR 40487

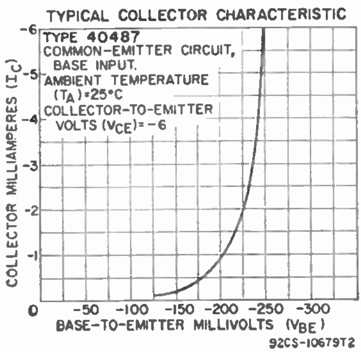
Ge p-n-p **drift-field** type used in mixer applications in conjunction with types 40488 (oscillator), 40489 (if amplifier), 40490 (af amplifier), 40491 (power amplifier), and 40495 (line rectifier) to provide a complement for AM broadcast-band radio receivers. JEDEC TO-1, **Outline** No.1. **Terminals:** 1 - emitter, 2 - base, 3 - collector.

MAXIMUM RATINGS

Collector-to-Base Voltage:			
Emitter open	V_{CBO}	−50	V
V_{EB} = −0.5 V, I_C = −50 μA	V_{CBV}	−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 up to 25°C	P_T	80	mW
T_A above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating	T_A	−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 = −0.05 mA, I_E = 0	$V_{(BR)CBO}$	−50 min	V
V_{EB} = −0.5 V, I_C = 0.05 mA	$V_{(BR)CBV}$	−34• min	V



CHARACTERISTICS (cont'd)

Emitter-to-Base Breakdown Voltage (I_E = 0.016 mA, I_C = 0)	$V_{(BR)EBO}$	−1.5 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}	−16 max	µA
Small-Signal Forward-Current Transfer Ratio (V_{CE} = −6 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	40 to 275	
Gain-Bandwidth Product (V_{CE} = −12 V, I_C = −1 mA)	f_T	40	MHz
Intrinsic Base-Spreading Resistance (V_{CB} = −12 V, I_C = −1 mA, f = 100 MHz)	$r_{bb'}$	25	Ω
Feedback Capacitance (V_{CB} = −12 V, I_E = 0)	C_{cb}	3.7 max	pF
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	390 max	°C/W

• This value does not apply to type 40488.

40488 TRANSISTOR

Ge p-n-p drift-field type used in oscillator applications in conjunction with types 40487 (mixer), 40489 (if amplifier), 40490 (af amplifier), 40491 (power amplifier), and 40495 (line rectifier) to provide a complement for AM broadcast-band radio receivers. JEDEC TO-1, **Outline** No.1. **Terminals:** 1 - emitter, 2 - base, 3 - collector. This type is identical with type 40487 except for the following items:

MAXIMUM RATINGS

Collector-to-Base Voltage:			
Emitter open	V_{CBO}	−12	V
V_{EB} = −0.5 V, I_C = −50 µA	V_{CBV}	−12	V
Emitter-to-Base Voltage	V_{EBO}	−0.5	V

CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = −0.05 mA, I_E = 0)	$V_{(BR)CBO}$	−12 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.016 mA, I_C = 0)	$V_{(BR)EBO}$	−0.5 min	V
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 kHz)	h_{fe}	27 to 275	
Gain-Bandwidth Product (V_{CE} = −12 V, I_C = −1 mA)	f_T	30	MHz

40489 TRANSISTOR

Ge p-n-p drift-field type used in if-amplifier applications in conjunction with types 40487 (mixer), 40488 (oscillator), 40490 (af amplifier), 40491 (power amplifier), and 40495 (line rectifier) to provide a complement for AM broadcast-band radio receivers. JEDEC TO-1, **Outline** No.1. **Terminals:** 1 - emitter, 2 - base, 3 - collector. This type is identical with type 40487 except for the following items:

MAXIMUM RATINGS

Emitter-to-Base Voltage	V_{EBO}	−0.5	V

CHARACTERISTICS

Emitter-to-Base Breakdown Voltage (I_E = 0.016 mA, I_C = 0)	$V_{(BR)EBO}$	−0.5 min	V
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 kHz)	h_{fe}	40 to 350	
Gain-Bandwidth Product (V_{CE} = −12 V, I_C = −1 mA)	f_T	30	MHz
Feedback Capacitance (V_{CB} = −12 V, I_E = 0)	C_{cb}	3.4 max	pF

TRANSISTOR 40490

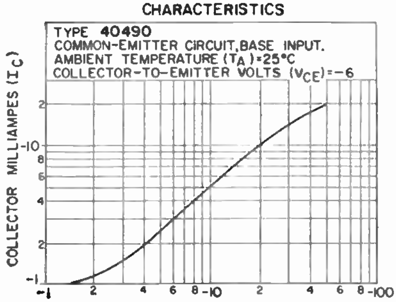
Ge p-n-p alloy-junction type used in af-amplifier and driver stages in conjunction with types 40487 (mixer), 40488 (oscillator), 40489 (if amplifier), 40491 (power amplifier), and 40495 (line rectifier) to provide a complement for AM broadcast-band radio receivers. JEDEC TO-1, Outline No.1. Terminals: 1 - emitter, 2 - base, 3 - collector.

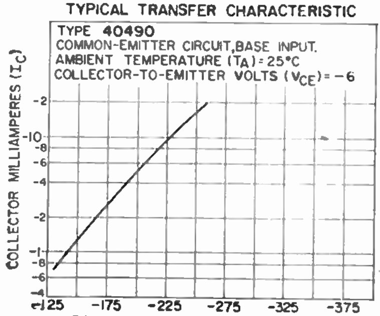
MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	−20	V
Collector-to-Emitter Voltage (R_{BE} ≤ 10000 Ω)	V_{CER}	−18	V
Emitter-to-Base Voltage	V_{EBO}	−2.5	V
Collector Current	I_C	−20	mA
Emitter Current	I_E	20	mA
Transistor Dissipation:			
T_A up to 55°C	P_T	0.12	W
T_A above 55°C	P_T	See curve page 116	
Temperature Range:			
Operating	T_A	−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 (R_{BE} = 10 kΩ, I_C = −1 mA)	$V_{(BR)CER}$	−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 (V_{CE} = −6 V, I_C = −1 mA, f = 1 kHz)	h_{fe}	170 to 425	
Small-Signal Forward-Current Transfer Ratio Cutoff Frequency (V_{CE} = −6 V, I_C = −1 mA)	f_{hfb}	10	MHz
Intrinsic Base-Spreading Resistance (V_{CE} = −6 V, I_C = −1 mA, f = 100 MHz)	$r_{bb'}$	200	Ω
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	390 max	°C/W





POWER TRANSISTOR 40491

Si n-p-n type used in class A af output-amplifier service in conjunction with types 40487 (mixer), 40488 (oscillator) 40489 (if amplifier), 40490 (af amplifier), and 40495 (line rectifier) to provide a complement for AM broadcast-band radio receivers. JEDEC TO-66 (with heat radiator), Outline No.22B. Terminals: 1 - base, 2 - emitter, Mounting Flange - collector and case.

MAXIMUM RATINGS

Collector-to-Base Voltage	V_{CBO}	300	V
Collector-to-Emitter Voltage (I_C = 5 mA, I_B = 0)	V_{CEO}	300	V

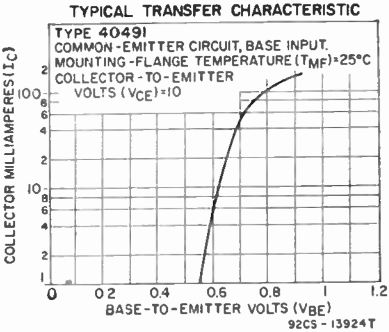
MAXIMUM RATINGS (cont'd)

Emitter-to-Base Voltage	V_{EBO}	2	V
Collector Current	I_C	150	mA
Emitter Current	I_E	−150	mA
Transistor Dissipation:			
T_A up to 55°C	P_T	3.8	W
T_A above 55°C	P_T	See curve page 116	
Temperature Range:			
Operating	T_A	−65 to 150	°C
Storage	T_{STG}	−65 to 150	°C
Lead-Soldering Temperature (10 s max)	T_L	255	°C

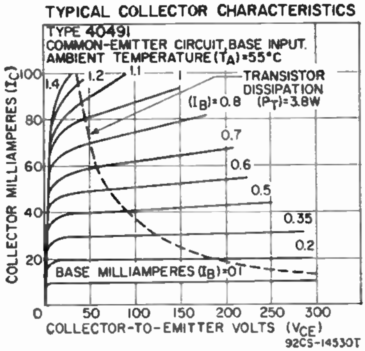
CHARACTERISTICS

Collector-to-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	300 min	V
Collector-to-Emitter Breakdown Voltage (I_C = 5 mA, I_B = 0)	$V_{(BR)CEO}$	300 min	V
Emitter-to-Base Breakdown Voltage (I_E = 0.1 mA, I_C = 0)	$V_{(BR)EBO}$	2 min	V
Collector-Cutoff Current:			
V_{CB} = 300 V, I_E = 0	I_{CBO}	100 max	µA
V_{CE} = 300 V, I_B = 0	I_{CEO}	5 max	mA
Static Forward-Current Transfer Ratio (V_{CE} = 10 V, I_C = 50 mA)	h_{FE}	30 to 250	
Gain-Bandwidth Product (V_{CE} = 50 V, I_C = 20 mA)	f_T	25	MHz
Intrinsic-Base-Spreading Resistance (V_{CE} = 50 V, I_C = 20 mA, f = 100 MHz)	$r_{bb'}$	20	Ω
Feedback Capacitance (V_{CB} = 50 V, I_E = 0)	C_{cb}	5	pF
Thermal Resistance, Junction-to-Mounting Flange	θ_{J-FM}	8 typ; 10 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	25 max	°C/W

TYPICAL TRANSFER CHARACTERISTIC



TYPICAL COLLECTOR CHARACTERISTICS



40500 TRANSISTOR

Si n-p-n epitaxial planar type used in af driver applications. JEDEC TO-104, Outline No.26 (3-lead). Terminals: 1 - emitter, 2 - base, 3 - collector and case.

MAXIMUM RATINGS

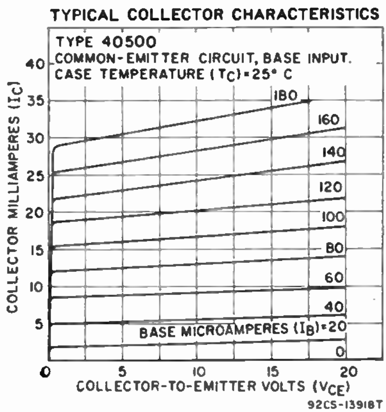
Collector-to-Emitter Voltage			
V_{BE} = −1 V	V_{CEV}	30	V
Base open	V_{CEO}	30	V
Collector-to-Base Voltage	V_{CBO}	7.5	V
Emitter-to-Base Voltage	V_{EBO}	7.5	V
Collector Current	I_C	200	mA
Emitter Current	I_E	−200	mA
Base Current	I_B	25	mA
Transistor Dissipation:			
T_C up to 75°C	P_T	2	W
T_C above 75°C	P_T	See curve page 116	
T_A up to 25°C	P_T	0.5	W
T_A above 25°C	P_T	See curve page 116	

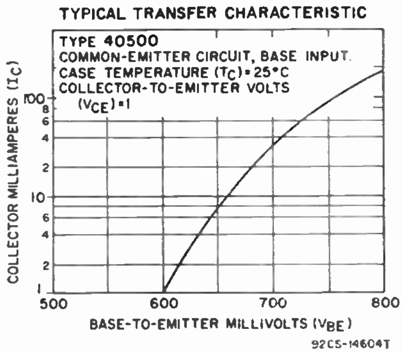
MAXIMUM RATINGS (cont'd)

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 (At case temperature = 25°C)

Collector-to-Emitter Breakdown Voltage:			
I_C = 10 mA, I_B = 0	$V_{(BR)CEO}$	30 min	V
V_{BE} = −1 V, I_C = 0.01 mA	$V_{(BR)CEV}$	20 min	V
Collector-Base Breakdown Voltage (I_C = 0.1 mA, I_E = 0)	$V_{(BR)CBO}$	30 min	V
Emitter-to-Base Breakdown Voltage (I_E = −0.05 mA, I_C = 0)	$V_{(BR)EBO}$	7.5 min	V
Collector-to-Emitter Saturation Voltage (I_C = 200 mA, I_B = 10 mA)	V_{CE}(sat)	0.15 typ; 0.25 max	V
Base-to-Emitter Saturation Voltage (I_C = 200 mA, I_B = 10 mA)	V_{BE}(sat)	0.8 typ; 1.3 max	V
Collector-Cutoff Current:			
V_{CB} = 25 V, I_E = 0	I_{CBO}	100 max	nA
V_{CB} = 25 V, I_E = 0, T_C = 85°C	I_{CBO}	5 max	μA
V_{CE} = 25 V, V_{BE} = −1 V	I_{CEV}	10 max	μA
Emitter-Cutoff Current (V_{BE} = −2.5 V, I_C = 0)	I_{EBO}	100 max	nA
Static Forward Current-Transfer Ratio			
V_{CE} = 6 V, I_C = 0.5 mA	h_{FE}	50 min; 75 typ	
V_{CE} = 10 V, I_C = 10 mA	h_{FE}	100 to 400	
V_{CE} = 1 V, I_C = 100 mA	h_{FE}	70 min; 175 typ	
Small-Signal Forward Current-Transfer Ratio (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{fe}	75 min; 200 typ	
Small-Signal Input Impedance (V_{CE} = 12 V, I_C = 10 mA, f = 1 kHz)	h_{ie}	600	Ω
Gain-Bandwidth Product (V_{CE} = 6 V, I_C = 1 mA, f = 100 MHz)	f_T	50 min; 80 typ	MHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	50 max	°C/W
Thermal Resistance, Junction-to-Ambient	θ_{J-A}	300 max	°C/W





TRANSISTOR 40501

Si n-p-n epitaxial planar type used in af driver applications. JEDEC TO-104, Outline No.27 (3-lead with heat sink). **Terminals:** 1 - emitter, 2 - base, 3 - collector and case (3-lead with heat sink). This type is identical with type 40500 except for the following items:

MAXIMUM RATINGS

Transistor Dissipation:			
T_A up to 25°C	P_T	1	W

CHARACTERISTICS (At case temperature = 25°C)

Thermal Resistance, Junction-to-Ambient	θ_{J-A}	150 max	°C/W

40513 POWER TRANSISTOR

Si **n-p-n** type featuring a base comprised of a homogeneous-resistivity silicon material and molded silicone plastic package having horizontal leads for mounting on printed-circuit boards. It is used in a wide variety of high-power switching and amplifier applications such as series and shunt regulators, drivers, and output stages for high-fidelity amplifiers. Outline No.49. **Terminals:** 1 - base, 2 - emitter, mounting flange, and collector. This type is electrically identical with type 40514.

40514 POWER TRANSISTOR

Si **n-p-n** type featuring a base comprised of a homogeneous-resistivity silicon material and molded silicone plastic package with vertical leads. This type fits a standard TO-3 socket. It is used in a wide variety of high-power switching and amplifier applications such as series and shunt regulators, drivers, and output stages for high-fidelity amplifiers. **Outline** No.48. See **Mounting Hardware** for desired mounting arrangement. **Terminals:** 1 - base, 2 - emitter, mounting flange, and collector. For collector-characteristics and transfer-characteristics curves, refer to type 2N5034.

MAXIMUM RATINGS

Collector-to-Emitter Sustaining Voltage (R_{BE} = 100 Ω)	V_{CER}(sus)	45	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	6	A
Peak Collector Current	i_C	12	A
Base Current	I_B	6	A
Transistor Dissipation:			
T_C up to 25°C	P_T	83	W
T_C above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating (Junction)	T_J(opr)	−65 to 150	°C
Storage	T_{STG}	−65 to 150	°C
Lead-Soldering Temperature (10 s max)	T_L	235	°C

CHARACTERISTICS (At case temperature = 25°C)

Emitter-to-Base Breakdown Voltage (I_E = 5 mA)	$V_{(BR)EBO}$	5 min	V
Collector-to-Emitter Sustaining Voltage (R_{BE} = 100 Ω, I_C = 0.2 A, tp = 300 μs, df = 1.8%)	V_{CER}(sus)	45 min	V
Base-to-Emitter Voltage (V_{BE} = 4 V, I_C = 2.5 A, tp = 300 μs, df = 1.8%)	V_{BE}	1.7 max	V
Collector-to-Emitter-to-Saturation Voltage (I_C = 2.5 A, t_p = 300 μs, df = 1.8%, I_B = 0.25 A)	V_{CE}(sat)	1 max	V
Collector-Cutoff Current:			
V_{CE} = 20 V, R_{BE} = 100 Ω	I_{CER}	2.5 max	mA
V_{CE} = 20 V, R_{BE} = 100 Ω, T_C = 150°C	I_{CER}	5 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 = 2.5 A, tp = 300 μs, df = 1.8%)	h_{FE}(pulsed)	20 to 70	
Gain-Bandwidth Product (V_{CE} = 4 V, I_C = 0.5 A)	f_T	0.8 to 2.8	MHz
Thermal Resistance, Junction-to-Case	θ_{J-C}	1.5 max	°C/W

40517 TRANSISTOR

Si **n-p-n double-diffused epitaxial** planar type used for low-noise amplifier, mixer, and oscillator applications. This type is for use in military applications. It is similar to type 2N3839. JEDEC TO-72, **Outline** No. 23. **Terminals:** 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

UHF TRANSISTOR 40518

Si n-p-n double-diffused epitaxial planar type used for low-noise amplifier, mixer, and oscillator applications. This type is specially preconditioned and tested for high-reliability aerospace and military applications. It is a high-reliability version of type 2N3839. JEDEC TO-72, Outline No. 23. Terminals: 1 - emitter, 2 - base, 3 - collector, 4 - connected to case.

RF TRANSISTOR 40519

Si n-p-n epitaxial planar type used for class C rf-amplifier, driver, and frequency-multiplier service 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:			
R_{BE} = 0	V_{CES}	40	V
Base open	V_{CEO}	16	V
Emitter-to-Base Voltage	V_{EBO}	5	V
Collector Current	I_C	500	mA
Transistor Dissipation:			
T_C up to 25°C	P_T	1	W
T_C above 25°C	P_T	See curve page 116	
T_A up to 25°C	P_T	0.3	W
T_A above 25°C	P_T	See curve page 116	
Temperature Range:			
Operating	T(opr)	−65 to 200	°C
Storage	T_{STG}	−65 to 175	°C
Lead-Soldering Temperature (10 s max)	T_L	265	°C

CHARACTERISTICS

Collector-to-Emitter Breakdown Voltage:			
I_C = 10 mA, I_B = 0, tp = 100 μs, df ≤ 0.02	$V_{(BR)CEO}$	16 min	V
I_C = 5 mA, V_{BE} = 0	$V_{(BR)CES}$	40 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, V_{BE} = 0, I_E = 0)	I_{CBO}	25 max	nA
Static Forward-Current Transfer Ratio (I_C = 50 mA, V_{CE} = 1 V)	h_{FE}	20 min	
Magnitude of Small-Signal Forward-Current Transfer Ratio (I_C = 50 mA, V_{CE} = 1 V, f = 100 MHz)	$\|h_{fe}\|$	3 min	
Output Capacitance (V_{CB} = 5 V, I_E = 0, f = 0.1 to 1 MHz)	C_{obo}	3.5 max	pF
Power Output, Frequency Doubler (P_{IE} = 15 mW, f(in) = 86 MHz, f(out) = 172 MHz)	P_{oe}	70 min	mW
Efficiency, Frequency Doubler (f(in) = 86 MHz, f(out) = 172 MHz)	η	20 min	%

LIST OF DISCONTINUED TRANSISTORS

(Shown for reference only; see page 117 for symbol identification.)

RCA Type	Material	Outline	MAXIMUM RATINGS V_{CB} (volts)	V_{EB} (volts)	I_C (amperes)	P_T (watts)	CHARACTERISTICS Min. h_{FE}	I_{CB} (μA)	Maximum Operating Temperature (°C)	Can be replaced by RCA type
2N105	Ge	*	—25	—	—0.015	0.035	55	—5	55	2N408
2N173	Ge	11	—60	—40	—15	150	35	—100	100	—
2N174	Ge	11	—80	—60	—15	150	25	—100	100	—
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
2N277	Ge	11	—40	—20	—15	150	35	—4000	100	—
2N278	Ge	11	—50	—30	—15	150	35	—15000	100	—
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
2N441	Ge	11	—40	—20	—15	150	20	—4000	100	—
2N442	Ge	11	—50	—30	—15	150	20	—4000	100	—
2N443	Ge	11	—60	—40	—15	150	20	—4000	100	—
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	—

* 1 - emitter, 2 - base, 3 - collector.

LIST OF DISCONTINUED TRANSISTORS (cont'd)

RCA Type	Material	Outline	MAXIMUM RATINGS V_{CB} (volts)	V_{EB} (volts)	I_C (amperes)	P_T (watts)	CHARACTERISTICS Min. h_{FE}	I_{CB} (μA)	Maximum Operating Temperature (°C)	Can be replaced by RCA type
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	—
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	—
2N1099	Ge	11	—80	—40	—15	150	35	—4000	100	—
2N1100	Ge	11	—100	—80	—15	150	25	—4000	100	—
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	—
2N1358	Ge	11	—80	—60	—15	150	25	—200	100	—
2N1384	Ge	11	—30	—1	—0.5	0.24	20	—8	85	—
2N1412	Ge	11	—100	—80	—15	150	25	—4000	100	—
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

LIST OF DISCONTINUED TRANSISTORS (cont'd)

RCA Type	Material	Outline	MAXIMUM RATINGS V_{CB} (volts)	V_{EB} (volts)	I_C (amperes)	P_T (watts)	CHARACTERISTICS Min. h_{FE}	I_{CB} (μA)	Maximum Operating Temperature (°C)	Can be replaced by RCA type
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
2N1708	Si	9	25	3	0.2	0.3	20	0.025	175	—
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	—
2N3230	Si	25	80	10	7	25	1000	—	200	—
2N3231	Si	25	100	10	7	25	1000	—	200	—
2N3241	Si	26	30	5	0.1	2	50	0.1	175	2N3241A
2N3242	Si	26	30	5	0.2	2	75	0.01	175	2N3242A
2N3435	Si	3	80	4	0.25	1	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	—
40255	Si	3	450	7	1	10	30	—	200	—
40256	Si	3	300	7	1	10	30	—	200	—
40264	Si	28	300	3	0.1	4	30	100	150	—
40269	Ge	3	—25	—12	0.1	0.15	50	—5	85	—
40350	Si	26	35	—	0.025	0.18	40	1	175	—
40351	Si	26	35	—	0.025	0.18	40	1	175	—
40352	Si	26	35	—	0.025	0.18	27	1	175	—

RCA Type	Material	Outline	MAXIMUM RATINGS I_D (mA)	V_{DS} (volts)	P_T (watts)	CHARACTERISTICS Y_{fs} (μmhos	I_{DS}(off) (pA)	r_{DS}(on) (ohms)	Maximum Operating Temperature (°C)	Can be replaced by RCA type
3N98	Si	23	15	32	0.15	1500	50	900	85	—
3N99	Si	23	15	32	0.15	2000	50	800	85	—

Thyristors

THE term **thyristor** is the generic name for semiconductor devices that have characteristics similar to those of thyratron tubes. Basically, this group includes bistable semiconductor devices that have three or more junctions (i.e., four or more semiconductor layers) and that can be switched between conducting states (from OFF to ON or from ON to OFF) within at least one quadrant of the principal voltage-current characteristic. There are several different types of thyristors, which differ primarily in the number of electrode terminals and in their operating characteristics in the third quadrant of the voltage-current characteristic, as shown in Table I. Reverse-blocking triode thyristors, commonly called **silicon controlled rectifiers** (SCR's), and bidirectional triode thyristors, usually referred to as **triacs**, are the most popular types. The discussions in this section deal primarily with these two thyristor devices.

Table I—Different Types of Thyristors

No. of Terminals	Third-Quadrant Operation		
	Blocking	Conducting	Switching
2	Reverse-blocking diode thyristor	Reverse-conducting diode thyristor	Bidirectional diode thyristor
3	Reverse-blocking triode thyristor	Reverse-conducting triode thyristor	Bidirectional triode thyristor

VOLTAGE-CURRENT CHARACTERISTIC

A silicon controlled rectifier (SCR) is basically a four-layer p-n-p-n device that has three electrodes (a cathode, an anode, and a control electrode called the gate). Fig. 158 shows the junction diagram, principal voltage-current characteristic, and schematic symbol for an SCR. A triac also has three electrodes (main terminal No. 1, main terminal No. 2, and gate) and may be considered as

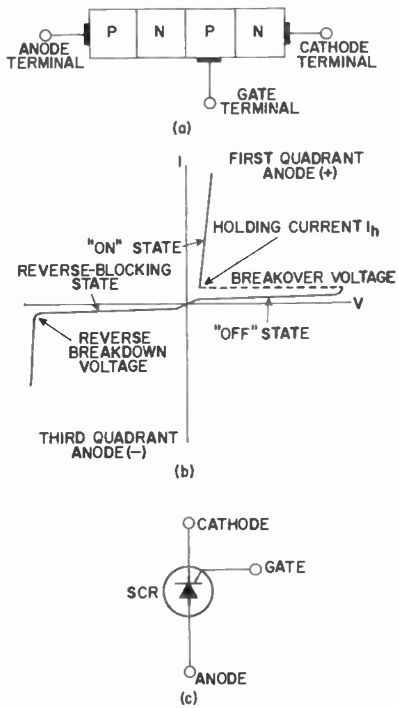


Figure 158. (a) Junction diagram, (b) principal voltage-current characteristic, and (c) schematic symbol for an SCR thyristor.

two parallel p-n-p-n structures oriented in opposite directions to provide symmetrical bidirectional electrical characteristics. Fig. 159 shows the junction diagram, voltage-current characteristic, and schematic symbol for a triac.

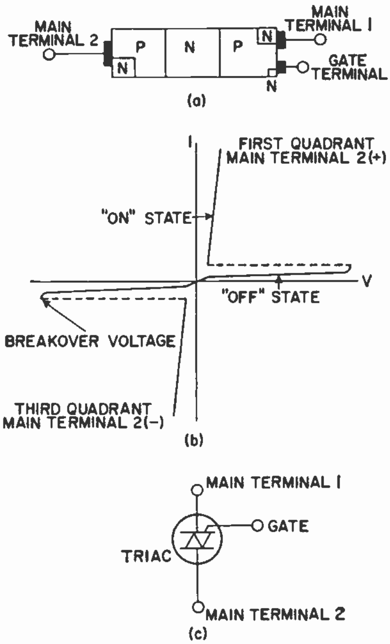


Figure 159. (a) Junction diagram, (b) principal voltage-current characteristic, and (c) schematic symbol for a triac thyristor.

Fig. 158b shows that under reverse-bias conditions (anode negative with respect to cathode) the SCR exhibits a very high internal impedance, and only a slight amount of reverse current, called the **reverse blocking current**, flows through the p-n-p-n structure. This current is very small until the reverse voltage exceeds the reverse breakdown voltage; beyond this point, however, the reverse current increases rapidly. The value of the reverse breakdown voltage differs for individual SCR types.

During forward-bias operation (anode positive with respect to cathode), the p-n-p-n structure of the SCR is electrically bistable and may exhibit either a very high impedance (forward-blocking or OFF state) or a very low impedance (forward-conducting or ON state). In the forward-blocking state, a small forward current, called the forward OFF-state current, flows through the SCR. The magnitude of this current is approximately the same as that of the reverse-blocking current that flows under reverse-bias conditions. As the forward bias is increased, a voltage point is reached at which the forward current increases rapidly, and the SCR switches to the ON state. This value of voltage is called the **forward breakover voltage**.

When the forward voltage exceeds the breakover value, the voltage drop across the SCR abruptly decreases to a very low value, referred to as the forward ON-state voltage. When an SCR is in the ON state, the forward current is limited primarily by the impedance of the external circuit. Increases in forward current are accompanied by only slight increases in forward voltage when the SCR is in the state of high forward conduction.

As shown in Fig. 159b, a triac exhibits the forward-blocking, forward-conducting voltage-current characteristic of a p-n-p-n structure for either direction of applied voltage. This bidirectional switching capability results because, as mentioned previously, a triac consists essentially of two p-n-p-n devices of opposite orientation built into the same crystal. The device, therefore, operates basically as two SCR's connected in parallel, but with the anode and cathode of one SCR connected to the cathode and anode, respectively, of the other SCR. As a result, the operating characteristics of the triac in the first and third quadrants of the voltage-current characteristics are the same, except for the direction of current flow and applied voltage. The triac characteristics in these quadrants are essentially identical to those of an SCR operated in the first quadrant. For the triac, however, the high-impedance state in the third quadrant is referred to as the OFF state rather than as the reverse-blocking state. Because of the symmetrical construction of the triac, the terms forward and reverse are not used in reference to this device.

Thyristors are ideal for switching applications. When the working voltage of a thyristor is below the breakover point, the current through the device is extremely small and the thyristor is effectively an open switch. When the voltage across the main terminals increases to a value exceeding the breakover point, the thyristor switches to its high-conduction state and is effectively a closed switch. The thyristor remains in the ON state until the current through the main terminals drops below a value which is called the **holding current**. When the source voltage of the main-terminal circuit cannot support a current equal to the holding current, the thyristor reverts back to the high-impedance OFF state.

The breakover voltage of a thyristor can be varied, or controlled, by injection of a signal at the gate, as indicated by the family of curves shown in Fig. 160. Although this family of curves is shown in the first quadrant typical of SCR operation, a similar set of curves can also be drawn for the third quadrant to represent triac operation. When the gate current is zero, the principal voltage must reach the breakover value $V_{(BO)}$ 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

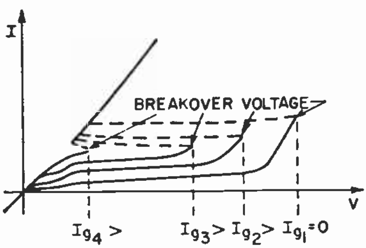


Figure 160. Curves showing breakover characteristics of a thyristor for different values of gate current.

of a rectifier. In normal operation, thyristors are operated with critical values well below the breakover voltage and are made to switch ON by gate signals of sufficient amplitude to assure that the device is switched to the ON state at the instant desired.

After the thyristor is triggered by the gate signal, the current through the device is independent of gate voltage or gate current. The thyristor remains in the ON state until the principal current is reduced to a level below that required to sustain conduction.

CONSTRUCTION

Construction details for typical RCA thyristors are shown in Figs. 161 through 165. Fig. 161 shows details for the 2-lead TO-5 package.

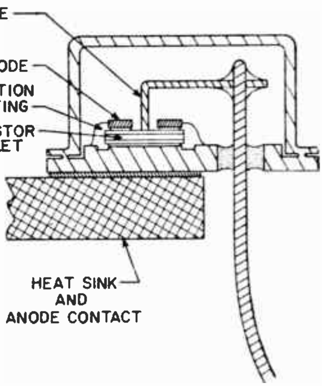


Figure 161. Cross-section of RCA two-lead TO-5 thyristor package.

This compact package is designed for applications in which mounting space is limited and can be attached to a wide variety of heat sinks with sizes and shapes to fit the available space. A typical heat-sink arrangement for an insulating mounting of this package is shown in Fig. 162. (Various types of thyristor heat-sink arrangements are described in RCA Publication SCR-501, "Heat Sink Guidance for RCA Thyristors Using TO-5 and Modified TO-5 Packages.") This package is used at current levels up to 7 amperes.

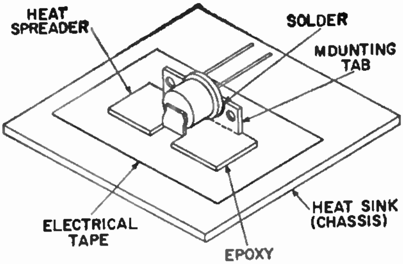


Figure 162. Typical heat-sink isolation technique for a chassis-mounted two-lead TO-5 thyristor.

In higher-current applications the TO-66, TO-3, and press-fit and stud-mounted TO-48 packages are used. Internal construction details of the press-fit package are shown in Fig. 163.

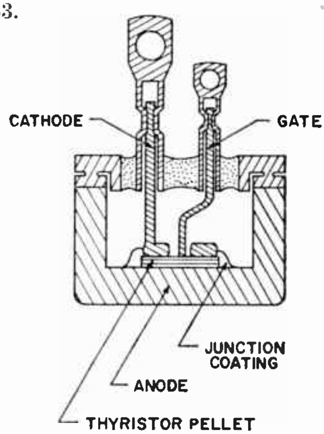


Figure 163. Cross-section of RCA press-fit thyristor package.

Construction details of a typical SCR pellet are shown in Fig. 164. The shorted-emitter construction used in RCA SCR's can be recognized by the metallic cathode electrode in direct contact with the p-type base layer around the periphery of the pellet. The gate, at the center of the pellet, also makes direct metallic contact to the p-type base so that the portion of this layer under the n-type emitter acts as an ohmic path for current flow between gate and cathode. Because this ohmic path is in parallel with the n-type emitter junction, current preferentially takes the ohmic path until the IR drop in this path reaches the junction threshold voltage of about 0.8 volt. When the gate voltage exceeds this value, the junction current increases rapidly, and injection of electrons by the n-type emitter reaches a level high enough to turn on the device.

In addition to providing a precisely controlled gate current, the shorted-emitter construction also improves the high-temperature and dv/dt (maximum allowable rate of rise of OFF-state voltage) capabilities of the device.

The center-gate construction of the SCR pellet provides fast turn-on and high di/dt capabilities. In an SCR, conduction is initiated in the cathode region immediately adjacent to the gate contact and must then propagate to the more remote regions of the cathode. Switching losses are influenced by the rate of propagation of conduction and the distance conduction must propagate from the gate. With a central gate, all regions of the cathode are in close proximity to the initially conducting region so that propagation distance is significantly decreased; as a result, switching losses are minimized.

Construction of a typical RCA triac pellet is shown in Fig. 165. In

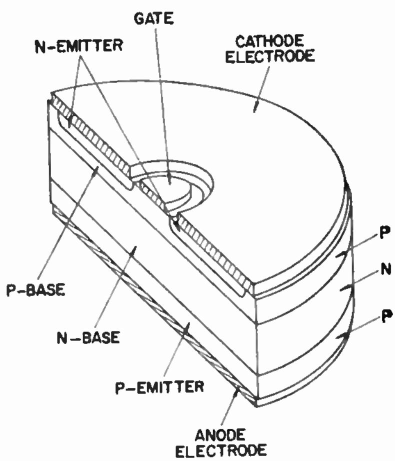


Figure 164. Cross-section of a typical SCR pellet.

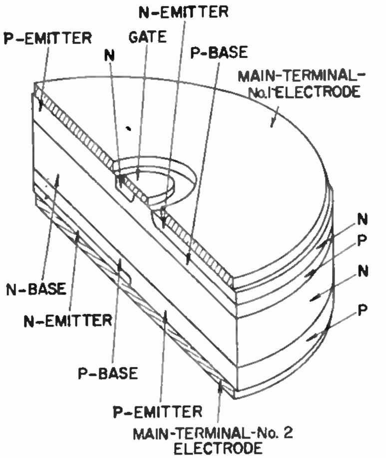


Figure 165. Cross-section of a typical triac pellet.

this device, the main-terminal-No. 1 electrode makes ohmic contact to a p-type emitter as well as to an n-type emitter. Similarly, the main-terminal-No. 2 electrode also makes ohmic contact to both types of emitters, but the p-type emitter of the main-terminal-No. 2 side is located opposite the n-type emitter of the main-terminal-No. 1 side, and the main-terminal-No. 2 n-type emitter is opposite the main-terminal-No. 1 p-type emitter. The net result is two four-layer switches in parallel, but oriented in opposite directions, in one silicon pellet. This type of construction makes it possible for a triac either to block or to conduct current in either direction between main terminal No. 1 and main terminal No. 2.

RATINGS AND CHARACTERISTICS

Thyristors must be operated within the maximum ratings specified by the manufacturer to assure best results in terms of performance, life, and reliability. These ratings define limiting values, determined on the basis of extensive tests, that represent the best judgment of the manufacturer of the safe operating capability of the device. The manufacturer also specifies a number of device parameters, called characteristics, which are directly measurable properties that define the inherent qualities and traits of the thyristor. Some of these characteristics are important factors in the determination of the maximum ratings and in the prediction of the performance, life, and reliability that the thyristor can provide in a given application.

Voltage Ratings

The voltage ratings of thyristors are given for both steady-state and transient operation and for both forward- and reverse-blocking conditions. For SCR's, voltages are considered to be in the forward or positive direction when the anode is positive with respect to the cathode. Negative voltages for SCR's are referred to as reverse-blocking voltages. For triacs, voltages are considered to be positive when main terminal No. 2 is positive with respect to main terminal No. 1. Alternatively, this condition may be referred to as operation in the first quadrant.

OFF-State Voltage—The repetitive peak OFF-state voltage V_{DRM} is the maximum value of OFF-state voltage, either transient or steady-state, that the thyristor should be required to block under the stated conditions of temperature and gate-to-cathode resistance. If this voltage is exceeded, the thyristor may switch to the ON state. The circuit designer should insure that the V_{DRM} rating is not exceeded to assure proper operation of the thyristor.

Under relaxed conditions of temperature or gate impedance, or when the blocking capability of the thyristor exceeds the specified rating, it may be found that a thyristor can block voltages far in excess of its repetitive OFF-state voltage rating V_{DRM}. Because the application of an excessive voltage to a thyristor may produce irreversible effects, an absolute upper limit should be imposed on the amount of voltage that may be applied to the main terminals of the device. This voltage rating is referred to as the peak OFF-state voltage V_{DM}. It should be noted that the peak OFF-state voltage has a single rating irrespective of the voltage grade of the thyristor. This rating is a function of the construction of the thyristor and of the surface properties of the pellet; it should not be exceeded under either continuous or transient conditions.

Reverse Voltages (For Reverse-Blocking Thyristors)—Reverse voltage ratings are given for SCR's to provide operating guidance in the third quadrant, or reverse-blocking mode. There are two voltage ratings for SCR's in the reverse-blocking mode: repetitive peak reverse voltage (V_{RRM}) and nonrepetitive peak reverse voltage (V_{RSM}).

The repetitive peak reverse voltage is the maximum allowable value of reverse voltage, including all repetitive transient voltages, that may be applied to the SCR. Because reverse power dissipation is small at this voltage, the rise in junction temperature because of this reverse dissipation is very slight and is accounted for in the rating of the SCR.

The nonrepetitive peak reverse voltage is the maximum allowable value of any nonrepetitive transient reverse voltage which may be applied to the SCR. These nonrepetitive transient voltages are allowed to exceed the steady-state ratings, even though the instantaneous power dissipation can be significant. While the transient voltage is applied, the junction temperature may increase, but removal of the transient voltage in a specified time allows the junction temperature to return to its steady-state operating temperature before a thermal runaway occurs.

ON-State Voltage—When a thyristor is in a high-conduction state, the voltage drop across the device is no different in nature from the forward-conduction voltage drop of a semiconductor diode, although the magnitude may be slightly higher. As in diodes, the ON-state voltage-drop characteristic is the major source of power losses in the operation of the thyristor, and the temperatures produced become a limiting feature in the rating of the device.

Current Ratings

Thyristor current ratings define maximum values for normal or repetitive currents and for surge or nonrepetitive currents. These maximum ratings are determined on the basis of the maximum junction-temperature rating, the junction-to-case thermal resistance, the internal power dissipation that results from the current flow through the thyristor, and the ambient temperature. The effect of these factors in the determination of current ratings is illustrated by the following example.

Fig. 166 shows curves of the maximum average forward power dissipation for the RCA-2N3873 SCR as a

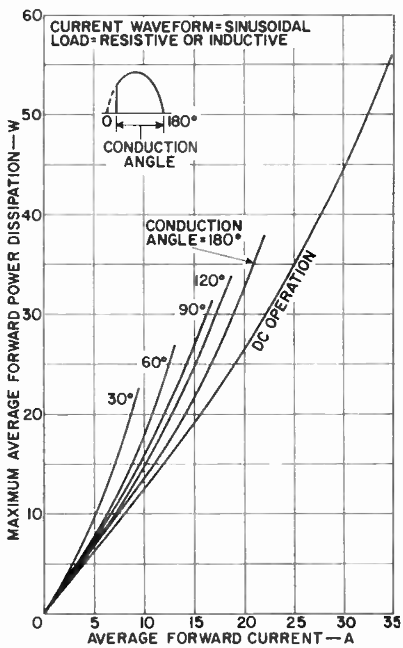


Figure 166. Power-dissipation rating chart for the 2N3873 SCR.

function of average forward current for dc operation and for various conduction angles. For the 2N3873, the junction-to-case thermal resistance θ_{J-C} is 0.92°C per watt and the maximum operating junction temperature T_J is 100°C. If the maximum case temperature $T_{C(max)}$ is assumed to be 65°C, the maximum average forward power dissipation can be determined as follows:

$$P_{AVG(max)} = \frac{T_{J(max)} - T_{C(max)}}{\theta_{J-C}}$$

$$= \frac{(100 - 65)°C}{0.92°C/watt}$$

$$= 38 \text{ watts}$$

The maximum average forward current rating for the specified conditions can then be determined from the rating curves shown in Fig. 166. For example, if a conduction angle of 180 degrees is assumed, the average forward current rating for a maximum dissipation of 38 watts is found to be 22 amperes.

These calculations assume that the temperature is uniform throughout the pellet and the case. The junction temperature, however, increases and decreases under conditions of transient loading or periodic currents, depending upon the instantaneous power dissipated within the thyristor. The current rating takes these variations into account.

ON-State Current—The ON-state current ratings for a thyristor indicate the maximum values of average, rms, and peak (surge) current that should be allowed to flow through the main terminals of the device, under stated conditions, when the thyristor is in the ON state. For heat-sink-mounted thyristors, these maximum ratings are based on the case temperature; for lead-mounted thyristors, the ratings are based on the ambient temperature.

The **maximum average ON-state current rating** is usually specified for a half-sine-wave current at a particular frequency. Fig. 167 shows

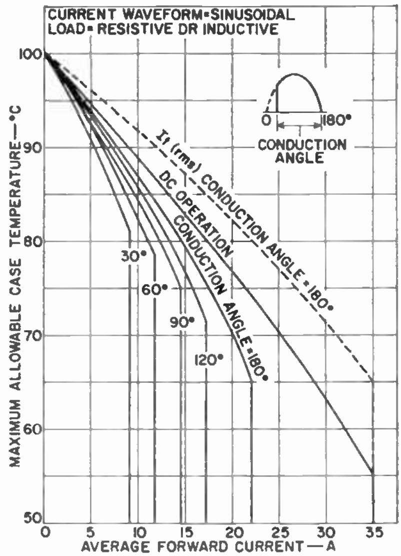


Figure 167. Current rating chart for the 2N3873 SCR.

curves of the maximum allowable average ON-state current $I_{TF(avg)}$ for the RCA-2N3873 SCR family as a function of case temperature. Because peak and rms currents may be high for small conduction angles, the curves in Fig. 167 also show maximum allowable average currents as a function of conduction angle. The maximum operating junction temperature for the 2N3873 is 100°C. The rating curves indicate, for a given case temperature, the maximum average ON-state current for which the average temperature of the pellet will not exceed the maximum allowable value. The rating curves may be used for only resistive or inductive loads. When capacitive loads are used, the currents produced by the charge or discharge of the capacitor through the thyristor may be excessively high, and a resistance should be used in series with the capacitor to limit the current to the rating of the thyristor.

The ON-state current rating for a triac is given only in rms values because these devices normally conduct alternating current. Fig. 168 shows an rms ON-state current rating curve for a typical triac as a function of case temperature. As with the SCR, the triac curve is derated to zero current when the case temperature rises to the maximum operating junction temperature. Triac current ratings are given for full-wave conduction under resistive or inductive loads. Precautions should be taken to limit the peak current to tolerable levels when capacitive loads are used.

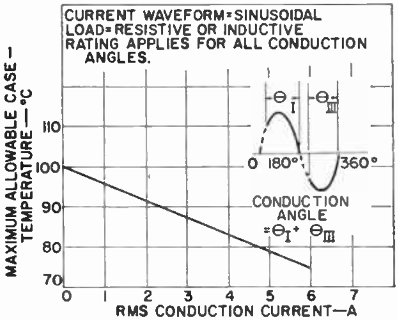


Figure 168. Current rating curve for a typical RCA triac.

The surge ON-state current rating $I_{TF(surge)}$ indicates the maximum peak value of a short-duration current pulse that should be allowed to flow through a thyristor during one ON-state cycle, under stated conditions. This rating is applicable for any rated load condition. During normal operation, the junction temperature of a thyristor may rise to the maximum allowable value; if the surge occurs at this time, the maximum limit is exceeded. For this reason, a thyristor is not rated to block OFF-state voltage immediately following the occurrence of a current surge. Sufficient time must be allowed to permit the junction temperature to return to the normal operating value before gate control is restored to the thyristor. Fig. 169 shows a surge-current rating curve for the 2N3873 SCR. This curve shows peak values of half-sine-wave forward (ON-state) current as a function of overload duration measured in cycles of the 60-Hz current. Fig. 170 shows surge-

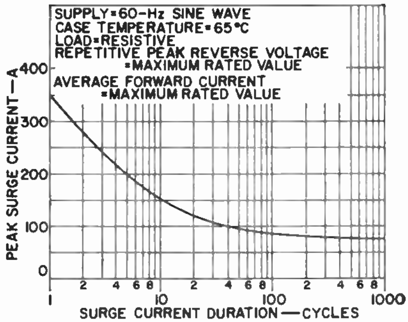


Figure 169. Surge-current rating curve for the 2N3873 SCR.

current rating curves for a typical triac. For triacs, the rating curve shows peak values for a full-sine-wave current as a function of the number of cycles of overload duration. Multicycle surge curves are the basis for the selection of circuit breakers and fuses that are used to prevent damage to the thyristor in the event of accidental short-circuit of the device. The number of surges permitted over the life of the thyristor should be limited to prevent device degradation.

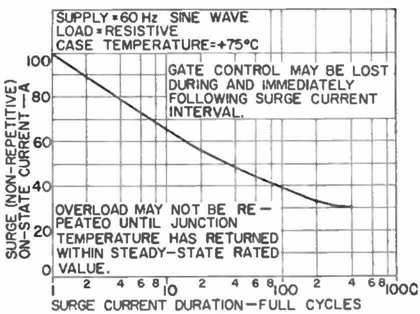


Figure 170. Surge-current rating chart for a typical triac.

Critical Rate of Rise of ON-State Current (di/dt)

In a thyristor, the load current is initially concentrated in the small area of the pellet when load current first begins to flow. This small area effectively limits the amount of current that the device can handle and results in a high voltage drop across the pellet in the first microsecond after the thyristor is triggered. If the rate of rise of current is not maintained within the rating of the thyristor, localized hot spots may occur within the pellet and permanent damage to the device may result. The waveshape for testing the di/dt capability of the RCA 2N3873 is shown in Fig. 171. The critical rate

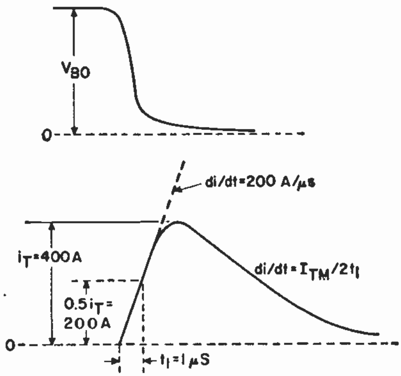


Figure 171. Voltage and current waveforms used to determine di/dt rating of the 2N3873 SCR.

of rise of ON-state current is dependent upon the size of the cathode area that begins to conduct initially, and the size of this area is increased for larger values of gate trigger current. For this reason, the di/dt rating is specified for a specific value of gate trigger current.

Holding and Latching Currents—After a thyristor has been switched to the ON-state condition, a certain minimum value of anode current is required to maintain the thyristor in this low-impedance state. If the anode current is reduced below this critical holding-current value, the thyristor cannot maintain regeneration and reverts to the OFF or high-impedance state. Because the holding current (I_H) is sensitive to changes in temperature (increases as temperature decreases), this rating is specified at room temperature with the gate open.

The latching-current rating of a thyristor specifies a value of anode current, slightly higher than the holding current, which is the minimum amount required to sustain conduction immediately after the thyristor is switched from the OFF state to the ON state and the gate signal is removed. Once the latching current (I_L) is reached, the thyristor remains in the ON, or low-impedance, state until its anode current is decreased below the holding-current value. The latching-current rating is an important consideration when a thyristor is to be used with an inductive load because the inductance limits the rate of rise of the anode current. Precautions should be taken to insure that, under such conditions, the gate signal is present until the anode current rises to the latching value so that complete turn-on of the thyristor is assured.

Critical Rate of Rise of OFF-State Voltage (dv/dt)

Because of the internal capacitance of a thyristor, the forward-blocking capability of the device is sensitive to the rate at which the forward voltage is applied. A steep rising voltage impressed across the main terminals of a thyristor causes a capacitive charging current to flow through the device. This charging current ($i = Cdv/dt$) is a function of the rate of rise of the OFF-state voltage.

If the rate of rise of the forward voltage exceeds a critical value, the capacitive charging current may become large enough to trigger the thyristor. The steeper the wavefront of applied forward voltage, the smaller the value of the thyristor breakover voltage becomes.

The use of the shorted-emitter construction in SCR's has resulted in a substantial increase in the dv/dt capability of these devices by providing a shunt path around the gate-to-cathode junction. Typical units can withstand rates of voltage rise up to 200 volts per microsecond under worst-case conditions. The dv/dt capability of a thyristor decreases as the temperature rises and is increased by the addition of an external resistance from gate to reference terminal. The dv/dt rating, therefore, is given for the maximum junction temperature with the gate open, i.e., for worst-case conditions.

Switching Characteristics

The ratings of thyristors are based primarily upon the amount of heat generated within the device pellet and the ability of the device package to transfer the internal heat to the external case. For high-frequency applications in which the peak-to-average current ratio is high, or for high-performance applications that require large peak values but narrow current pulses, the energy lost during the turn-on process may be the main cause of heat generation within the thyristor. The switching properties of the device must be known, therefore, to determine power dissipation which may limit the device performance.

When a thyristor is triggered by a gate signal, the **turn-on time** of the device consists of two stages, a delay time t_d and a rise time t_r, as shown in Fig. 172. The total turn-on time t_{gt} is defined as the time interval between the initiation of the gate signal and the time when the resulting current through the thyristor reaches 90 per cent of its maximum value with a resistive load. The **delay time** t_d is defined as the time interval between the 10-per-cent point of the leading edge of the gate-trigger voltage and the 10-per-cent point of the

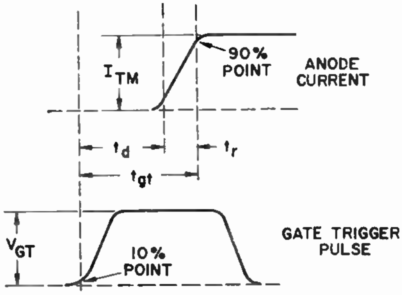


Figure 172. Gate current and voltage turn-on waveforms for a thyristor.

resulting current with a resistive load. The **rise time** t_r is the time interval required for the principal current to rise from 10 to 90 per cent of its maximum value. The total turn-on time, therefore, is the sum of both the delay and rise times of the thyristor.

Although the turn-on time is affected to some extent by the peak OFF-state voltage and the peak ON-state current level, it is influenced primarily by the magnitude of the gate-trigger current pulse. Fig. 173 shows the variation in turn-on time with gate-trigger current for the RCA-2N3873 SCR.

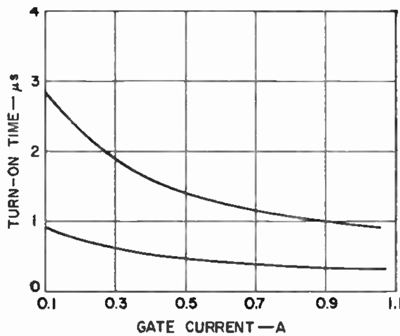


Figure 173. Turn-on time characteristics for the 2N3873 SCR.

To guarantee reliable operation and provide guidance for equipment designers in applications having short conduction periods, the voltage drop across RCA thyristors, at a given instantaneous forward current and at a specified time after turn-on from an OFF-state condition, is given in the published data. The waveshape for the initial ON-state voltage for the RCA-2N3873 SCR is shown in Fig. 174. This initial voltage, together with the time required for reduction of the dynamic forward voltage drop during the spreading time, is an indication of the current-switching capability of the thyristor.

When the entire junction area of a thyristor is not in conduction, the current through that fraction of the pellet area in conduction may result in large instantaneous power losses.

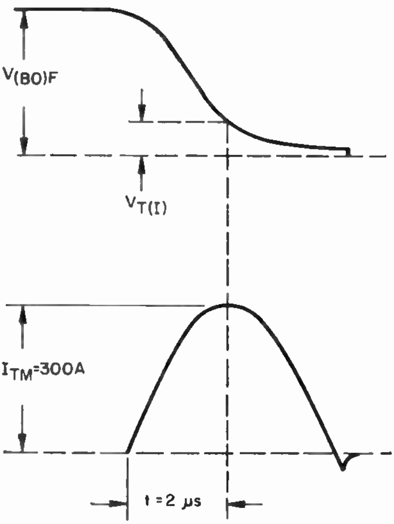


Figure 174. Initial ON-state voltage and current waveforms for the 2N2873 SCR.

These turn-on switching losses are proportional to the current and the voltage from cathode to anode of the device, together with the repetition rate of the gate-trigger pulses. The instantaneous power dissipated in a thyristor under such conditions is shown in Fig. 175. The curves shown in this figure indicate that the peak

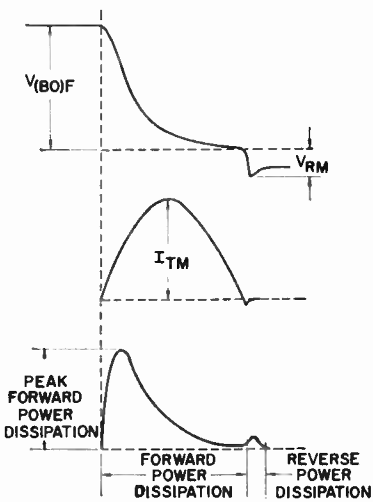


Figure 175. Instantaneous power dissipation in a thyristor during turn-on.

power dissipation occurs in the short interval immediately after the device starts to conduct, usually in the first microsecond. During this time interval, the peak junction temperature may exceed the maximum operating temperature given in the manufacturer's data; in this case, the thyristor should not be required to block voltages immediately after the conduction interval. If the thyristor must block voltages immediately following the conduction interval, the junction-temperature rating must not be exceeded.

The **turn-off time** of an SCR also consists of two stages, a reverse-recovery time and a gate-recovery time, as shown in Fig. 176. When the

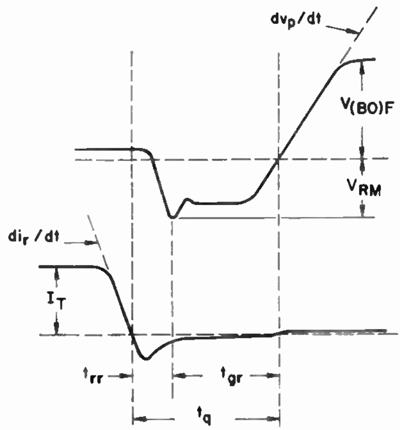


Figure 176. Circuit-commutated turn-off voltage and current waveforms for a thyristor.

forward current of an SCR is reduced to zero at the end of a conduction period, application of reverse voltage between the anode and cathode terminals causes reverse current to flow in the SCR until the reverse-blocking junction establishes a depletion region. The time interval between the application of reverse voltage and the time that the reverse current passes its peak value to a steady-state level is called the **reverse-recovery time** t_{rr}. A second recovery period, called the **gate-recovery time** t_{gr}, must then elapse for the forward-blocking junction to establish a forward-depletion region so that forward-blocking voltage can be re-applied and successfully blocked by the SCR.

The gate-recovery time of an SCR is usually much longer than the reverse-recovery time. The total time from the instant reverse-recovery current begins to flow to the start of the re-applied forward-blocking voltage is referred to as the circuit **commutated turn-off time** t_q. The turn-off time is dependent upon a number of circuit parameters, including the ON-state current prior to turn-off, the rate of change of current during the forward-to-reverse transition, the reverse-blocking voltage, the rate of change of the re-applied forward voltage, the gate trigger level, the gate bias, and the junction temperature. The junction temperature and the ON-state current, however, have a more significant effect on turn-off time than any of the other factors. Because the turn-off time of an SCR depends upon a number of circuit parameters, the manufacturer's turn-off time specification is meaningful only if these critical parameters are listed and the test circuit used for the measurement is indicated.

Gate Characteristics

SCR's and triacs are specifically designed to be triggered by a signal applied to the gate terminal. The manufacturer's specifications indicate the magnitudes of gate current and voltage required to turn on these devices. Gate characteristics, however, vary from device to device even among devices within the same family. For this reason, manufacturer's specifications on gating characteristics provide a range of values in the form of characteristic diagrams. A diagram such as that shown in Fig. 177 is given to define the limits of gate currents and voltages that may be used to trigger any given device of a specific family. The boundary lines of maximum and minimum gate impedance on this characteristic diagram represent the loci of all possible triggering points for thyristors in this family. The curve OA represents the gate characteristic of a specific device that is triggered within the shaded area.

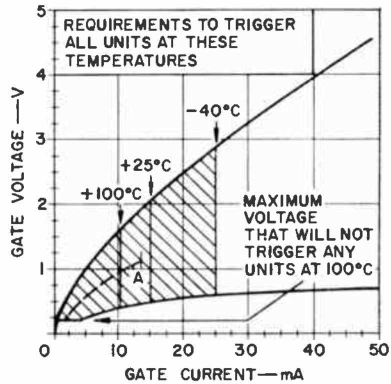


Figure 177. Gate-characteristics curves for a typical RCA SCR.

The magnitude of gate current and voltage required to trigger a thyristor varies inversely with junction temperature. As the junction temperature increases, the level of gate signal required to trigger the thyristor becomes smaller. Worst-case triggering conditions occur, therefore, at the minimum operating junction temperature.

The gate nontrigger voltage V_{gnt} is the maximum dc gate voltage that may be applied between gate and cathode of the thyristor for which the device can maintain its rated blocking voltage. This voltage is usually specified at the rated operating temperature (100°C) of the thyristor. Noise signals in the gate circuit should be maintained below this level to prevent unwanted triggering of the thyristor.

When very precise triggering of a thyristor is desired, the thyristor gate must be overdriven by a pulse of current much larger than the dc gate current required to trigger the device. The use of a large current pulse reduces variations in turn-on time, minimizes the effect of temperature variations on triggering characteristics, and makes possible very short switching times.

The coaxial gate structure and the "shorted-emitter" construction techniques used in RCA thyristors have greatly extended the range of limiting gate characteristics. As a result, the gate-dissipation ratings of RCA thyristors are compatible with the power-handling capabilities of other elements of these devices. Advantage can be taken of the higher peak-power capability of the gate to improve dynamic performance, increase di/dt capability, minimize interpulse jitter, and reduce switching losses. This higher peak-power capability also allows greater interchangeability of thyristors in high-performance applications.

The forward gate characteristics for thyristors, shown in Fig. 178, indicate the maximum allowable pulse widths for various peak values of gate input power. The pulse width is determined by the relationship that exists between gate power input and the increase in the temperature of the thyristor pellet that results from the application of gate power. The curves shown in Fig. 178a are for RCA SCR's that have relatively small current ratings (2N4101, 2N4102, and 40379 families), and the curves shown in Fig. 178b are for RCA SCR's that have larger current ratings (2N4103, 2N3873, and 2N3899 families). Because the higher-current thyristors have larger pellets, they also have greater thermal capacities than the smaller-current devices. Wider gate trigger pulses can therefore be used on these devices for the same peak value of gate input power.

Because of the resistive nature of the "shorted-emitter" construction, similar volt-ampere curves can be constructed for reverse gate voltages and currents, with maximum allowable pulse widths for various peak-power values, as shown in Fig. 179.

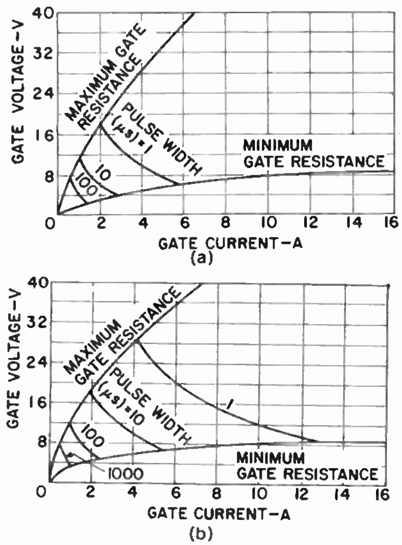


Figure 178. Forward-gate characteristics for pulse triggering of RCA SCR's: (a) low-current types; (b) high-current types.

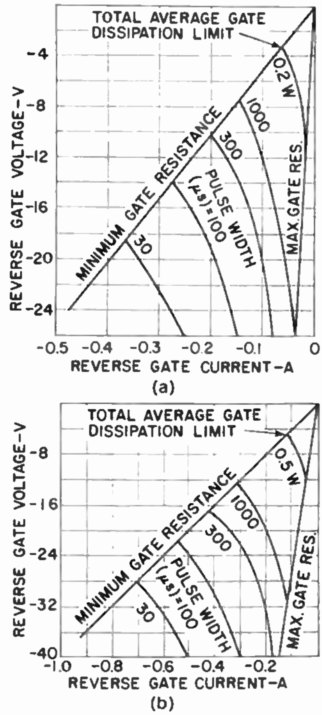


Figure 179. Reserve gate characteristics of RCA SCR's: (a) low-current types; (b) high-current types.

These curves indicate that reverse dissipations do not exceed the maximum allowable power dissipation for the device.

The total average dissipation caused by gate-trigger pulses is the sum of the average forward and reverse dissipations. This total dissipation should correspond to the average gate power dissipation shown in the published data for the selected SCR. If the average gate dissipation exceeds the maximum published value, as the result of high forward gate-trigger pulses and transient or steady-state reverse gate biasing, the maximum allowable forward-conduction-current rating of the device must be reduced to compensate for the increased rise of junction temperature caused by the increased gate power dissipation.

The triac can be triggered in any of four operating modes, as summarized in Table II. The quadrant designations refer to the operating quadrant on the principal voltage-current characteristics, shown in Fig. 159 (either I or III), and the polarity symbol represents the gate-to-main-terminal-No. 1 voltage.

Table II—Triac Triggering Modes

Gate-to-Main-Terminal-No. 1 *Voltage*	to-Main-Terminal-No. 1 Main-Terminal-No. 2- *Voltage*	Operating Quadrant
Positive	Positive	I(+)
Negative	Positive	I(−)
Positive	Negative	III(+)
Negative	Negative	III(−)

The gate-trigger requirements of the triac are different in each operating mode. The I(+) mode (gate positive with respect to main terminal No. 1 and main terminal No. 2 positive with respect to main terminal No. 1), which is comparable to equivalent SCR operation, is usually the most sensitive. The smallest gate current is required to trigger the triac in this mode. The other three operating modes require larger gate-trigger currents. For RCA triacs, the maximum trigger-current rating in the published data is the largest value of gate current that is required to trigger the selected device in any operating mode.

TRANSIENT PROTECTION

Voltage transients occur in electrical systems when some disturbance disrupts the normal operation of the system. These disturbances may be produced by various sources (such as lightning surges, energizing transformers, and load switching), and may generate voltages which are well above the rating of the thyristor. Thyristors, in general, will switch from the OFF-state to the ON-state whenever the forward breakover voltage of the device is exceeded, and energy is then transferred from the thyristor to the load. Because the internal resistance of thyristors is high during the OFF-state, the nature of some transients may cause considerable energy to be dissipated in the thyristor before breakover occurs. Also, the transient voltage may exceed the maximum allowable voltage rating and, therefore, may cause irreversible damage to the thyristor. In either case, transient-suppression techniques must be used to prevent device destruction.

The use of thyristors that have a voltage rating greater than the highest transient voltage expected in the system is one way to provide protection against destructive transients. This method, however, is not always the most economical technique. The effects of voltage transients in thyristor circuits can also be decreased by a reduction of the rate at which the energy is dissipated in the device by relocation of the switching elements or by a change in the sequence of switching. Other preventive methods include the use of external circuit components, such as nonlinear resistors and RC snubber networks, which limit the peak voltage across the thyristor.

The most common type of transient voltage suppressor is the RC network. This network is connected in parallel with the thyristor, as shown in Fig. 180. The value of the resistor should be selected on the basis of the di/dt rating of the thyristor. The size of the capacitor required for suppression of transient voltages is a function of many circuit parameters and is difficult to predict with any degree of accuracy. Actual transient measurements on the equipment will determine the values of circuit elements required. The charging time constant of the capacitor

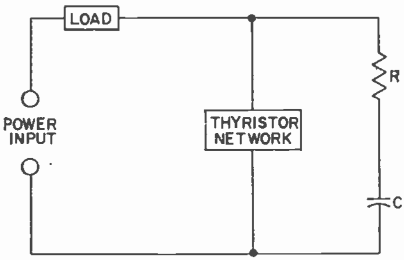


Figure 180. Diagram showing use of RC network for transient suppression in thyristor circuits.

should be greater than the expected duration of the transient so that the increase in capacitor voltage during the transient interval is negligible.

GENERAL TRIGGERING CONSIDERATIONS

The gate signal used to trigger a thyristor must be of sufficient strength to meet all gate current and voltage requirements specified in the published data on the thyristor to assure sustained forward conduction. Triggering requirements are usually stated in terms of dc voltage and current. Because it is common practice to pulse-fire thyristors, it is also necessary to consider the duration of firing pulse required. A trigger pulse that has an amplitude just equivalent to the dc requirements must be applied for a relatively long period of time (approximately 30 microseconds) to ensure that the gate signal is provided during the full turn-on period of the thyristor. As the amplitude of the gate-triggering signal is increased, the turn-on time of the thyristor is decreased, and the width of the gate pulse may be reduced. When highly inductive loads are used, the inductance controls the current-rise portion of the turn-on time. For this type of load, the width of the gate pulse must be made long enough to assure that the principal current rises to a value greater than the latching-current level of the device. The latching current of RCA thyristors is always less than twice the holding current.

The application usually determines whether a simple or somewhat sophisticated triggering circuit should be used to trigger a given thyristor. Triggering circuits can be as numerous and as varied as the applications in which they are used; this text discusses the basic types only.

Many applications require that a thyristor be switched full ON or full OFF in a manner similar to the operation of a relay. Although higher currents are handled by the thyristor, only small trigger or gate currents are required from the control circuit or switch. The simplest method of accomplishing this type of triggering is illustrated by the circuits shown in Fig. 181.

The diagrams indicate that the only function of resistance R_G is to control the gate current to a level sufficient to trigger all devices. The resistance, however, serves another purpose. After firing, the thyristor switches to its low-impedance state; depending on the forward-current

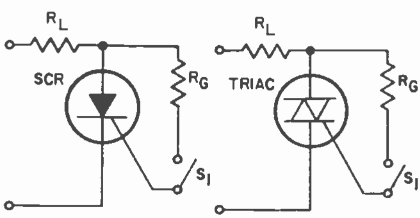


Figure 181. Simple thyristor triggering methods.

magnitude, the voltage drop across the thyristor can be as high as a few volts. It cannot be assumed that if the resistor were removed from the gate circuit, the gate switch would carry only enough current to trigger the device and then decrease to zero. Because the gate has a low impedance, it carries a large percentage of the forward current. The gate resistor R_G assures that the gate current will decrease to a negligible value after the thyristor is fired.

When an ac resistive trigger network is used, a certain degree of phase firing can be accomplished. The degree of control varies from 90- to 180-degree conduction when an SCR is used and from 180- to 360-degree conduction when a triac is used. This degree of control is illustrated in Fig. 182. With maximum resistance in either circuit, the thyristor is OFF. As the resistance is reduced, a point is reached at which sufficient gate trigger current is provided at the peak of the voltage wave to trigger the thyristor. The thyristor initially turns on with a conduction angle θ_C of 90 degrees. A further reduction in resistance increases the conduction angle from 90 degrees toward 180 degrees for an SCR and from 90 degrees and 270

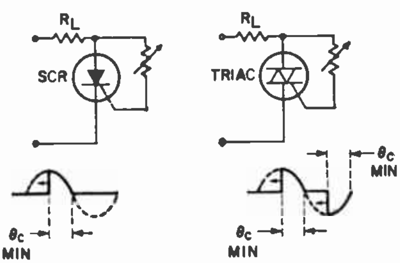


Fig. 182. Degree of control over conduction angles when ac resistive network is used to trigger SCR's and triacs.

degrees to zero and 180 degrees, respectively, for a triac.

The easiest method to obtain a phase angle greater than 90 degrees for half-wave operation is to use a resistance-capacitance triggering network. Fig. 183 shows the simplest form of such networks for use with an SCR and a triac.

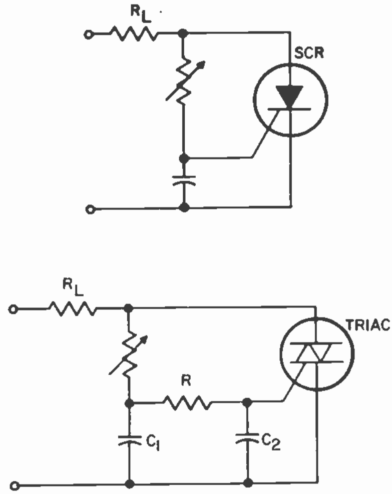


Figure 183. RC triggering networks used for phase control triggering of thyristors.

A variety of thyristor triggering devices are available to overcome the disadvantages noted for simple resistance or resistance-capacitance triggering circuits. These triggering devices have a smaller range of characteristics and are not so temperature-sensitive. Basically, a thyristor triggering device exhibits a negative resistance after a critical voltage is reached, so that the gate-current requirement of the thyristor can be obtained as a pulse from the discharge of the phase-shift capacitor. Because the gate pulse need be only microseconds in duration, the gate-pulse energy and the size of the triggering components are relatively small. Triggering circuits of this type employ elements such as neon bulbs, trigger diodes, unijunction transistors, and two-transistor switches.

The most elementary form of triggering-device circuit is shown in Fig. 184. The voltage-current charac-

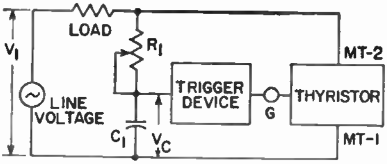


Figure 184. Thyristor power control in which switching is controlled by basic triggering-device circuit.

teristic for the triggering device in this circuit is shown in Fig. 185.

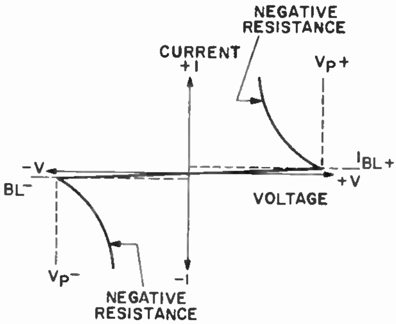


Figure 185. Voltage-current characteristic for triggering device shown in Fig. 185.

The magnitude and duration of the gate-current pulse is determined by the interaction of the capacitor C_1, the triggering-device characteristics, and the impedance of the thyristor gate. Fig. 186 shows the typical shape of the gate-current pulse that is produced.

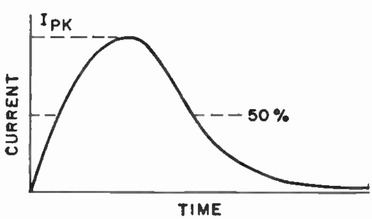


Figure 186. Typical gate-current waveform for circuit shown in Fig. 185.

POWER CONTROL

Silicon controlled rectifiers have been widely accepted in power-control applications in industrial systems where high-performance requirements justify the economics of the application. Historically, in the commercial high-volume market, economic considerations have precluded the use of the thyristor. However, with the development of several families of thyristors by RCA designed specifically for mass-production economy and rated for 120- and 240-volt line operation, the use of these devices in controls for many types of small electric motors has been made economically feasible. The controls can be designed to provide good performance, maximum efficiency, and high reliability in compact packaging arrangements.

The simplest form of half-wave power control was shown in Fig. 182. This circuit provides a simple, non-regulating half-wave power control that begins at the 90-degree conduction (peak-voltage) point and may be adjusted to within a few degrees of full conduction (180-degree half-cycle).

The half-wave proportional control shown in Fig. 187 is a non-regulating circuit whose function depends upon an RC delay network for gate phase-lag control. This circuit is better than simple resistance firing circuits because the phase-shifting characteristics of the RC network permit the firing of the SCR beyond the peak of the impressed voltage, resulting in small conduction angles. On the positive half-cycle of the applied voltage, capacitor C is charged through the network R_a and R_b. When the voltage across capacitor C exceeds the gate-firing voltage of the SCR, the SCR is turned on; during the remaining portion of the half-cycle, ac power is applied to the load.

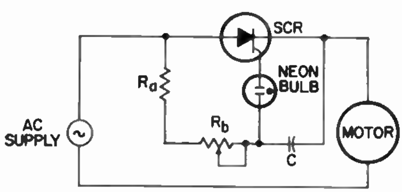


Figure 187. SCR half-wave proportional power control circuit.

The delay in firing the SCR depends upon the time-constant network (R_a, R_b, C) which produces a gate-firing voltage that is shifted in phase with respect to the supply voltage. The amount of phase shift is adjusted by R_b. With maximum resistance in the circuit, the RC time constant is longest. This condition results in a large phase shift with a correspondingly small conduction angle. With minimum resistance, the phase shift is small, and essentially the full line voltage is applied to the load.

The control circuit uses the breakdown voltage of a neon lamp as a threshold setting for firing the SCR. The NE-83 neon lamp is specifically designed for handling the high-current pulses required to trigger SCR's. When the voltage across capacitor C reaches the breakdown voltage of the neon lamp, the lamp fires and C discharges through the lamp to its maintaining voltage. At this point, the lamp again reverts to its high-impedance state. The discharge of the capacitor from breakdown to maintaining voltage of the neon lamp provides a current pulse of sufficient magnitude to fire the SCR. Once the SCR has fired, the voltage across the phase-shift network reduces to the forward voltage drop of the SCR for the remainder of the half-cycle. The range of conduction angles of this circuit is approximately 30 to 150 degrees. The high breakdown voltage of the neon lamp improves noise rejection and prevents erratic firing of the SCR because of brush noises on the voltage supply lines.

When SCR's are used to provide full-wave power control, two of these thyristor devices are usually required. Because of the bidirectional switching characteristics of triacs, however, only one of these devices is needed to provide full-wave motor control. Fig. 188 shows three thyristor full-wave power controls.

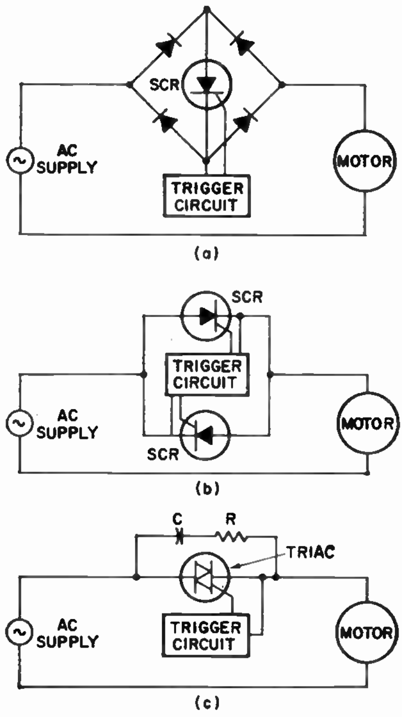


Figure 188. Full-wave thyristor motor control circuits using (a) bridge rectifier and a single SCR; (a) inverse parallel SCR's; (c) a triac.

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 greater than 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. 189, this reverse current flow increases slightly as the bias voltage increases, but then tends

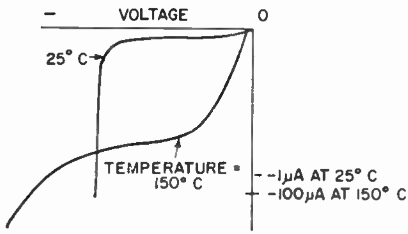


Figure 189. Typical reverse characteristics.

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.

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. 190, 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. 190 shows the effects of an increase in temperature on the forward-current characteristic of a silicon

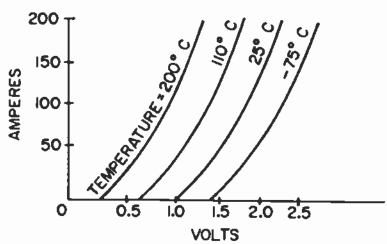


Figure 190. Typical forward characteristics.

rectifier. In certain applications, close control of ambient temperature is required for satisfactory operation. Close control is not usually required, however, in power circuits.

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. 191 and 192 help to illustrate the relationships among these ratings. For example, Fig. 191 shows the current variation with time of a sine wave

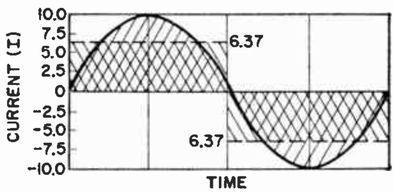


Figure 191. Variation of current of a sine wave with time.

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

$$I_{av} = 0.637\ I_{peak}$$

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. 192 shows the square of the current for the sine wave of Fig. 191. 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

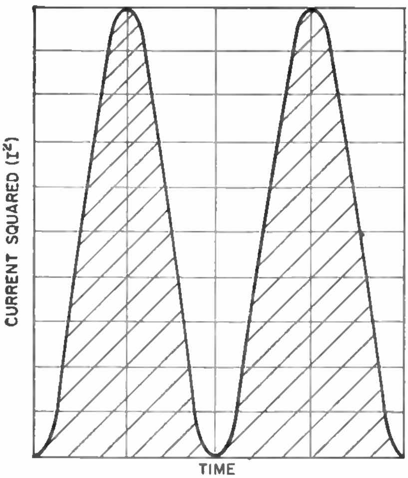


Figure 192. Variation of the square of sine-wave current with time.

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. 191 and 192 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:

$$I_{peak} = \pi \times I_{av} = 3.14\ I_{av}$$
$$I_{av} = (1/\pi)\ I_{peak} = 0.32\ I_{peak}$$
$$I_{rms} = (\pi/2)\ I_{av} = 1.57\ I_{av}$$
$$I_{av} = (2/\pi)\ I_{rms} = 0.64\ I_{rms}$$
$$I_{peak} = 2\ I_{rms}$$
$$I_{rms} = 0.5\ I_{peak}$$

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 III later in this section.

Published data for silicon rectifiers usually include maximum ratings for both average and peak forward current. As shown in Fig. 193, 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.

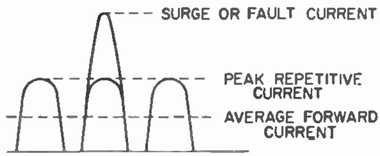


Figure 193. Representation of rectifier currents.

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. 194 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.

The fusing requirements for a given circuit can be determined by use of a coordination chart such as that shown in Fig. 195. Two characteristics are plotted on the coordination chart initially: (A) the surge rating curve for the rectifier, and

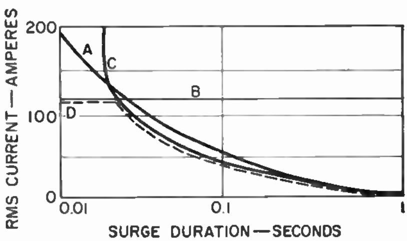


Figure 195. Typical coordination chart for determining fusing requirements (A - surge-rating chart for 20-ampere rectifier, B - expected surge current in half-wave circuit, C - opening characteristics of protective device, D - resulting surge current in modified circuit).

(B) the maximum surge (fault current) expected in the circuit. In Fig. 195, 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. 195.

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

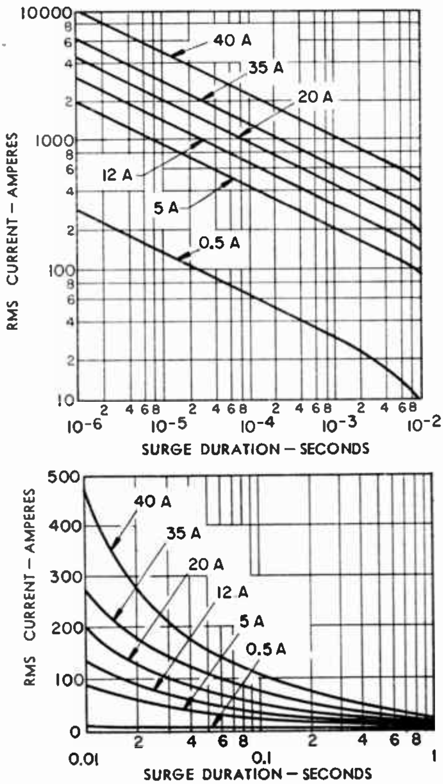


Figure 194. Universal surge rating charts for RCA rectifiers.

"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. 195 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. 196 through 202 show seven basic rectifier configurations. (Filters used to smooth the rectifier output are not shown for each circuit, but are discussed later.) Figs. 196 through 202 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. 196 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

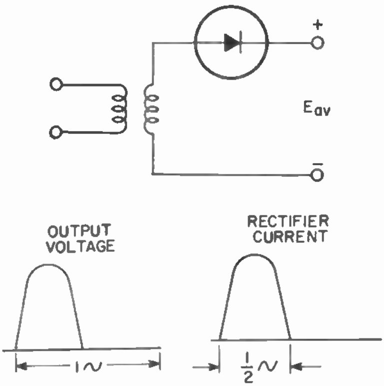


Figure 196. Single-phase half-wave circuit.

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.

Fig. 197 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. 196, 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. 198 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. 197 for the same transformer voltage, or to expose the individual rectifier cell to only half as much peak

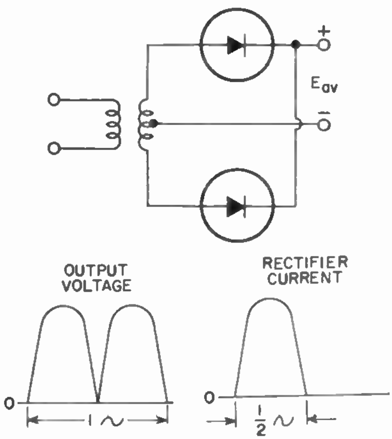


Figure 197. Single-phase full-wave circuit with center-tap.

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.

The three-phase circuits shown in Figs. 199 through 202 are usually found in heavy industrial equipment such as high-power transmitters. The **three-phase (Y) half-wave** circuit

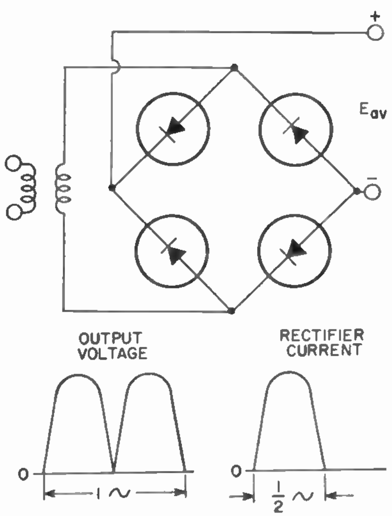


Figure 198. Single-phase full-wave circuit without center-tap.

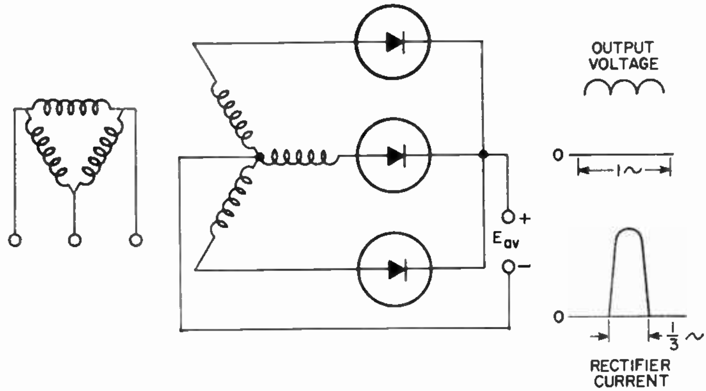


Figure 199. Three-phase (Y) half-wave circuit.

shown in Fig. 199 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. 200 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. 199 for the same transformer conditions. In addition, this circuit, as well as those shown in Figs. 201 and 202, has an extremely small percentage of ripple.

The **six-phase "star"** circuit shown in Fig. 201, 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. 202 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. 199.

Table III lists voltage and current ratios for the circuits shown in Figs. 196 through 202 for resistive or inductive loads. These ratios apply for sinusoidal ac input voltages. It is

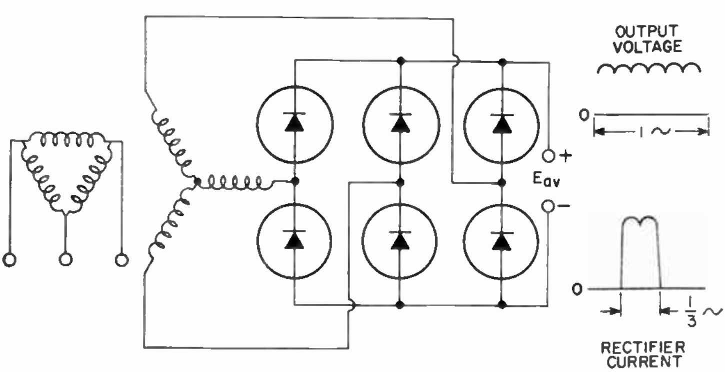


Figure 200. Three-phase (Y) full-wave bridge circuit.

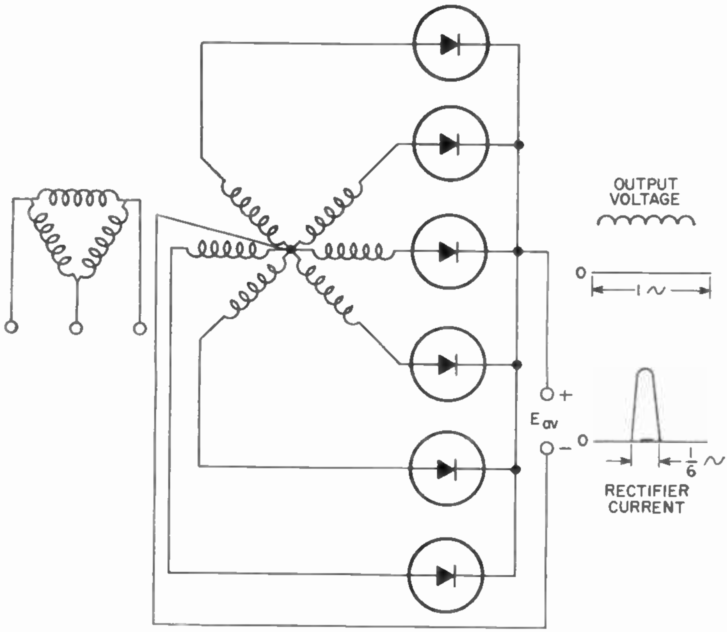


Figure 201. Six-phase "star" circuit.

generally recommended that inductive loads rather than resistive loads be used for filtering of rectifier current, except for the circuit of Fig. 196. Current ratios given for inductive loads apply only when a filter

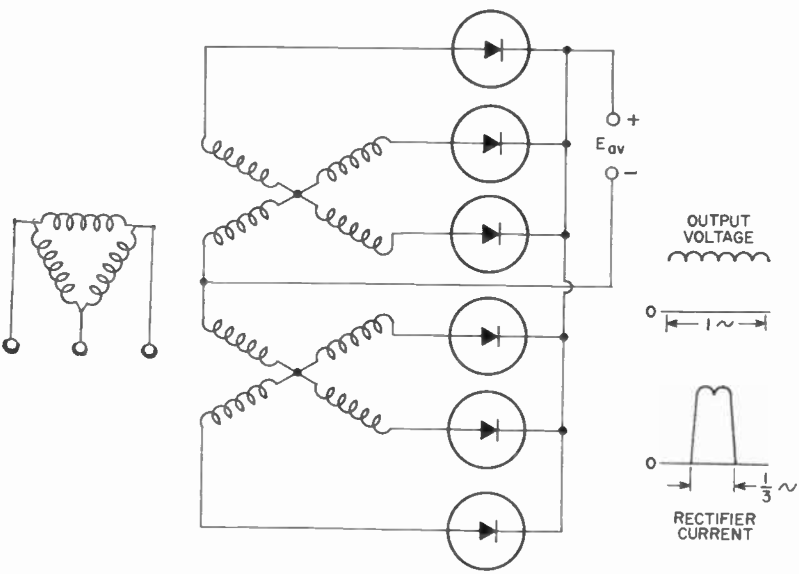


Figure 202. Three-phase double-Y and interphase transformer circuit.

CIRCUIT RATIOS	*Fig. 196*	*Fig. 197*	*Fig. 198*	*Fig. 199*	*Fig. 200*	*Fig. 201*	*Fig. 202*
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 III—Voltage and current ratios for rectifier circuits shown in Figs. 196 through 202. Fig. 196 uses a resistive load, and Figs. 197 through 202 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 III can be used to determine the parameters and characteristics of the circuit.

In Table III, 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.

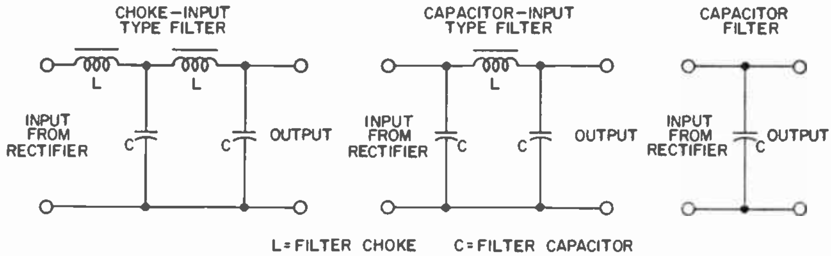


Figure 203. Typical filter circuits.

Typical filter circuits are shown in Fig. 203.

If an input capacitor is used, consideration 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.

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.

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. 204. 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. 205. Conventional diodes do

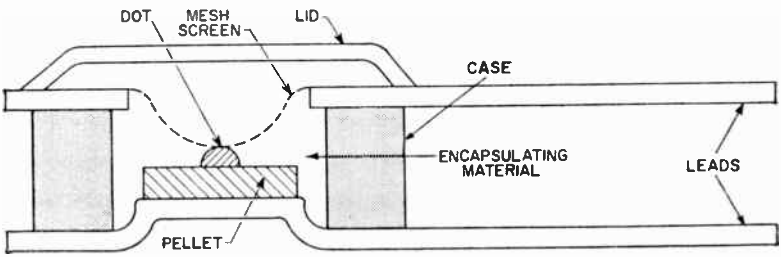


Figure 204. Structure of a tunnel diode.

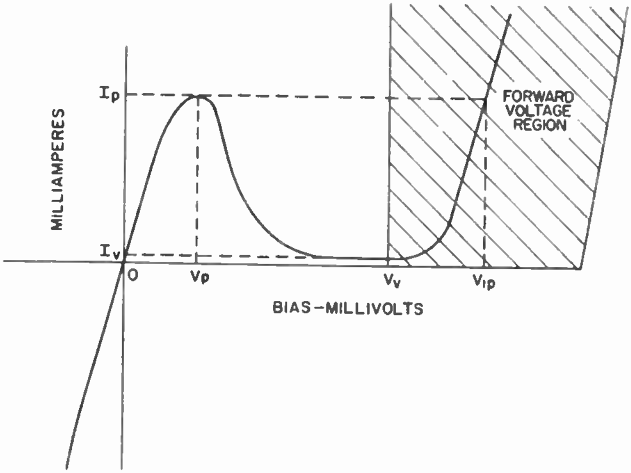


Figure 205. Typical current-voltage characteristic of a tunnel diode.

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. 206, 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

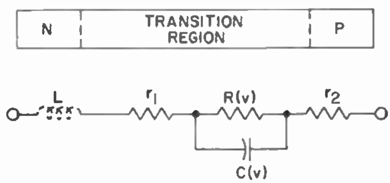


Figure 206. Equivalent circuit for a tunnel diode.

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.

The dashed portion L in Fig. 206 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 MHz).

Fig. 207 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. 207. This expression has two very useful interpretations:

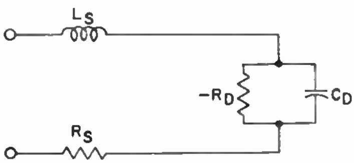


Figure 207. Equivalent circuit for a tunnel diode biased in the negative-resistance region.

(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.

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. 208, 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.

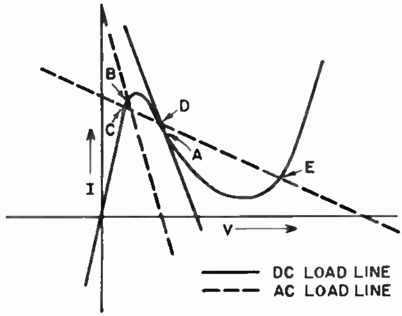


Figure 208. Typical load lines for tunnel-diode circuits.

Because tunnel diodes can operate effectively at frequencies above 300 MHz, 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 MHz. 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 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. 208; 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. 209a, 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. 209b. 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.

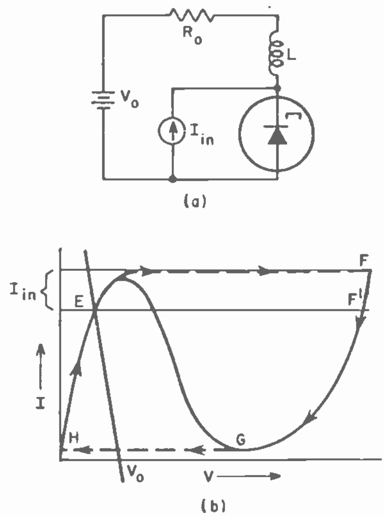
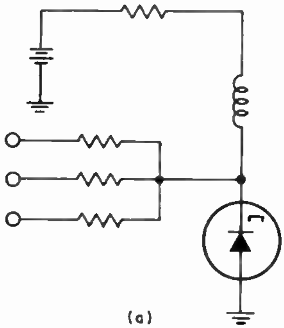


Figure 209. Basic tunnel-diode logic circuit.

Fig. 210a 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. 210b 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".



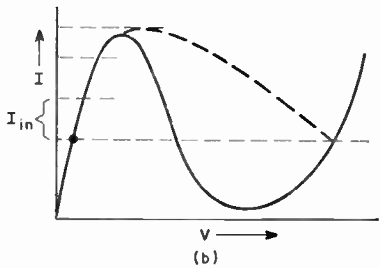


Figure 210. Tunnel-diode "AND" gate.

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. 211 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.

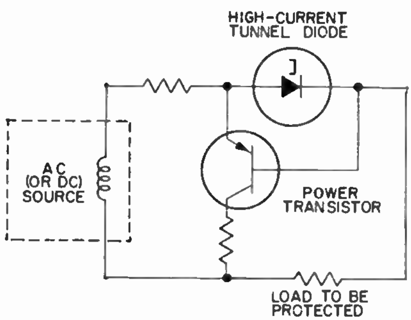


Figure 211. Overload sensor circuit using tunnel diode.

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. 212. In conventional rectifiers, current flow is substantial in the forward direction, but

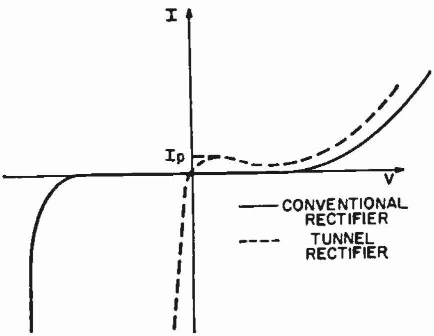


Figure 212. Current-voltage characteristics of tunnel rectifier and conventional rectifier.

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.")

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. 213 shows the use of tunnel rectifiers to provide directional coupling in a tunnel-diode logic circuit.

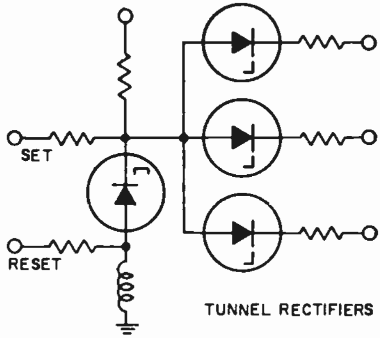


Figure 213. Logic circuit using a tunnel diode and three tunnel rectifiers.

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. 214a. 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. 214b. 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

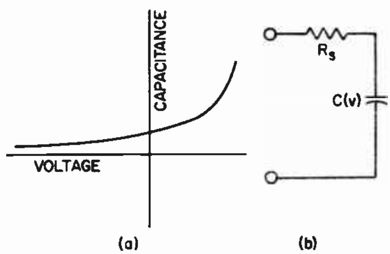


Figure 214. (a) Capacitance-voltage relationship and (b) equivalent circuits for a varactor diode.

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. 215. The circuit is driven by a sinusoidal voltage source V_s having

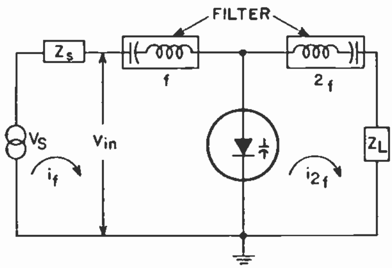


Figure 215. Varactor-diode frequency multiplier.

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.

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. 216 shows the transfer characteristics of a transistor; Fig. 217 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 section on **Transistor Applications.**)

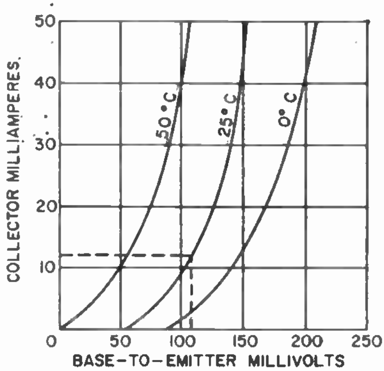


Figure 216. Transfer characteristics of transistor.

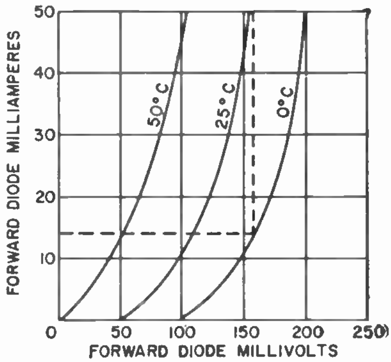


Figure 217. Forward characteristics of compensating diode.

Thyristor, Rectifier, and Diode Symbols

Data for RCA thyristors (SCR's and triacs), silicon 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

THYRISTORS

Commutating dv/dt	critical rate of applied commutating voltage
Critical dv/dt	critical rate of rise of off-state voltage
di/dt	rate of rise of on-state current
di_R/dt	rate of rise of on-state current (reverse condition)
dv_D/dt	rate of rise of off-state voltage (forward condition)
i_D	instantaneous off-state current)
i_R	instantaneous reverse off-state current
i_T	instantaneous on-state current
I_D	peak off-state current
I_{GDM}	peak gate off-state current
I_{GT}	dc gate-trigger current
I_{GM}	peak gate-trigger current
I_H	dc holding current
I_{RD}	peak reverse blocking current
$I_{T(AV)}$	average on-state current
I_{TRM}	peak pulse current
$I_{T(RMS)}$	rms on-state current
I_{TSM}	peak surge (non-repetitive) on-state current
$P_{G(AV)}$	average gate power dissipation
P_{GM}	peak gate power dissipation
P_M	dynamic dissipation
R_L	load resistance
t_{gt}	gate-controlled turn-on time
t_q	circuit - commutated turn-off time
T_C	case temperature
T_{stg}	storage temperature
v_D	instantaneous off-state voltage
V_D	off-state voltage

v_T	instantaneous on-state voltage
$V_{(BO)}$	breakover voltage
V_{DRM}	repetitive peak off-state voltage
V_{GM}	peak gate voltage
$\|V_{GM}+\| - \|V_{GM}-\|$	gate symmetry, peak voltage
V_{GT}	dc gate-trigger voltage
V_{RM}	peak reverse blocking voltage
V_{RRM}	repetitive peak reverse voltage
V_{RSM}	non-repetitive peak reverse voltage
V_{TM}	peak on-state voltage

TUNNEL DIODES AND TUNNEL RECTIFIERS

C_j	junction capacitance
C_p	case capacitance
C_{tv}	valley-point terminal capacitance
f_o	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 Thyristors, Rectifiers, and Diodes

Thyristors

SILICON CONTROLLED RECTIFIERS — 2N681—2N690

Si all-diffused three-junction types for use in power-control and power-switching applications. JEDEC TO-48, Outline No.17. Terminals: Long Lug - cathode, Short Lug - gate, Mounting Stud - anode.

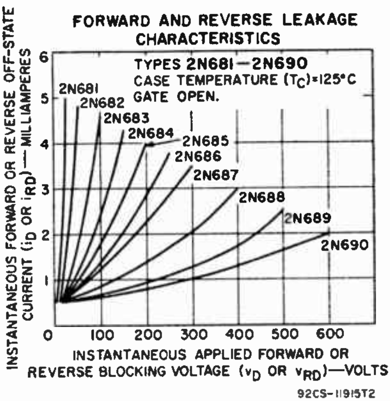
MAXIMUM RATINGS (For sinusoidal ac supply voltage at f = 50 to 400 Hz with resistive or inductive load)

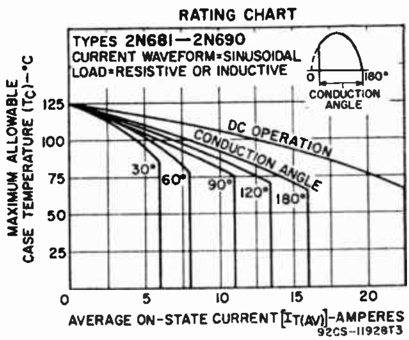
	2N681	2N682	2N683	2N684	2N685	2N686	2N687	2N688	2N689	2N690	
V_{RSM}	35	75	150	225	300	350	400	500	600	720	V
V_{RRM}	25	50	100	150	200	250	300	400	500	600	V
V_{DRM}	600										V
$I_{T(AV)}$	16 (conduction angle = 180°, T_C = 65°C)										A
$I_{T(RMS)}$	25										A
I_{TSM}	150 (1 cycle applied voltage)										A
P_{GM}	5										W
$P_{G(AV)}$	0.5										W
I_{GM}	2										A
V_{GM}	10, 5										V
T_{stg}	−65 to 150										°C
T_C	−65 to 125										°C

CHARACTERISTICS (At maximum electrical rating at T_C = 125°C)

	2N681	2N682	2N683	2N684	2N685	2N686	2N687	2N688	2N689	2N690	
$V_{(BO)}$(min)	25	50	100	150	200	250	300	400	500	600	V
I_D(max)	6.5	6.5	6.5	6.5	6	5.5	5	4	3	2.5	mA
I_{RD}(max)	6.5	6.5	6.5	6.5	6	5.5	5	4	3	2.5	mA
v_T(max)	0.86 (on-state current = 25 A, T_C = 65°C)										V
I_{GT}(max)	25										mA
V_{GT}(max)	3 (−65 to 125°C)										V
V_{GT}(min)	0.25										V
I_H	15										mA
θ_{J-C}	2										°C/W

Thyristors (cont'd)





2N1842A—2N1850A SILICON CONTROLLED RECTIFIERS

Si all-diffused three-junction types for use in power-control and power-switching applications. JEDEC TO-48, Outline No.17. Terminals: Long Lug - cathode, Short Lug - gate, Mounting Stud - anode.

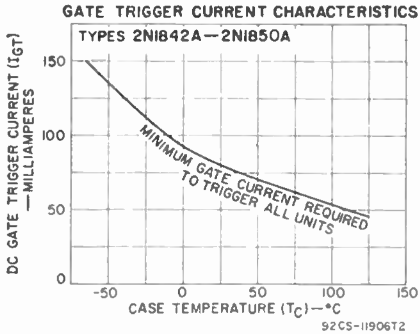
MAXIMUM RATINGS (For sinusoidal ac supply voltage at f = 50 to 400 Hz with resistive or inductive load)

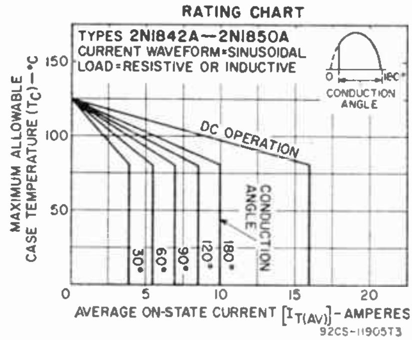
	2N1842A	2N1843A	2N1844A	2N1845A	2N1846A	2N1847A	2N1848A	2N1849A	2N1850A	
V_{RSM}	35	75	150	225	300	350	400	500	600	V
V_{RRM}	25	50	100	150	200	250	300	400	500	V
V_{DRM}					600					V
$I_{T(AV)}$					10 (conduction angle = 180°, Tc = 80°C)					V
$I_{T(RMS)}$					16					A
I_{TSM}					125 (1 cycle applied voltage)					A
P_{GM}					5					W
$P_{G(AV)}$					0.5					W
I_{GM}					2					A
V_{GM}					10, 5					V
T_{stg}					−65 to 125					°C
T_C					−65 to 125					°C

CHARACTERISTICS (At maximum electrical rating at Tc = 125°C)

	2N1842A	2N1843A	2N1844A	2N1845A	2N1846A	2N1847A	2N1848A	2N1849A	2N1850A	
$V_{(BO)}$(min)	25	50	100	150	200	250	300	400	500	V
I_D(max)	22.5	19	12.5	6.5	6	5.5	5	4	3	mA
I_{RD}(max)	22.5	19	12.5	6.5	6	5.5	5	4	3	mA
v_T					1.2 (Tc = 80°C)					V
I_{GT}					45					mA
V_{GT}(max)					3.5 (Tc = −40°C)					V
V_{GT}(max)					3.7 (Tc = −65°C)					V
V_{GT}(min)					0.25					V
V_{GT}(min)					0.3 (Tc = 100°C)					V
I_H					8					mA
θ_{J-C}					2					°C/W

Thyristors (cont'd)





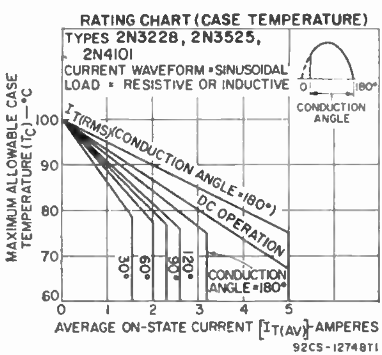
SILICON CONTROLLED RECTIFIERS

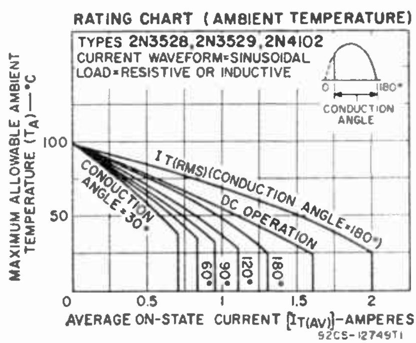
2N3228
2N3525, 2N3528, 2N3529, 2N4101, 2N4102

Si all-diffused three-junction types for use in power-control and power-switching applications. Types 2N3228, 2N3525, and 2N4101: JEDEC TO-66, Outline No.22. Terminals: 1 - gate, 2 - cathode, Case - anode. Types 2N3528, 2N3529, and 2N4102: JEDEC TO-8, Outline No.5. Terminals: 1 - cathode, 2 - gate, 3 - anode (connected to case).

MAXIMUM RATINGS (For sinusoidal ac supply voltage at f = 50 to 400 Hz with resistive or inductive load)

	2N3228	2N3525	2N4101	2N3528	2N3529	2N4102	
V_{RSM}	330	660	700	330	660	700	V
V_{RRM}	200	400	600	200	400	600	V
V_{DRM}	600	600	600	600	600	700	V
$I_{T(AV)}$ (conduction angle = 180°)	3.2 (T_C = 75°C)			1.3 (T_A = 25°C)			A
$I_{T(RMS)}$	5 (T_C = 75°C)			2 (T_A = 25°C)			A
I_{TSM} (1 cycle applied voltage)	60						A
I^2t (1 to 8.3 ms)	15						A^2s
Critical di/dt	200						A/μs
$P_{G(AV)}$	0.5						W
P_{GM} (peak, forward, or reverse for 10 μs)	13						W
T_{stg}	−40 to 125						°C
T_C	−40 to 100						°C



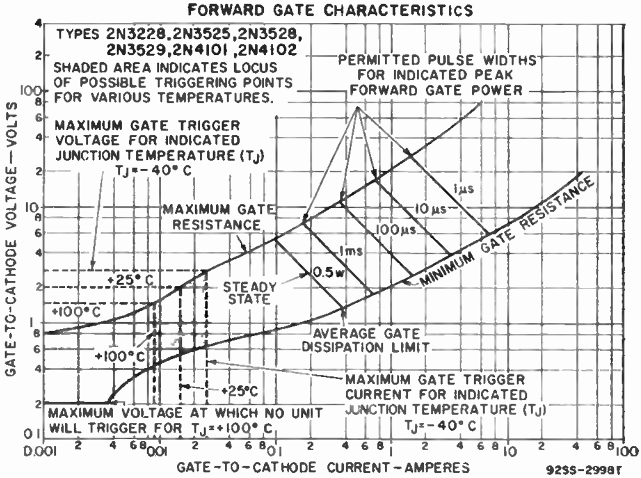


Thyristors (cont'd)

CHARACTERISTICS (At maximum electrical rating at T_C = 25°C)

	2N3228	2N3528	2N3525	2N3529	2N4101	2N4102	
$V_{(BO)}$ (T_C = 100°C)	200 min		400 min		600 min		V
I_D (v_D = $V_{(BO)}$ min value, T_C = 100°C)	0.1 typ		0.2 typ		0.4 typ		mA
	1.5 max		3 max		4 max		mA
	0.05 typ		0.1 typ		0.2 typ		mA
I_{RD} (V_{RD} = V_{RRM}, T_C = 100°C)	0.75 max		1.5 max		2 max		mA
v_T (on-state current = 30 A)	2.15 typ; 2.8 max						V
I_{GT}	8 typ; 15 max						mA(dc)
V_{GT}	1.2 typ; 2 max						V(dc)
I_H	10 typ; 20 max						mA
Critical dv/dt (V_D = $V_{(BO)}$ min value, exponential rise, T_C = 100°C)	10 typ; 200 max						V/μs
t_{gt} (V_D = $V_{(BO)}$ min value, i_T = 4.5 A, I_{GT} = 200 mA, 0.1 μs rise time)	0.75 typ; 1.5 max						μs
t_q (i_T = 2 A, 50 μs pulse width, dv_D/dt = 20 V/μs, di_R/dt = 30 A, I_{GT} = 200 mA, T_C = 75°C)	15 typ; 50 max						μs
θ_{J-C}	4 max	—	4 max	—	4 max	—	°C/W
θ_{J-A}	—	40 max	—	40 max	—	40 max	°C/W

FORWARD GATE CHARACTERISTICS



2N3525 SILICON CONTROLLED RECTIFIER

Si all-diffused three-junction type for use in power-control and power-switching applications. JEDEC TO-66, Outline No.22. Terminals: 1 - gate, 2 - cathode, Case - anode. For data, refer to type 2N3228.

2N3528, 2N3529 SILICON CONTROLLED RECTIFIERS

Si all-diffused three-junction types for use in power-control and power-switching applications. JEDEC TO-8, Outline No.5. Terminals: 1 - cathode, 2 - gate, 3 - anode (connected to case). For data, refer to type 2N3228.

Thyristors (cont'd)

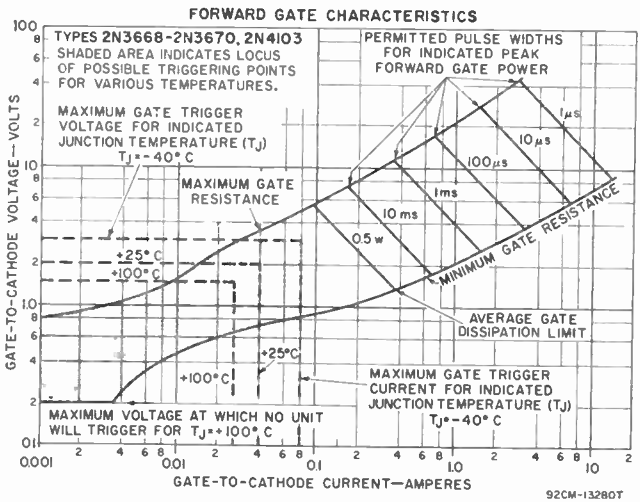
SILICON CONTROLLED RECTIFIERS

2N3668—2N3670
2N4103

Si all-diffused three-junction types for use in power-control and power-switching applications. JEDEC TO-3, Outline No.2. Terminals: 1 - gate, 2 - cathode, Case - anode.

MAXIMUM RATINGS (For sinusoidal ac supply voltage at f = 50 to 400 Hz with resistive or inductive load)

	2N3668	2N3669	2N3670	2N4103	
V_{RSM}	150	330	660	700	V
V_{RRM}	100	200	400	600	V
V_{DRM}	600	600	600	700	V
$I_{T(AV)}$ (conduction angle = 180°, T_C = 80°C)	8				A
$I_{T(RMS)}$	12.5				A
I_{TSM} (1 cycle applied voltage)	200				A
Critical di/dt	200				A/μs
I^2t (1 to 8.3 ms)	165				A^2s
P_{GM} (peak, forward, or reverse for 10 μs)	40				W
$P_{G(AV)}$	0.5				W
T_{stg}	−40 to 125				°C
T_C	−40 to 100				°C



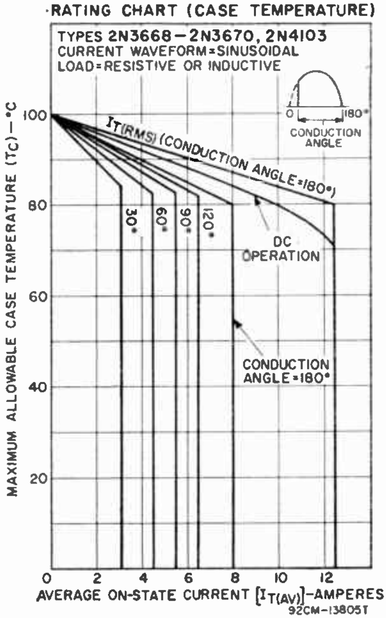
CHARACTERISTICS (At maximum electrical rating at T_C = 25°C)

	2N3668	2N3669	2N3670	2N4103	
$V_{(BO)}$ (T_C = 100°C)	100 min	200 min	400 min	600 min	V
I_D (T_C = 100°C, V_D = $V_{(BO)}$ min value	0.2 typ	0.25 typ	0.3 typ	0.35 typ	mA
	2 max	2.5 max	3 max	4 max	mA
I_{RD} (V_{RD} = V_{RRM})	0.05 typ	0.1 typ	0.2 typ	0.3 typ	mA
	1 max	1.25 max	1.5 max	3 max	mA
v_T (on-state current = 25 A)	1.5 typ; 1.8 max				V
I_{GT}	1 min, 20 typ, 40 max				mA (dc)
V_{GT}	1.5 typ; 2 max				V (dc)
I_H	0.5 to 50				mA
Critical dv/dt (V_D = $V_{(BO)}$ min value, exponential rise, T_C = 100°C)	10 min; 100 typ				V/μs

Thyristors (cont'd)

CHARACTERISTICS (cont'd)

	2N3668	2N3669	2N3670	2N4103	
t_{gt} (V_D = $V_{(BO)}$ min value, i_T = 8 A, I_{GT} = 200 mA, 0.1 µs rise time)	0.75 min; 1.25 typ				µs
t_q (i_T = 8 A, 50 µs pulse width, dv_D/dt = 20 V/µs, di_R/dt = 30 A/µs, I_{GT} = 200 mA, T_C = 80°C)	20 typ; 50 max				µs
Θ_{J-C}	1.7 max				°C/W



2N3870—2N3873 SILICON CONTROLLED RECTIFIERS

Si all-diffused three-junction types for use in power-control and power-switching applications. Outline No.31. Terminals: Long Lug - cathode, Short Lug - gate, Case - anode. For curve of forward gate characteristics, refer to type 2N3668.

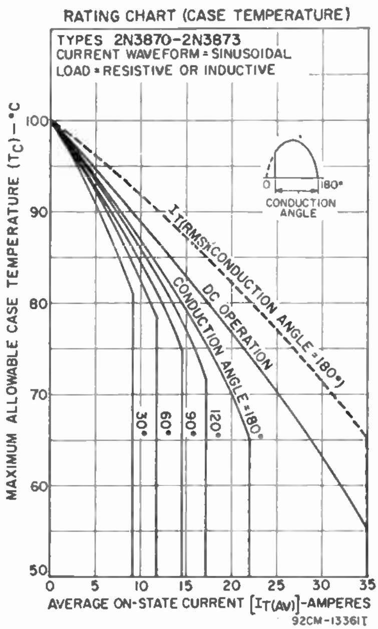
MAXIMUM RATINGS (For sinusoidal ac supply voltage at f = 50 to 400 Hz with resistive or inductive load)

	2N3870	2N3871	2N3872	2N3873	
V_{RSM}	150	330	660	700	V
V_{RRM}	100	200	400	600	V
V_{DRM}	700				V
$I_{T(AV)}$ (conduction angle = 180°, T_C = 65°C)	22				A
$I_{T(RMS)}$	35				A
I_{TSM} (1 cycle applied voltage)	350				A
Critical di/dt	200				A/µs
P_{GM} (peak, forward, or reverse for 10 µs)	40				W
$P_{G(AV)}$	0.5				W
T_{stg}	−40 to 125				°C
T_C	−40 to 100				°C

Thyristors (cont'd)

CHARACTERISTICS (At maximum electrical rating at T_C = 25°C)

	2N3870	2N3871	2N3872	2N3873	
$V_{(BO)}$ (T_C = 100°C)	100 min	200 min	400 min	600 min	V
I_D (V_D = $V_{(BO)}$ min value,	0.2 typ	0.25 typ	0.3 typ	0.35 typ	mA
T_C = 100°C)	2 max	2.5 max	3 max	4 max	mA
I_{RD} (V_{RD} = $V_{(BO)}$ min value, T_C = 100°C)	3 max				mA
v_T (on-state current = 100 A)	1.7 typ; 2.1 max				V
v_T (initial) (i_T = 300 A, t = 2 µs, V_D = $V_{(BO)}$ min value, I_{GT} = 200 mA)	15 typ; 25 max				V
I_{GT}	1 min, 25 typ, 40 max				mA(dc)
V_{GT}	1.1 typ; 2 max				V(dc)
I_H	0.5 to 70				mA
Critical dv/dt (V_D = $V_{(BO)}$ min value, exponential rise, T_C = 100°C)	10 min; 100 typ				V(dc)
t_{gt} (V_D = $V_{(BO)}$ min value, i_T = 30 A, I_{GT} = 200 mA, 0.1 µs rise time)	0.75 to 2				µs
t_q (i_T = 18 A, 50 µs pulse width, dv_D/dt = 20 V/µs, di_R/dt = 30 A/µs, I_{GT} = 200 mA, T_C = 80°C)	15 to 40				µs



SILICON CONTROLLED RECTIFIERS 2N3896—2N3899

Si all-diffused three-junction types for use in power-control and power-switching applications. Outline No.32. Terminals: Long Lug - cathode, Short Lug - gate, Mounting Stud - anode. Types 2N3896, 2N3897, 2N3898, and 2N3899 are electrically identical with types 2N3870, 2N3871, 2N3872, and 2N3873, respectively.

Thyristors (cont'd)

2N4101, 2N4102 SILICON CONTROLLED RECTIFIERS

Si all diffused three junction types for use in power-control and power-switching applications, 2N4101: JEDEC TO-66, Outline No.22. Terminals: 1 - gate, 2 - cathode, Case - anode. 2N4102: JEDEC TO-8, Outline No.5. Terminals: 1 - cathode, 2 - gate, 3 - anode (connected to case). For data, refer to type 2N3228.

2N4103 SILICON CONTROLLED RECTIFIER

Si all-diffused three-junction type for use in power-control and power-switching applications. JEDEC TO-3, Outline No.2. Terminals: 1 - gate, 2 - cathode, Case - anode. For data, refer to types 2N3668—2N3670.

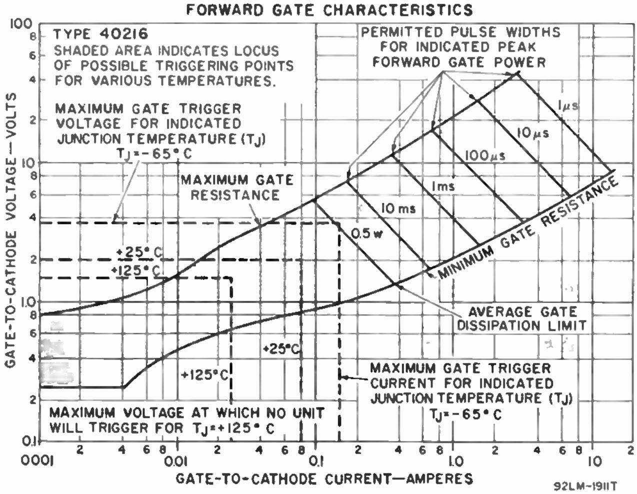
40216 SILICON CONTROLLED RECTIFIER

Si all-diffused three-junction type for use in radar pulse modulators, inverters, switching regulators, and other applications requiring a large ratio of peak to average current. JEDEC TO-48, Outline No. 17. Terminals: Long Lug - cathode, Short Lug - gate, Mounting Stud - anode.

MAXIMUM RATINGS

V_{RSM}	720	V
V_{RRM}	600	V
V_{DRM}	600	V
$I_{T(RMS)}$ (T_C = 65°C)	35	A
I_{TRM}	900	A
P_M (T_C = 65°C)	30	W
P_{GM} (peak, forward or reverse, for 10 μs)	40	W
$P_{G(AV)}$	0.5	W
T_{stg}	−65 to 150	°C
T_C	−65 to 125	°C

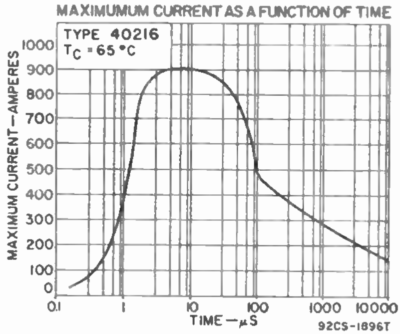
FORWARD GATE CHARACTERISTICS



Thyristors (cont'd)

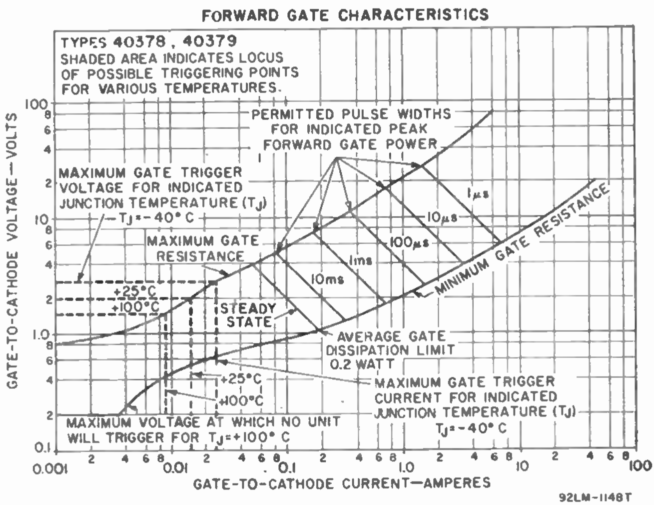
CHARACTERISTICS (At maximum electrical rating at T_C = 25°C)

$V_{(BO)}$ (T_C = 125°C)	600 min	V
I_D (T_C = 125°C)	10 max	mA
I_{RD} (T_C = 125°C)	10 max	mA
I_{GT}	1 min, 25 typ, 80 max	mA(dc)
V_{GT}	1.1 typ; 2 max	V(dc)
I_H	0.5 to 70	mA
Critical dv/dt (V_D = $V_{(BO)}$ min value, exponential rise, T_C = 125°C)	20 min; 50 typ	μs
t_{gt} (V_D = $V_{(BO)}$ min value, i_T = 30 A, I_{GT} = 200 mA, 0.1 μs min rise time)	1.25	μs
t_q (i_T = 18 A, 50 μs pulse width, dv_D/dt = 20 V/μs, di_R/dt = 30 A/μs, I_{GT} = 200 mA, T_C = 80°C)	15 to 40	μs
θ_{J-C}	2 max	°C/W



SILICON CONTROLLED RECTIFIERS 40378, 40379

Si all-diffused three-junction types for use in power-control and power-switching applications. Outline No.29. Terminals: 1 - cathode, 2 - gate, Case - anode.



Thyristors (cont'd)

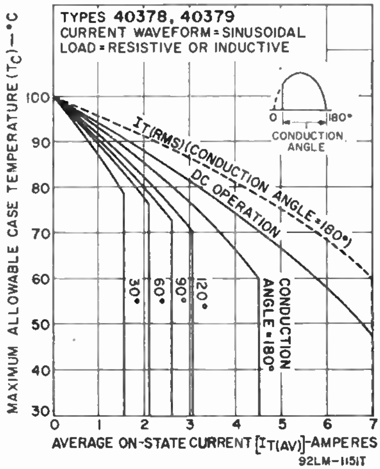
MAXIMUM RATINGS (For sinusoidal ac supply voltage at f = 50 to 400 Hz with resistive or inductive load)

<table>
<tr><th></th><th>40378</th><th>40379</th><th></th></tr>
<tr><td>V_{RSM}</td><td>330</td><td>660</td><td>V</td></tr>
<tr><td>V_{RRM}</td><td>200</td><td>400</td><td>V</td></tr>
<tr><td>V_{DRM}</td><td colspan="2">600</td><td>V</td></tr>
<tr><td>$I_{T(AV)}$ (conduction angle = 180°, T_C = 60°C)</td><td colspan="2">4.5</td><td>A</td></tr>
<tr><td>$I_{T(RMS)}$</td><td colspan="2">7</td><td>A</td></tr>
<tr><td>I_{TSM} (1 cycle applied voltage)</td><td colspan="2">80</td><td>A</td></tr>
<tr><td>P_{GM} (peak, forward or reverse, for 10 μs)</td><td colspan="2">13</td><td>W</td></tr>
<tr><td>$P_{G(AV)}$</td><td colspan="2">0.2</td><td>W</td></tr>
<tr><td>T_{stg}</td><td colspan="2">−40 to 150</td><td>°C</td></tr>
<tr><td>T_C</td><td colspan="2">−40 to 100</td><td>°C</td></tr>
</table>

CHARACTERISTICS (At maximum electrical rating at T_C = 25°C)

<table>
<tr><th></th><th>40378</th><th>40379</th><th></th></tr>
<tr><td>$V_{(BO)}$ (T_C = 100°C)</td><td>200 min</td><td>400 min</td><td>V</td></tr>
<tr><td rowspan="2">I_D (T_C = 100°C, V_D = $V_{(BO)}$ min value)</td><td>0.1 typ</td><td>0.2 typ</td><td>mA</td></tr>
<tr><td>1 max</td><td>2 max</td><td>mA</td></tr>
<tr><td rowspan="2">I_{RD} (T_C = 100°C, V_{RD} = V_{RRM})</td><td>0.05 typ</td><td>0.1 typ</td><td>mA</td></tr>
<tr><td>0.5 max</td><td>1 max</td><td>mA</td></tr>
<tr><td>v_T (on-state current = 30 A)</td><td colspan="2">1.9 typ; 2.5 max</td><td>V</td></tr>
<tr><td>I_{GT}</td><td colspan="2">8 typ; 15 max</td><td>mA (dc)</td></tr>
<tr><td>V_{GT}</td><td colspan="2">1.2 typ; 2 max</td><td>V (dc)</td></tr>
<tr><td>I_H</td><td colspan="2">12</td><td>mA</td></tr>
<tr><td rowspan="2">Critical dv/dt (V_D = $V_{(BO)}$ min value, exponential rise, T_C = 100°C)</td><td>10 min</td><td>20 min</td><td>V/μs</td></tr>
<tr><td>200 typ</td><td>200 typ</td><td>V/μs</td></tr>
<tr><td>θ_{J-C}</td><td colspan="2">5 max</td><td>°C/W</td></tr>
</table>

RATING CHART (CASE TEMPERATURE)



40429, 40430 TRIACS

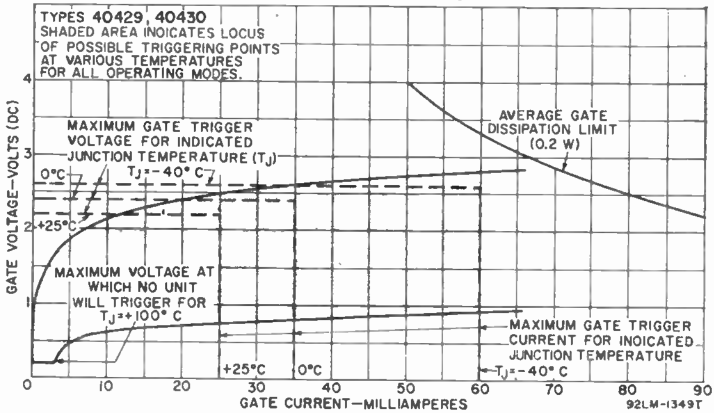
Si gated bidirectional all-diffused types used for control of ac loads in applications such as lighting, heating, induction motor control, and static switching. JEDEC TO-66, Outline No.22. Terminals: 1 - gate, 2 - main terminal 1, Case - main terminal 2.

Thyristors (cont'd)

MAXIMUM RATINGS (For sinusoidal ac supply voltage at f = 50 and 60 Hz with resistive or inductive load; all voltages are specified with reference to main terminal 1)

	40429		40430	
V_{DRM}● (T_J = −40 to 100°C)	200		400	V
$I_{T(RMS)}$ (T_C = 75°C, conduction angle = 360°)		6		A
I_{TSM} (1 cycle applied sinusoidal principal voltage)		80		A
I_{GM}* (1 μs max)		1		A
P_{GM}* (1 μs max, I_{GM} ≤ 1 A peak)		20		W
$P_{G(AV)}$		0.2		W
T_{stg}		−40 to 150		°C
T_C		−40 to 100		°C

GATE CHARACTERISTICS

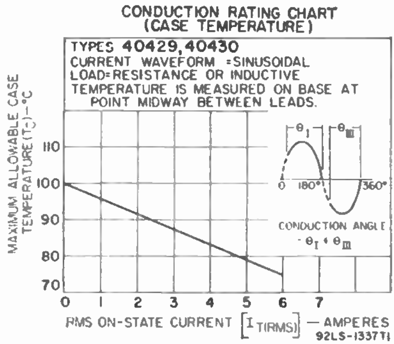


CHARACTERISTICS (At maximum electrical ratings at T_C = 25°C; all voltages are specified with reference to main terminal 1)

	40429		40430	
I_D● (T_J = 100°C, V_{DRM} = max rated value)	0.1 typ 2 max		0.2 typ 4 max	mA mA
v_T● (i_T = 30 A peak)		1.6 typ; 2.2 max		V(peak)
i_H● (initial principal current = 150 mAdc)		10 typ; 30 max		mA(dc)
Commutating dv/dt● (v_D = V_{DRM}, $I_{T(RMS)}$ = 6 A, commutating di/dt = 4 A/ms):				
T_C = 75°C		5		V/μs
T_C = 50°C		8		V/μs
Critical dv/dt● (v_D = V_{DRM}, exponential voltage rise, gate open, T_C = 100°C)	30		20	V/μs
I_{GT} (v_D = 6 Vdc, R_L = 12 Ω):				
I+ mode, V_{T2} positive, V_G positive		10 typ; 25 max		mA(dc)
I− mode, V_{T2} positive, V_G negative		20 typ; 25 max		mA(dc)
III+ mode, V_{T2} negative, V_G positive		20 typ; 25 max		mA(dc)
III− mode, V_{T2} negative, V_G negative		10 typ; 25 max		mA(dc)
V_{GT}●* (v_D = 6 Vdc, R_L = 12 Ω)		1 typ; 2.2 max		V
V_{GT}●* (v_D = V_{DRM}, R_L = 125 Ω, T_C = 100°C)		0.2 min		V
t_{gt}●* (v_D = V_{DRM}, I_{GT} = 80 mA, 0.1 μs t_r, i_T = 10 A peak)		2.2		μs

● For either polarity of main terminal 2 voltage (V_{T2}) with reference to main terminal 1.
* For either polarity of gate voltage (V_G) with reference to main terminal 1.

Thyristors (cont'd)

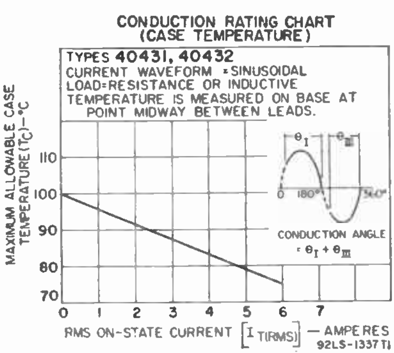


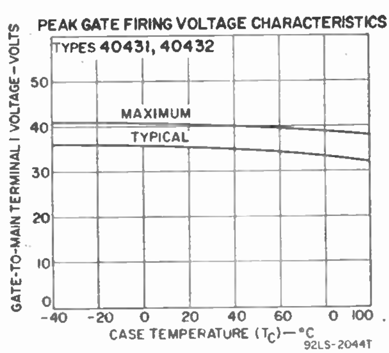
40431, 40432 TRIACS

Si gated bidirectional all-diffused types used for phase control of ac loads in applications such as light dimming, universal and induction motor control, and heater control. These devices have integral triggers. JEDEC TO-5 (modified), Outline No.3 (modified). Terminals: 1 - main terminal 1, 2 - gate, Case - main terminal 2.

MAXIMUM RATINGS (For sinusoidal ac supply voltage at f = 50 and 60 Hz with resistive or inductive load)

	40431	40432	
V_{DRM} (gate open, T_J = −40 to 100°C)	200	400	V
$I_{T(RMS)}$ (T_C = 75°C, conduction angle = 360°)	6	6	A
I_{TSM} (1 cycle applied sinusoidal principal voltage)	100	100	A
I_{GTM} (2 µs max)	1	1	A
P_{GM} (2 µs max, I_{GTM} ≤ 1 A peak)	20	20	W
$P_{G(AV)}$	0.2	0.2	W
T_{stg}*▲	−40 to 150	−40 to 150	°C
T_C*▲	−40 to 100	−40 to 100	°C





Thyristors (cont'd)

CHARACTERISTICS (At maximum electrical rating at T_C = 25°C)

	40431	40432	
I_D● (gate open, T_J = 100°C, V_{DRM} = max rated value)	0.1 typ 2 max	0.2 typ 4 max	mA mA
v_T● (i_T = 30 A)	1.6 typ; 2.25 max		V(peak)
I_H● (initial principal current = 150 mAdc)	10 typ; 30 max		mA(dc)
Commutating dv/dt● (v_D = V_{DRM}, $I_{T(RMS)}$ = 6 A, commutating di/dt = 4 A/ms, gate open):			
T_C = 75°C	5		V/µs
T_C = 50°C	8		V/µs
Critical dv/dt● (v_D = V_{DRM}, exponential voltage rise, gate open, T_C = 100°C)	30	20	V/µs
V_{GDM}‡	20 min, 35 typ, 40 max		V
$\lvert V_{GM}^{+}\rvert - \lvert V_{GM}^{-}\rvert$‡	±1 typ; ±3 max		V
I_{GDM}‡	40 typ; 200 max		µA
Gate Trigger Capacitance‡ (v_D = 6 Vdc, R_L = 12 Ω, T_C = 100°C)	0.1 to 2		µF
t_{gt} (v_D = V_{DRM}, I_{GT} = 80 mA, 0.1 µs rise time, i_T = 10 A peak)	2.2		µs

● For either polarity of main-terminal 2 voltage (V_{T2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
* For information on the reference point of temperature measurement, see section on Outlines.
▲ When these devices are soldered directly to the heat sink, a 60-90 solder should be used. Exposure time should be just sufficient to cause the solder to flow freely.
‡ This characteristic does not apply to types 40485 and 40486.

TRIACS 40485, 40486

Si gated bidirectional all-diffused types used for control of ac loads in such applications as light dimming, universal and induction motor control, and heater control. JEDEC TO-5 (modified), Outline No.3 (modified). Terminals: 1 - main terminal No.1; 2 - gate, Case - main terminal No.2. Types 40485 and 40486 are identical with types 40431 and 40432, respectively, except for the following items:

CHARACTERISTICS (At maximum electrical rating at T_C = 25°C)

I_{GT}●■ (v_D = 6 Vdc, R_L = 12 Ω):		
I+ mode, V_{T2} positive, V_G positive	10 typ; 25 max	mA(dc)
I− mode, V_{T2} positive, V_G negative	20 typ; 25 max	mA(dc)
III+ mode, V_{T2} negative, V_G positive	20 typ; 25 max	mA(dc)
III− mode, V_{T2} negative, V_G negative	10 typ; 25 max	mA(dc)
V_{GT}●■:		
v_D = 6 Vdc, R_L = 12 Ω	1 typ; 2.2 max	V
v_D = V_{DRM}, R_L = 125 Ω, T_C = 100°C	0.2 min	V

● For either polarity of main-terminal 2 voltage (V_{T2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.

TRIACS 40502, 40503

Si gated bidirectional all-diffused types used for power-control and power-switching applications. JEDEC TO-66 (with heat radiator), Outline No.22A (with heat radiator). Terminals: 1 - gate, 2 - main terminal 1, Case - main terminal 2 (with heat radiator). Types 40502 and 40503 are electrically identical with types 40429 and 40430, respectively.

Thyristors (cont'd)

40504—40506 SILICON CONTROLLED RECTIFIERS

Si all-diffused three-junction types used in power-control and power-switching applications. JEDEC TO-66 (with heat radiator), Outline No.22A (with heat radiator). Terminals: 1 - gate, 2 - cathode, Case - anode (with heat radiator). Types 40404, 40405, and 40406 are electrically identical with types 2N3228, 2N3525, and 2N4101, respectively.

40507, 40508 SILICON CONTROLLED RECTIFIERS

Si all-diffused three-junction types used in power-control and power-switching applications. Outline No.29 (with Outline No.3 heat radiator). Terminals: 1 - cathode, 2 - gate, Case - anode (with heat radiator). Types 40507 and 40508 are electrically identical with types 40378 and 40379, respectively.

40509, 40510 TRIACS

Si all-diffused three-junction types used in power-control and power-switching applications. JEDEC TO-5 (modified), Outline No.3 (modified with heat radiator). Terminals: 1 - main terminal 1, 2 -gate, Case - main terminal 2 (with heat radiator). Types 40509 and 40510 are electrically identical with types 40485 and 40486, respectviely.

40511, 40512 TRIACS

Si gated bidirectional integral-trigger types used for power-control and power-switching applications. JEDEC TO-5 (modified), Outline No.3 (modified with heat radiator). Terminals: 1 - main terminal 1, 2 - gate, Case - main terminal 2 (with heat radiator). Types 40511 and 40512 are electrically identical with types 40431 and 40432, respectively.

40525—40530 TRIACS

Si gate-controlled full-wave types used for switching from a blocking state to a conducting state for either polarity of applied voltage with positive or negative gate triggering. These types can be controlled with economical transistor circuits for use in low-power phase-control and load-switching applications. JEDEC TO-5 (modified), Outline No.3 (modified). Terminals: 1 - main terminal 1, 2 - gate, 3 - main terminal 2 and case.

MAXIMUM RATINGS (For sinusoidal ac supply voltage at f = 50 and 60 Hz with resistive or inductive load)

	40525	40526	40527	40528	40529	40530	
V_{DRM}● (gate open):							
T_J = −40 to 90°C	100	200	400	—	—	—	V
T_J = −40 to 100°C	—	—	—	100	200	400	V
$I_{T(RMS)}$ (conduction angle = 360°)							
T_C = 60°C		2.5		—	—	—	A
T_C = 70°C	—	—	—		2.5		A
T_A = 25°C		0.35			0.4		A
I_{TSM} (1 cycle sinusoidal principal voltage)			25				A
I_{GTM}■ (1 μs max)			0.5				A
P_{GM}■ (1 μs max)			10				W
$P_{G(AV)}$:							
T_A = 25°C			0.05				W
T_C = 60°C			0.15				W
T_{stg}●			−40 to 150				°C
T_C●			−40 to 100				°C

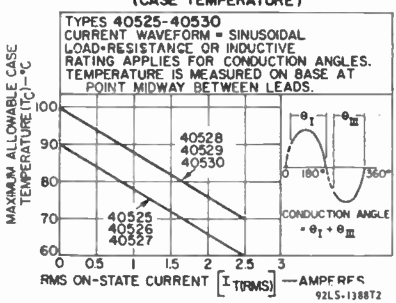
Thyristors (cont'd)

CHARACTERISTICS (At maximum electrical ratings at T_C = 25°C)

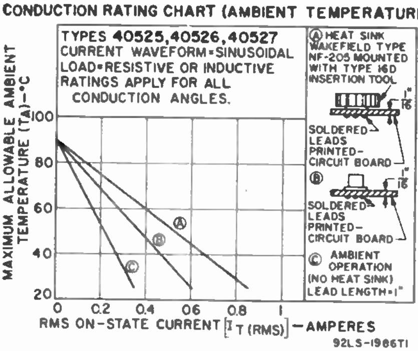
	40525	40526	40527	40528	40529	40530	
I_D● (gate open, V_{DRM} = max rated value):							
T_J = 100°C	—	—	—	0.2 typ; 0.75 max			mA
T_J = 90°C	0.2 typ; 0.75 max			—	—	—	mA
v_T● (i_T = 10 A peak)	1.7 typ; 2.2 max						V (peak)
I_H● (initial principal current = 150 mAdc)	2 typ; 5 max			6.5 typ; 15 max			mA (dc)
Critical dv/dt● (v_D = V_{DRM}, exponential voltage rise, gate open):							
T_C = 100°C	—	—	—	10			V/µs
T_C = 90°C	5			—	—	—	V/µs
I_{GT}●■ (v_D = 6 Vdc, R_L = 39 Ω):							
I+ mode, V_{T2} positive, V_G positive	1 typ; 3 max			3.5 typ; 10 max			mA (dc)
I− mode, V_{T2} positive, V_G negative	2 typ; 3 max			7 typ; 10 max			mA (dc)
III+ mode, V_{T2} negative, V_G positive	2 typ; 3 max			7 typ; 10 max			mA (dc)
III mode, V_{T2} negative, V_G negative	1 typ; 3 max			3.5 typ; 10 max			mA (dc)
V_{GT}●■:							
v_D = 6 Vdc, R_L = 39 Ω	1 typ; 2.2 max						V
v_D = V_{DRM}, R_L = 125 Ω, T_C = 100°C	—	—	—	0.15 min			V
v_D = V_{DRM}, R_L = 125 Ω, T_C = 90°C	0.15 min			—	—	—	V

● For either polarity of main-terminal 2 voltage (V_{T2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.

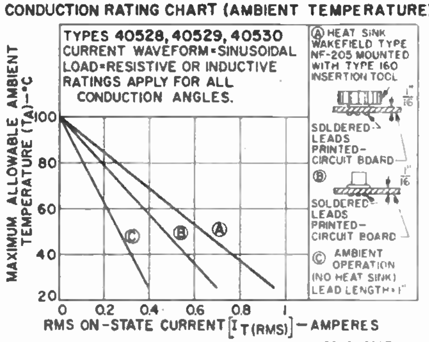
CONDUCTION RATING CHART (CASE TEMPERATURE)



CONDUCTION RATING CHART (AMBIENT TEMPERATURE)



CONDUCTION RATING CHART (AMBIENT TEMPERATURE)



Thyristors (cont'd)

40531—40536 **TRIACS**

Si gated bidirectional types used for power-control and power-switching applications. JEDEC TO-5 (with heat radiator), Outline No.3 (with heat radiator). Terminals: 1 - main terminal 1, 2 - gate, 3 - main terminal 2 and case (with heat radiator). Types 40531, 40532, 40533, 40534, 40535, and 40536 are electrically identical with types 40525, 40526, 40527, 40528, 40529, and 40530, respectively.

Silicon Diffused-Junction Rectifiers

RCA TYPE	OUTLINE JEDEC	OUTLINE NO.	MAXIMUM RATINGS I_{FAV} at T_C A	°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
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	CHARACTERISTICS 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	i_{FM} (surge) A	V_{RMS} V	V_{RM} and V_M (block) V	CHARACTERISTICS V_{FM} V	I_{RM} (dynamic) mA
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	1.3	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	i_{FM} (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: 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)	CHARACTERISTICS: 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 Plug-in 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 Bridge 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

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.	Rise Time (ps) 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

Compensating Diodes

1N2326 COMPENSATING DIODE

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	Reverse	Dissipation ‡ (mW)	Ambient-Temperature (°C) Range Operating	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

Compensating Diodes

COMPENSATING DIODE 40428

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}	−0.5	V
DC Forward Current	I_{FM}	100	mA
Peak Forward Current	$i_F(max)$	200	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

DC Forward Voltage Drop:		min	typ	max	
$T_C = 25°C$	V_{FAV}	235	260	285	mV
$T_A = 25°C$	V_{FAV}	225	250	275	mV

Damper Diodes

1N4785 DAMPER DIODE

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

40442 DAMPER DIODE

Ge diffused-junction type used in transistorized 114-degree, 18-kilovolt horizontal-deflection systems in television receivers with types 2N3730, 2N3731, 2N3732, 40439, and 40440 to make up a complete transistor/damper-diode complement. JEDEC TO-3, **Outline** No.2. **Terminals**: 1 - cathode, 2 - no connection, Mounting Flange - anode and case. This type is identical to type 1N4785 except for the following items:

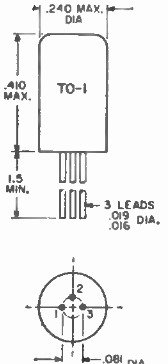
MAXIMUM RATINGS

Peak Reverse Voltage	v_{RM}	200	V
Continuous Reverse Voltage	V_{RM}	40	V

CHARACTERISTICS

Peak Reverse Voltage (I_R = 1 mA)	v_{RM}	200 min	V

Outlines



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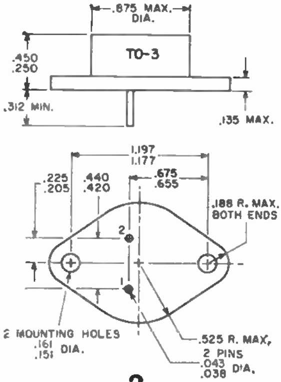

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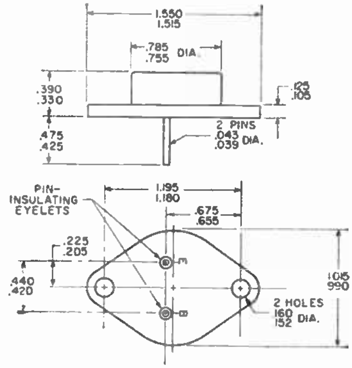

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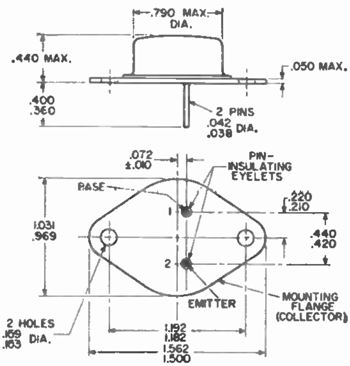

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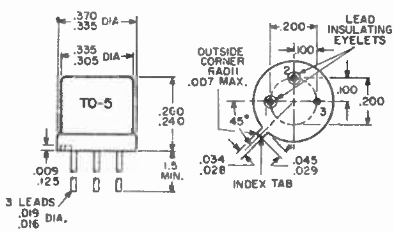

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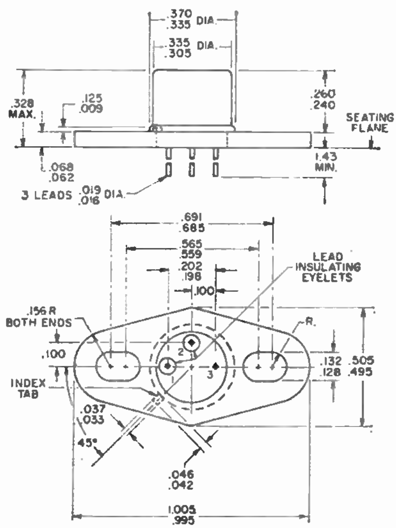
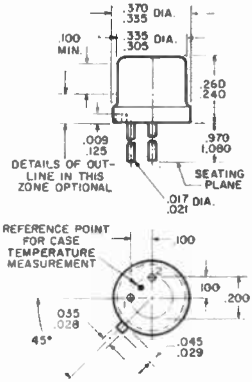


3 (With Flange)

Outlines (cont'd)



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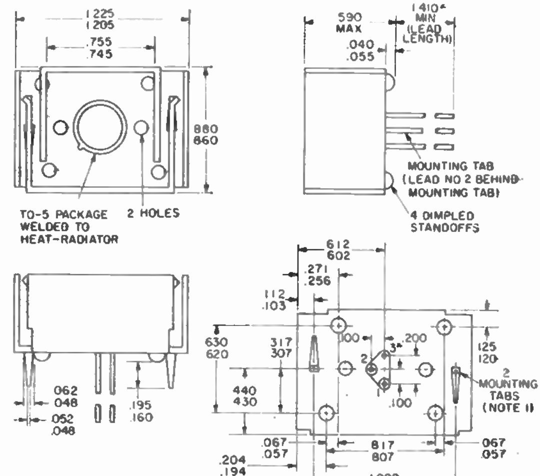
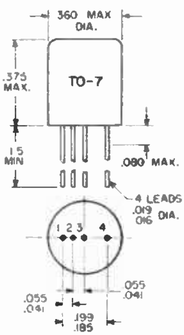


NOTE 1: RECOMMENDED HOLE SIZE FOR PRINTED-CIRCUIT BOARD IS 0.070 DIA.

* MODIFIED TO-5 TYPE IS A 2 LEAD PACKAGE HAVING LEAD LENGTHS OF 0.9 min. LENGTH.

3 (With Heat Radiator)



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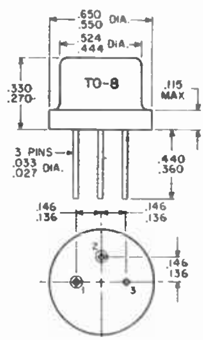

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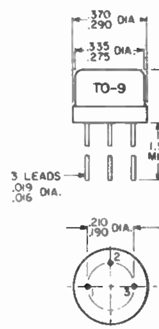

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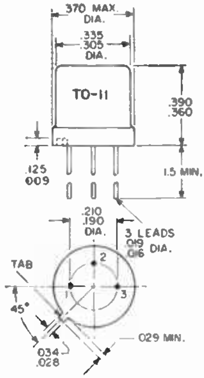

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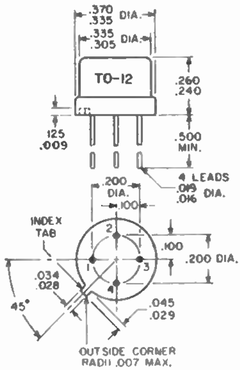

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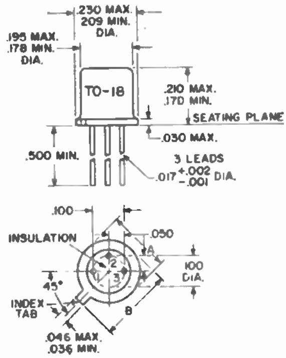

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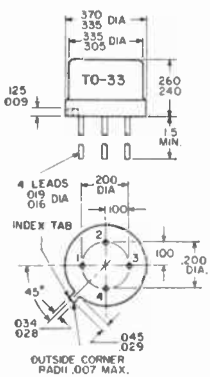

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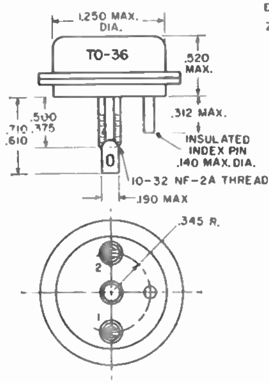

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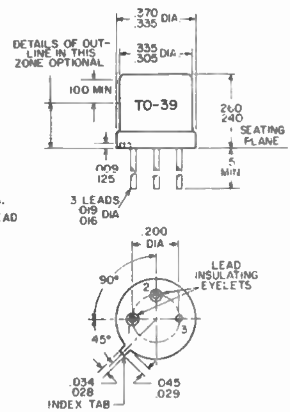

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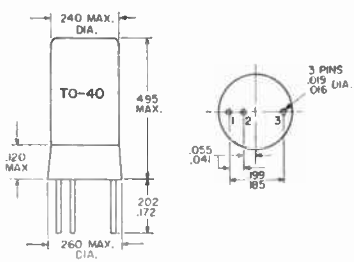

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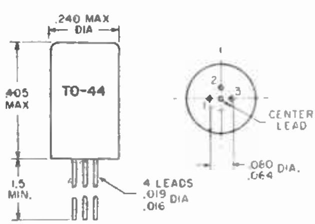

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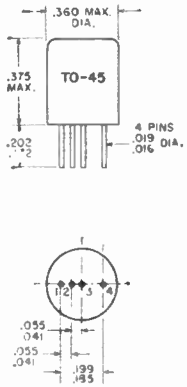

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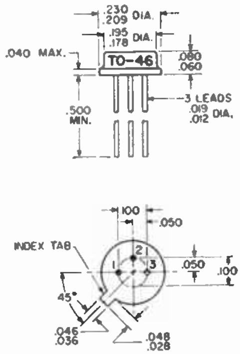

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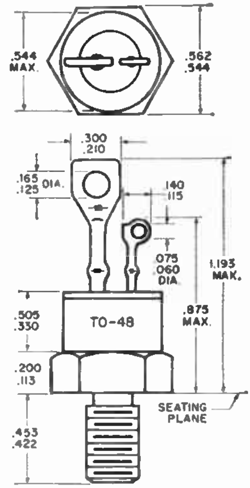

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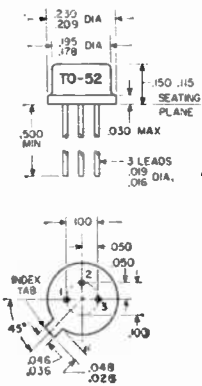

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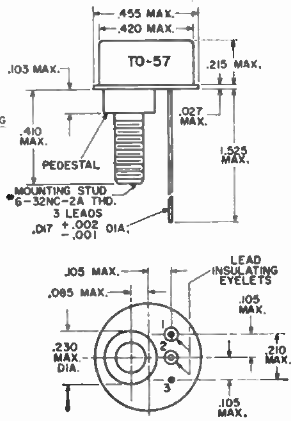

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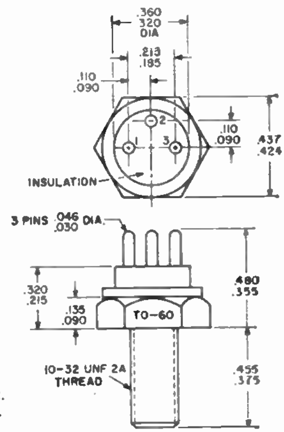

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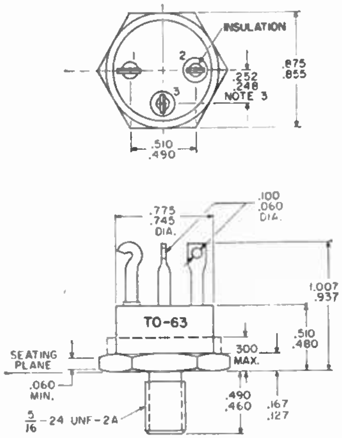

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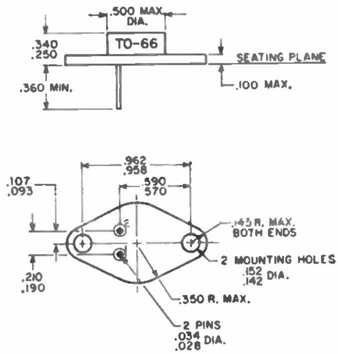

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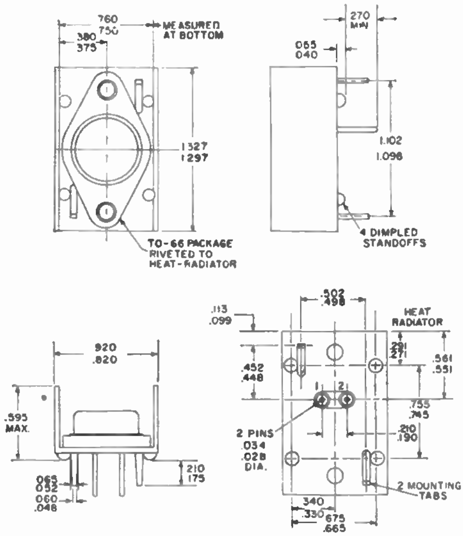
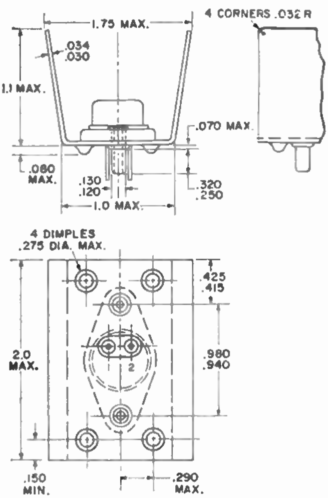
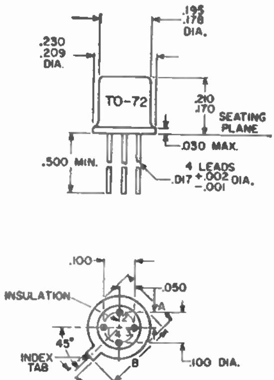




22 A (With Heat Radiator) 22B (With Heat Radiator)

Outlines (cont'd)



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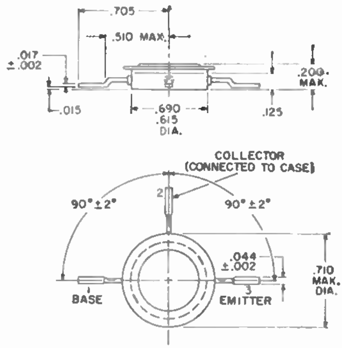

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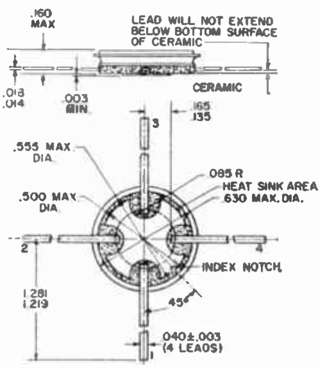

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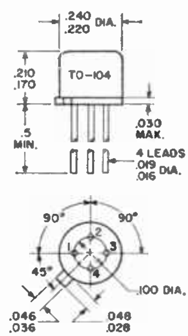
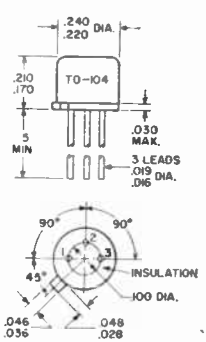


26 (4-Lead)



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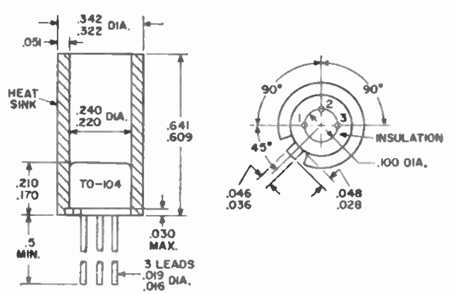
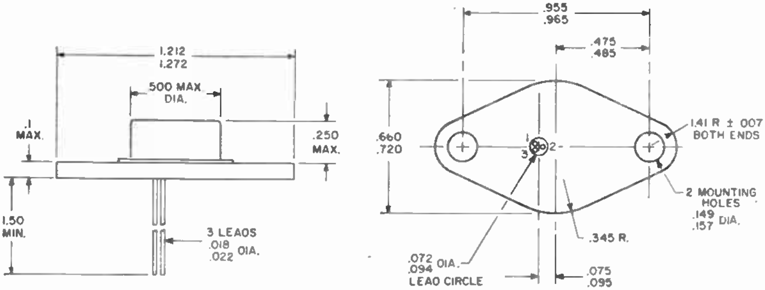


27 (3-Lead With Heat Sink)

Outlines (cont'd)



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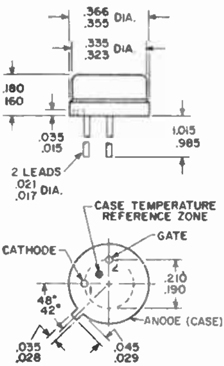

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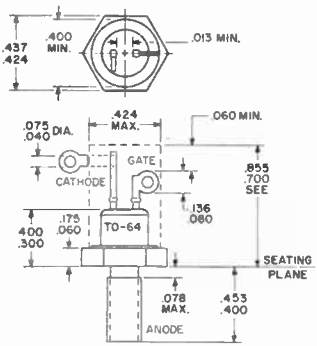

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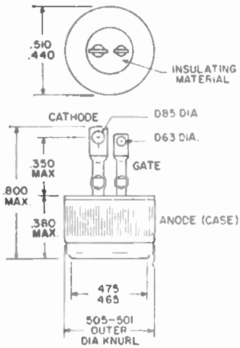
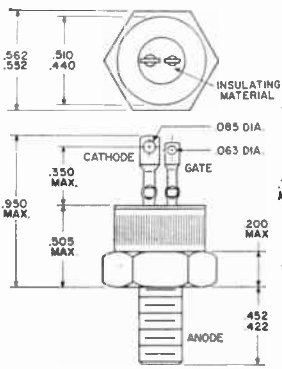


31 (Press Fit)



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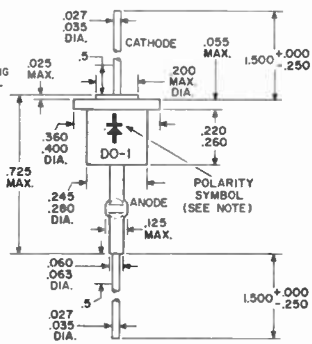
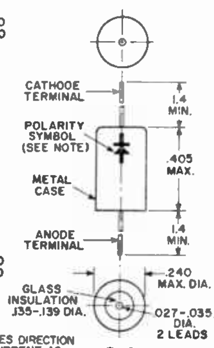


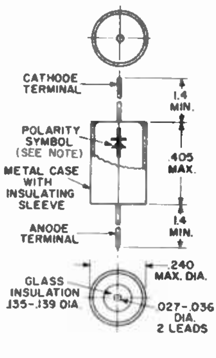


NOTE: ARROW INDICATES DIRECTION OF FORWARD CURRENT AS INDICATED BY DC AMMETER

33

34

Outlines (cont'd)



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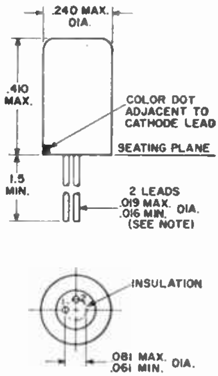

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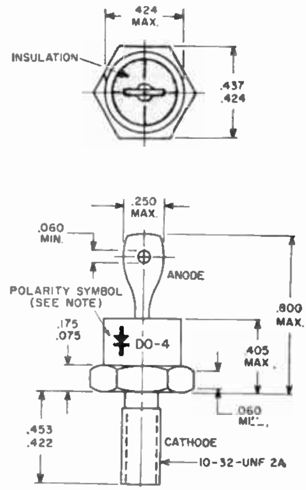

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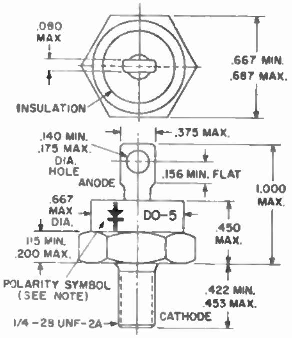

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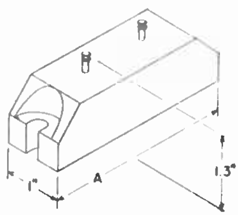
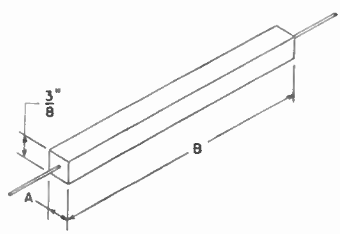


39

Outline No.	"A" (Inches)
39a	2⅜
39b	2⅜
39c	2⅜
39d	3¼
39e	3¼
39f	4½
39g	4½
39h	4½
39i	5½
39j	5½

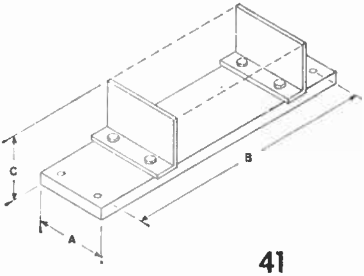


NOTE: ARROW INDICATES DIRECTION OF FORWARD CURRENT AS INDICATED BY DC AMMETER

40

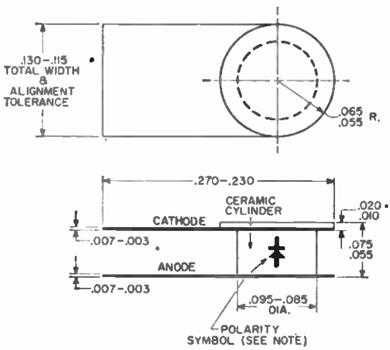
Outline No.	"A" (Inches)	"B" (Inches)
40a	⅜	2
40b	⅜	3½
40c	⅜	4½
40d	¾	3½
40e	¾	3½
40f	¾	4½
40g	¾	4½

Outlines (cont'd)



41

Outline No.	"A" (Inches)	"B"	"C"	Outline No.	"A" (Inches)	"B"	"C"
41a	2¼	5¼	2	41q	3	11⅞	3⅜
41b	2¼	7	2	41r	3	14¼	3⅜
41c	2¼	8¾	2	41s	3	16⅝	3⅜
41d	2¼	10½	2	41t	3	7⅛	3⅜
41e	2¼	12¼	2	41u	3	9½	3⅜
41f	2¼	14	2	41v	3	11⅞	3⅜
41g	2¼	15¾	2	41w	3	14¼	3⅜
41h	2¼	5¼	2	41x	3	16⅝	3⅜
41i	2¼	7	2	41y	5½	7 11/16	5⅝
41j	2¼	8¾	2	41z	5½	10¼	5⅝
41k	2¼	10½	2	41aa	5½	12 13/16	5⅝
41l	2¼	12¼	2	41bb	5½	15⅜	5⅝
41m	2¼	14	2	41cc	5½	7 11/16	5⅝
41n	2¼	15¾	2	41dd	5½	10¼	5⅝
41o	3	7⅛	3⅜	41ee	5½	12 13/16	5⅝
41p	3	9½	3⅜	41ff	5½	15⅜	5⅝



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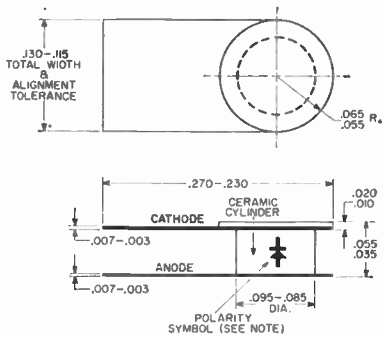

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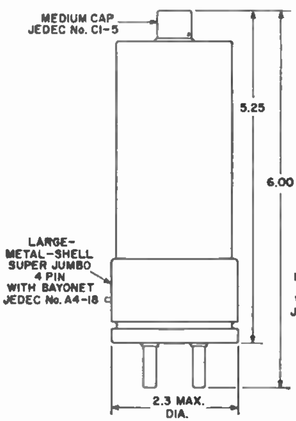

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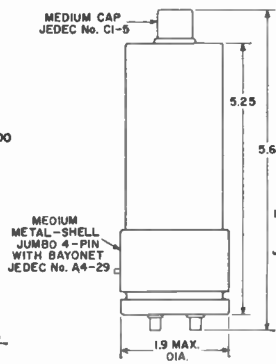

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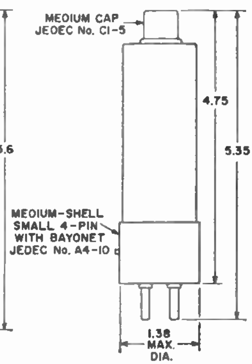
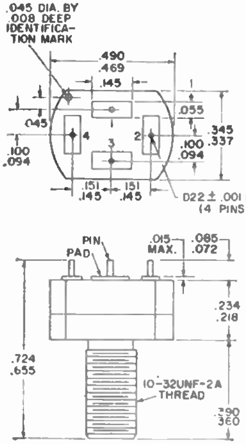


46

NOTE: ARROW INDICATES DIRECTION OF FORWARD CURRENT AS INDICATED BY DC AMMETER

Outlines (cont'd)



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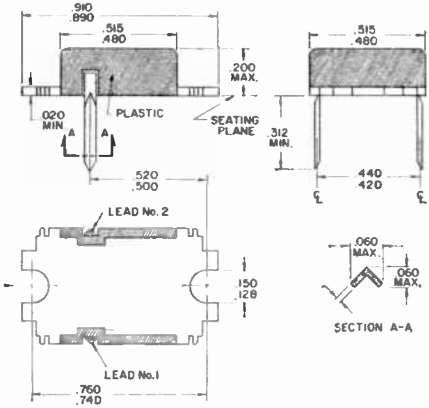

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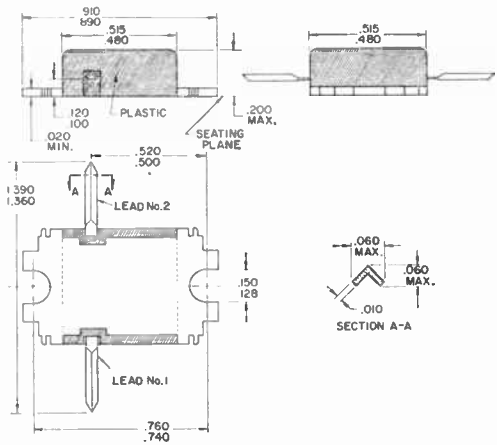

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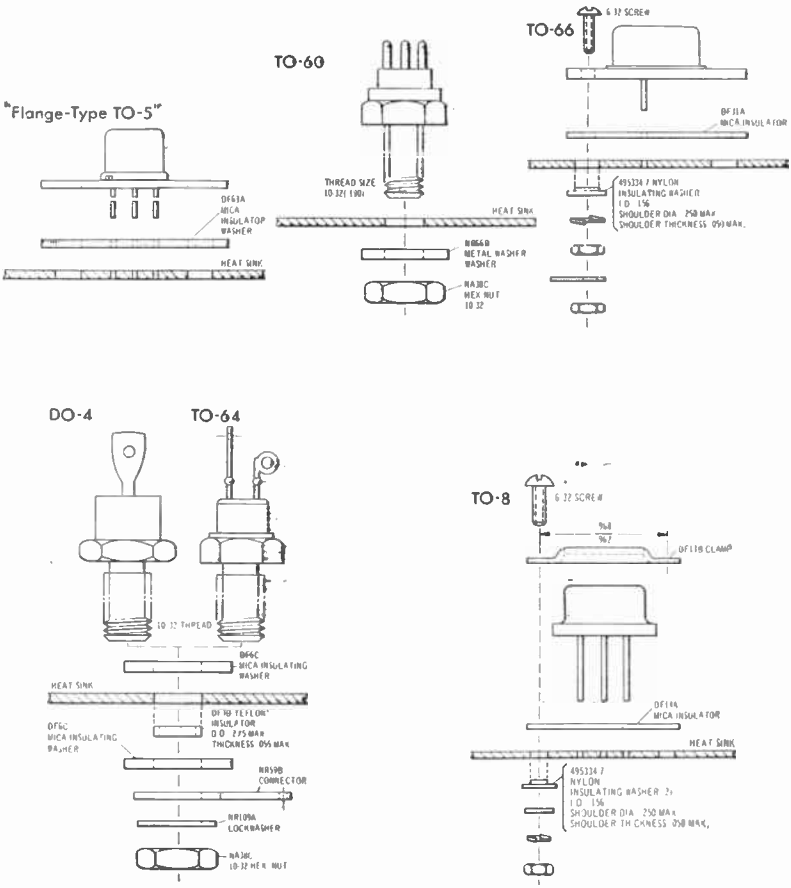
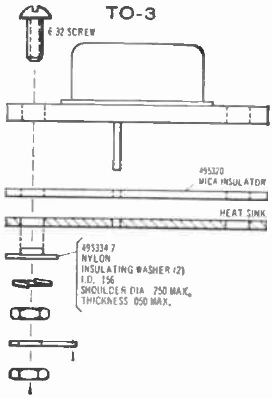
Mounting Hardware

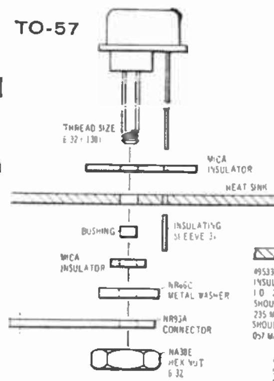


Mounting Hardware (cont'd)

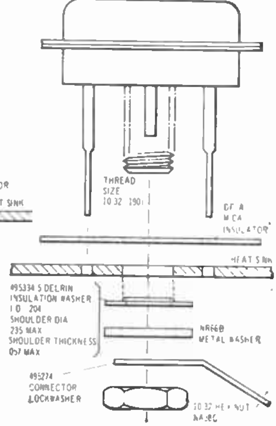
TO-3



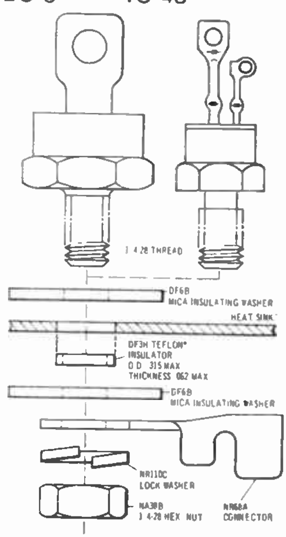
TO-57



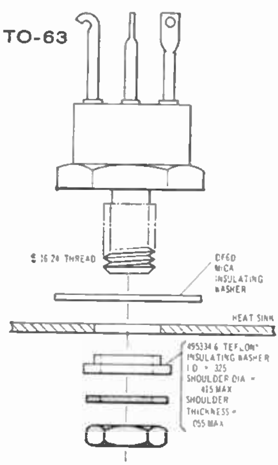
TO-36



DO-5 TO-48

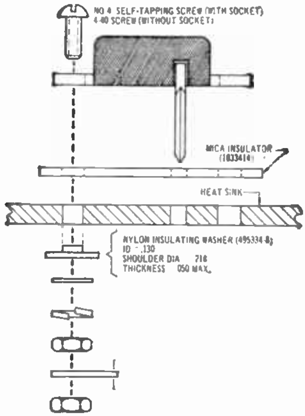


TO-63

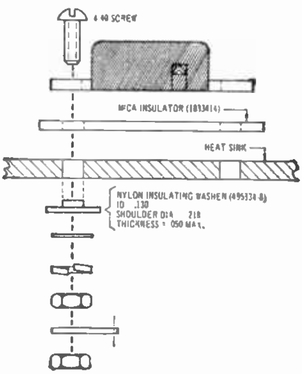


Mounting Hardware (cont'd)

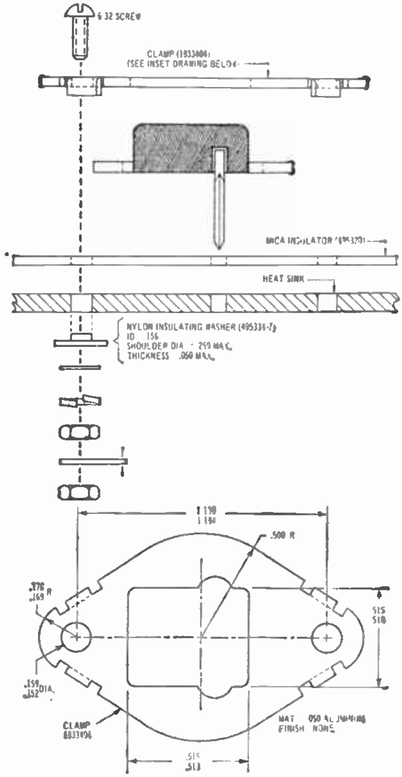
OUTLINE 48



OUTLINE 49



"OUTLINE 48 in place of TO-3 Type"



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

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13-3 All-American-Five AC/DC Radio Receiver 469
13-4 High-Quality FM Tuner for Multiplex Receiver 472
13-5 FM Stereo Multiplex Demodulator 474
13-6 High-Quality Preamplifier for Phono, FM, or Tape Pickup 477
13-7 1-Watt AC/DC Phonograph Amplifier for Use with Crystal Cartridges 478
13-8 High-Quality, 8-Watt Complementary-Symmetry Audio Power Amplifier 480
13-9 9.5-Watt Complementary-Symmetry Audio Power Amplifier 482
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13-12 25-Watt Complementary-Symmetry Audio Power Amplifier 487
13-13 High-Quality 35-Watt Audio Power Amplifier 489
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13-20 175-MHz 35-Watt Power Amplifier 506
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13-22 500-MHz 1-Watt Power Oscillator 508
13-23 Grid-Dip Meter 509

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13-25	Electronic Keyer	511
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13-40	Bistable Multivibrator	534
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MANUFACTURERS OF SPECIAL COMPONENTS AND MATERIALS
REFERRED TO IN PARTS LISTS

Arco Electronics, Inc.
Community Drive
Great Neck, N. Y.

Arnold Magnetics Corp.
6050 West Jefferson Blvd.
Los Angeles, Calif.

Automatic Winding Division
General Instrument Co.
65 Governeur Street
Newark, N. J.

Better Coil and Transformer Inc.
Goodland, Ind.

Columbus Process Electronics Co.
Columbus, Ind.

Elmwood Sensors, Inc.
1563 Elmwood Avenue
Cranston, R. I.

Ferroxcube Corp. of America
Old Kings Highway
Saugerties, New York

Freed Transformer Co.
1718 Weirfield Street
Brooklyn, N. Y.

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.

Magnetic Metals Corp.
Hayes Avenue at 21st Street
Camden, N. J.

P. R. Mallory and Co. Inc.
3029 E. Washington Street
Indianapolis, Ind.

Micro Switch
Division of Honeywell, Inc.
Freeport, Ill.

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.

Potter and Brumfield
Div. of American Machine and Foundry Co.
1200 E. Broadway
Princeton, Ind.

Radio Condenser Corp.
Davis and Copewood Street
Camden, N. J.

Stancor Electronics, Inc.
3501 West Addison Street
Chicago, Ill.

Thompson-Ramo-Wooldridge, Inc.
Electronic Components Division
666 Garland Place
Des Plaines, Ill.

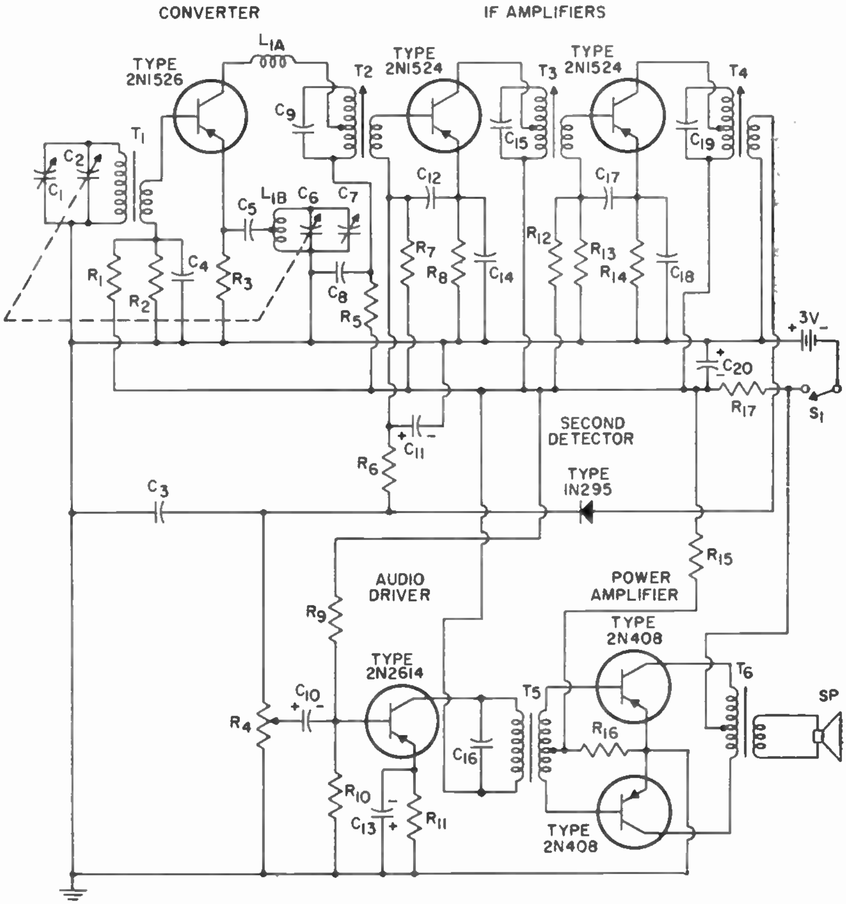
Thordarson
7th and Bellmont
Mt. Carmel, Ill.

Triad
305 N. Briant Street
Huntington, Indiana

Triwec Transformer Co.
3261 Milwaukee Avenue
Chicago, Ill.

Vitramon, Inc.
Box 544
Bridgeport, Conn.

13-1 3-VOLT PORTABLE RADIO RECEIVER



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_4, 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 kHz
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)
SP = speaker; voice-coil impedance, 12 to 15 ohms
T_1 = antenna transformer; primary, 110 turns of No. 10/41 Litz wire wound on a 3/4"-by-1/8"-by-4" fer-

13-1 3-VOLT PORTABLE RADIO RECEIVER (cont'd)

Parts List (cont'd)

rite 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 kHz

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)

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 is mixed with a local-oscillator signal developed by the tuned circuit L_{1B}, C_6, and C_7 to produce the 455-kHz 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}.

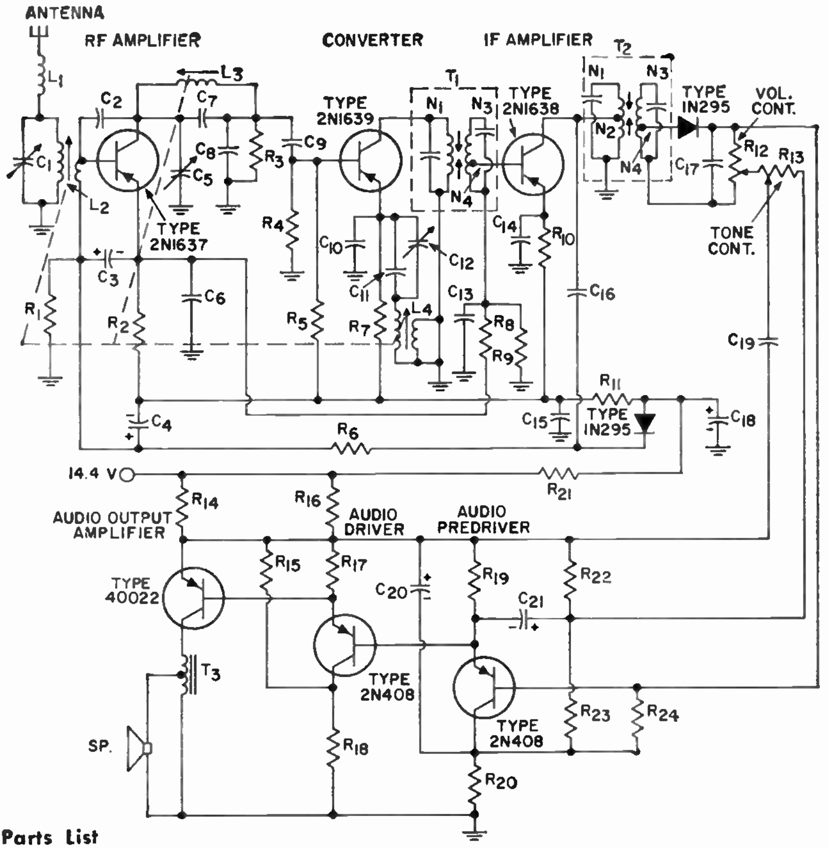
The 455-kHz signal from the converter stage is amplified by two if-amplifier stages using 2N1524 transistors. The amplified if signal is then demodulated in the second-detector circuit. The 1N295 detector diode rectifies the if signal, and capacitor C_3 filters out the rf components so that only the 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.

13-2 12-VOLT AUTOMOBILE RADIO RECEIVER

Circuit Description

This 5-transistor superheterodyne radio receiver operates from the storage battery in automobiles that employ a 12-volt ignition system. The rf amplifier uses a high-gain 2N1637 transistor to provide the increased sensitivity and higher signal-to-noise ratio required in automobile radio receivers. The tuned rf amplifier selects and amplifies the amplitude-modulated rf signals from the desired broadcast station picked up by the automobile whip antenna. In the 2N1639 converter stage, the amplitude-modulated rf signal from the rf amplifier is mixed with a local-oscillator signal developed by the tuned circuit consisting of oscillator

13-2 12-VOLT AUTOMOBILE RADIO RECEIVER (cont'd)



Parts List

C_1 = trimmer capacitor, 5 to 80 pF, Arco No. 462 or equiv.
C_2 = 2 pF, silver mica
C_3 = 2.2 μF, electrolytic, 3 V
C_4 = 25 μF, electrolytic, 6 V
C_5, C_{12} = trimmer capacitor, 110 to 580 pF, Arco No. 467 or equiv.
C_6, C_9, C_{13}, C_{14}, C_{15}, C_{19} = 0.05 μF ceramic disc
C_7 = 200 pF, silver mica
C_8 = 0.005 μF, ceramic disc
C_{10} = 0.0075 μF, ceramic disc
C_{11} = 330 pF, silver mica
C_{16} = 180 pF, silver mica
C_{17} = 0.02 μF, ceramic disc
C_{18} = 100 μF, electrolytic, 15 V
C_{20} = 50 μF, electrolytic, 6 V
C_{21} = 100 μF, electrolytic, 3 V
L_1 = rf choke, 5μH
L_2, L_3, L_4 = ganged tuning-coil assembly; manufactured by F. W. Sickles Co. and Radio Condenser Corp.
L_2 = antenna coil; primary = variable inductor, tunes with 110-pF capacitance from 535 to 1610 kHz, Q = 65 at 1610 kHz; secondary = 3½ turns
L_3 = rf coil, variable inductor, tunes with 600-pF capacitance from 535 to 1610 kHz, Q = 65 at 1610 kHz
L_4 = oscillator coil; primary = variable inductor, tunes with 470-pF capacitance from 797.5 to 1872.5 kHz, Q = 65 at 1872.5 kHz; secondary = 30 turns
R_1 = 82000 ohms, 0.5 watt
R_2 = 560 ohms, 0.5 watt
R_3 = 180 ohms, 0.5 watt
R_4 = 56000 ohms, 0.5 watt
R_5 = 5700 ohms, 0.5 watt
R_6 = 8200 ohms, 0.5 watt
R_7 = 1500 ohms, 0.5 watt
R_8 = 5600 ohms, 0.5 watt
R_9 = 0.1 megohm, 0.5 watt
R_{10} = 470 ohms, 0.5 watt
R_{11} = 100 ohms, 0.5 watt
R_{12} = volume control, potentiometer, 2500 ohms, 0.5 watt, audio taper
R_{13} = tone control, potentiometer, 1000 ohms, 0.5 watt, audio taper
R_{14} = 3.3 ohms, 1 watt
R_{15} = 82 ohms, 0.5 watt
R_{16} = 68 ohms, 0.5 watt
R_{17} = 120 ohms, 0.5 watt
R_{18} = 220 ohms, 0.5 watt
R_{19} = 1200 ohms, 0.5 watt
R_{20} = 4700 ohms, 0.5 watt
R_{21} = 680 ohms, 0.5 watt
R_{22}, R_{24} = 3300 ohms, 0.5 watt
R_{23} = 33000 ohms, 0.5 watt

13-2 12-VOLT AUTOMOBILE RADIO RECEIVER (cont'd)

Parts List (cont'd)

T_1 = first if (262.5-kHz) transformer (includes 220-pF capacitor across each winding); primary unloaded Q = 47, primary loaded Q = 40.56; secondary unloaded Q = 47; secondary loaded Q = 39.4; input impedance = 68200 ohms; turns ratio of tapped secondary, N_3/N_1 = 18.25; Automatic No. E2742208AX, Thompson-Ramo-Wooldridge No. EO14127, or equiv.

T_2 = second if (262.5-kHz) transformer (includes 110-pF capacitor across each winding); primary unloaded Q = 47, primary loaded Q = 33.8; secondary unloaded Q = 47, secondary loaded Q = 23.5; turns ratio of tapped primary, N_1/N_2 = 4.28; turns ratio of tapped secondary N_3/N_4 = 10.2; input impedance = 6000 ohms; Automatic No. E2742208-BX, Thompson-Ramo-Wooldridge No. EO14128, or equiv.

T_3 = output transformer; transforms 22 ohms at 425 mA dc to 3.5 ohms; Thordarson-Meissner No. TR-168, or equiv.

Circuit Description (cont'd)

coil L_4 and capacitors C_{11} and C_{12} to provide a signal at the receiver intermediate frequency of 262.5 kHz (this value, rather than 455 kHz, is used in auto radios because the if amplifier provides greater gain and selectivity at the lower frequency).

The antenna circuit, rf amplifier, and converter 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 kHz above the frequency to which the other circuits are tuned. Trimmer capacitors C_1, C_5, and C_{12} are adjusted to provide the proper tracking relationship.

The 262.5-kHz signal from the converter stage is amplified by a single 2N1638 if amplifier and is then demodulated in the 1N295 second-detector circuit. The audio signal from the detector, which is developed across the volume-control potentiometer R_{12}, is coupled through the tone-control potentiometer R_{13} to the audio-amplifier section of the receiver. In this section, the audio signal is amplified by two 2N408 voltage amplifiers (audio predriver and driver stages) and applied to the base circuit of the 40022 power amplifier stage which drives the speaker.

A portion of the audio-frequency signal from the detector is coupled from the wiper arm of the tone control through a frequency-selective network to the audio amplifiers. The tone-control network by de-emphasis of low frequencies tends to equalize the amplitudes of low- and high-frequency audio signals.

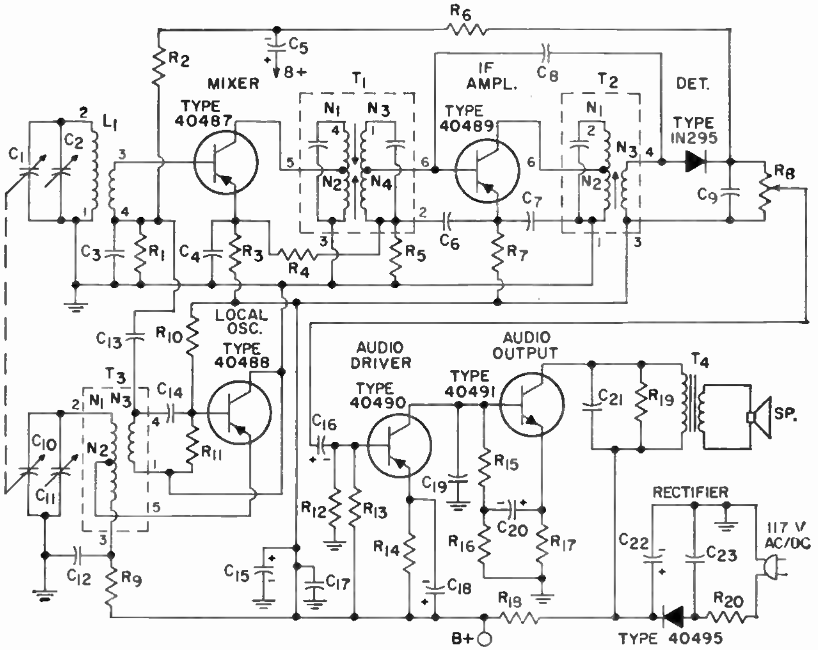
13-3 ALL-AMERICAN-FIVE AC/DC RADIO RECEIVER

Circuit Description

This five-transistor 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 40495 half-wave rectifier circuit. This receiver is comparable in both performance and cost with a typical five-tube broadcast receiver of the type commonly referred to as the "All America Five." Previous five-transistor receivers have matched the performance of five-tube receivers except with respect to overload capability. Limitations on the allowable voltage swing at the base of transistors impose a restriction not normally encountered with vacuum tubes and have usually required the use of an overload diode.

The receiver uses separate mixer and oscillator stages with one if-amplifier stage, rather than the more conventional complement of a converter stage with two if-amplifier stages, to permit application of agc voltage at a point where signal voltages are low, i.e., at the base of the mixer stage. This technique results

13-3 ALL-AMERICAN-FIVE AC/DC RADIO RECEIVER (cont'd)



Parts List

C_1, C_2, C_{10}, C_{11} = ganged tuning capacitor; antenna section (C_1 + C_2), 10 to 228 pF; oscillator section (C_{10} + C_{11}), 9 to 118 pF
C_3 = 0.005 µF, ceramic disc
C_4, C_6, C_7, C_{12}, C_{17} = 0.05 µF, ceramic disc
C_5 = 10 µF, electrolytic, 3 V
C_8 = 6.8 pF, NPO ceramic
C_9 = 0.02 µF, ceramic disc
C_{13} = 0.001 µF, ceramic disc
C_{14} = 200 pF, ceramic disc
C_{15} = 100 µF, electrolytic, 25 V
C_{16} = 10 µF, electrolytic, 12 V
C_{18} = 100 µF, electrolytic, 10 V
C_{19} = 0.047 µF, ceramic disc
C_{20} = 10 µF, electrolytic, 10 V
C_{21}, C_{23} = 0.01 µF, ceramic disc, 300 V
C_{22} = 100 µF, electrolytic, 150 V
L_1 = antenna coil; core material, Ferramic Q or equiv.; primary, 120 turns of No. 32 wire wound 43 turns per inch; secondary, 5 turns of No. 34 wire; output impedance, 260 ohms at 1500 kHz; primary inductance, 0.413 µH at 790 kHz; unloaded Q, 125 at 600 kHz and 130 at 1400 kHz
R_1 = 0.27 megohm, 0.5 watt
R_2 = 1000 ohms, 0.5 watt
R_3 = 0.82 megohm, 0.5 watt
R_4 = 2200 ohms, 0.5 watt
R_5 = 82000 ohms, 0.5 watt
R_6 = 18000 ohms, 0.5 watt
R_7 = 680 ohms, 0.5 watt
R_8 = Volume control, potentiometer, 2500 ohms, 0.5 watt, audio taper
R_9, R_{11} = 6800 ohms, 0.5 watt
R_{10}, R_{12} = 22000 ohms, 0.5 watt
R_{13} = 4700 ohms, 0.5 watt
R_{14} = 560 ohms, 0.5 watt
R_{15} = 1500 ohms, 0.5 watt
R_{16} = 180 ohms, 0.5 watt
R_{17} = 270 ohms, 0.5 watt
R_{18} = 5600 ohms, 0.5 watt
R_{19} = 10000 ohms, 0.5 watt
R_{20} = 250 ohms, 0.5 watt
T_1 = first if (455-kHz) transformer (includes 110-pF capacitors across primary and secondary windings); turns ratio of tapped primary, N_1/N_2 = 3.16; turns ratio of tapped secondary, N_3/N_4 = 33.4; primary unloaded Q = 80, primary loaded Q = 75.68; secondary unloaded Q = 80; secondary loaded Q = 64; input impedance = 14550 ohms; coefficient of coupling = 0.85; Thompson-Ramo-Wooldridge No. EO-22646, Automatic No. EX-15267, or equiv.
T_2 = second if (455-kHz) transformer (includes 110-pF capacitor across primary winding); turns ratio of tapped primary, N_1/N_2 = 2.57; turns ratio of lower section of primary to secondary, N_2/N_3 = 3.36; unloaded Q = 80; loaded Q = 35.2; input impedance = 18000 ohms; Thompson-Ramo-Wooldridge No. EO-22645, Automatic No. EX-15267, or equiv.
T_3 = oscillator coil; turns ratio of full primary to section of primary below tap, N_1/N_2 = 26; ratio of full primary to secondary, N_1/N_3 = 9.6; full primary tunes with 100-pF capacitance at 990 kHz; Automatic No. E-6181A65-51, or equiv.
T_4 = audio output transformer; primary impedance, 2500 ohms; secondary impedance, 3.2 ohms; Triad No. S-12X, or equiv.

13-3 ALL-AMERICAN-FIVE AC/DC RADIO RECEIVER (cont'd)

Circuit Description (cont'd)

in good overload performance without need for an overload diode. The use of a separate grounded-collector oscillator stage also provides excellent frequency stability throughout the agc range.

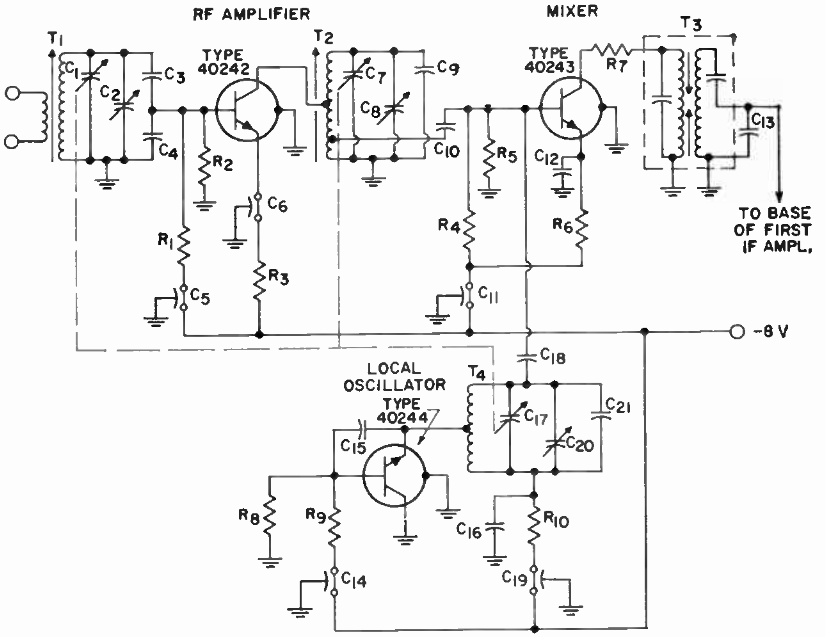
The mixer stage uses a 40487 germanium transistor that has a collector idling current of 1.4 milliamperes. The oscillator signal is injected to the base of the mixer transistor by the local oscillator stage which uses a 40488 transistor. The secondary winding of the antenna coil L_1 is designed to keep signal voltages as low as possible on the base of the mixer. Under maximum agc conditions, the operating current of the mixer transistor is reduced to approximately 20 microamperes. Optimum mixer gain is obtained when the oscillator signal is injected at a level of 120 millivolts. The mixer-oscillator approach also provides low noise and excellent oscillator stability (0.018 kHz per volt per meter of input signal and 0.085 kHz per volt of supply-voltage variation).

The if-amplifier stage employs a neutralized 40489 transistor that provides power gain of 41 dB within the limits of unconditional stability. The operating point of this stage is set at 18 volts and 2.5 milliamperes for optimum dynamic range and improved large-signal-handling capability. The oscillator transistor also receives partial gain control under very strong signal conditions. Selectivity is determined by the double-tuned input transformer T_1 and the single-tuned output transformer T_2. The if transformers have equal unloaded Q and equal tuning capacitance for economy and ease of production. The receiver is designed for transistor interchangeability, and over-all gain variations are minimal.

The 40490 driver transistor and 40491 output transistor used in the two-stage audio amplifier section develop a power gain of 75 dB and deliver an output of one watt to a 3-ohm load with distortion of less than 10 per cent. The 40491 output transistor is designed to operate from the ac power line with no protective devices. High-voltage transients may be developed when the output transistor is overdriven to high values of collector current and is then abruptly cut off. Protection from such transients is provided by use of an unbypassed 270-ohm resistor in the emitter circuit of output stage to limit the base current of the output unit to a safe maximum value. The voltage developed across the resistor (R_{17}) at the maximum safe value of collector current is designed to equal the maximum voltage on the base. As a result, the output current is clamped to a value equal to this voltage divided by the emitter resistance.

Frequency	600	1000	1400	kHz
50-mW Sensitivity	175	130	100	μV/m
(S + N)/N at Sensitivity	21	21	20	dB
AGC Figure of Merit (50,000 μV/m reference)	27.4	29.4	30	dB
Image Rejection	—	—	48	dB
IF Rejection	40	—	—	dB
Adjacent-Channel Attenuation (1000 μV/m level)	32	24	23	dB
6-dB Bandwidth	5.1	8.3	8.5	kHz
20-dB Bandwidth	13.8	16.5	20.2	kHz
60-dB Bandwidth	52	62	70	kHz
RF Overload:				
at 30% Modulation	—	2	—	V/m
at 80% Modulation	—	0.9	—	V/m

13-4 HIGH-QUALITY FM TUNER FOR MULTIPLEX RECEIVER



RF SECTION

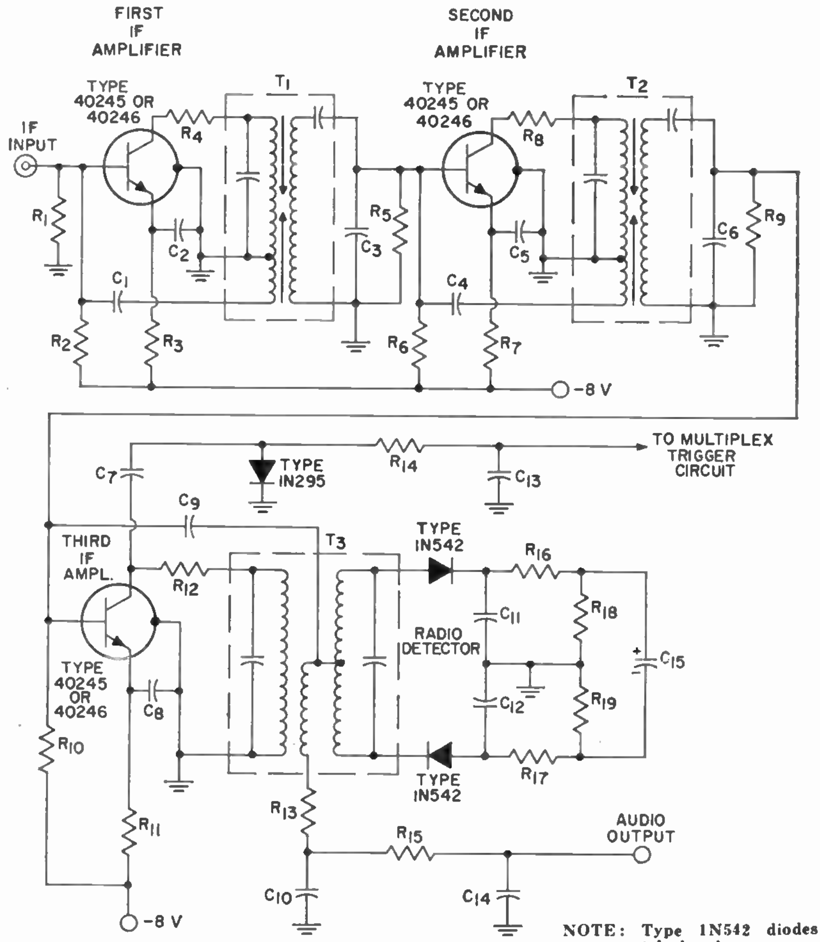
Parts List for RF Section

C_1, C_7, C_{17} = ganged tuning capacitors, C_1, C_7 = 7.25 to 19 pF; C_{17} = 6 to 21 pF
C_2, C_8 = trimmer capacitor (part of ganged tuning capacitor assembly), approximately 17 pF maximum.
C_3, C_9 = 5.6 pF, miniature ceramic
C_4 = 27 pF, ceramic disc
C_5, C_6, C_{11}, C_{14}, C_{19} = feed-through capacitor, 1000 pF
C_{10} = 2000 pF, ceramic disc, 1000 V
C_{12} = 0.01 μF, ceramic disc
C_{13}, C_{16} = 1000 pF, ceramic disc, 1000 V
C_{15} = 3.3 pF, NPO ceramic
C_{18} = 0.22 pF to 3.3 pF (value determines oscillator injection voltage and is dependent upon factors such as circuit layout and placement of components)
C_{20} = tubular trimmer capacitor, 1.5 to 10 pF
C_{21} = 12 pF, ceramic disc
R_1, R_4 = 3300 ohms, 0.5 watt
R_2, R_5 = 18000 ohms, 0.5 watt
R_3, R_6 = 330 ohms, 0.5 watt
R_7 = 100 ohms, 0.5 watt
R_8 = 8200 ohms, 0.5 watt
R_9 = 4700 ohms, 0.5 watt
R_{10} = 1500 ohms, 0.5 watt
T_1 = FM antenna transformer; slug-tuned; slug, 0.250 inch long, 0.181 inch in diameter, Arnold Type 1RN9 or equiv.; secondary, 4 turns of No. 22 bare-tinned copper wire wound with 1 wire-diameter spacing between adjacent turns or 7/32-inch outer-diameter coil form, resonates with 27-pF capacitance at 100 MHz, impedance = 6100 ohms; primary, 2 turns of No. 30 Gripeze wire close wound below cold end of secondary and in same direction, impedance (includes shunting effect of rf amplifier biasing network) = 460 ohms.
T_2 = rf interstage coil; 4 turns of No. 18 bare-tinned copper wire wound with approximately ⅛-inch spacing between turns on 5/16-inch diameter coil form (coil form is removed after coil is wound); resonates with 27-pF capacitance at 100 MHz; impedance of full winding, 6100 ohms; input tap located so that impedance at tap = 590 ohms; output tap located so that impedance at input tap is 540 ohms with the transformer properly loaded.
T_3 = oscillator coil; 3½ turns of No. 18 bare-tinned copper wire wound with 3/32-inch spacing between turns on 7/32-inch-diameter coil form (coil form is removed after coil is wound), center tapped.
T_4 = first if (10.7-MHz) transformer, Thompson-Ramo-Wooldridge No. E019309-R4 or equiv.

Parts List for IF Section

C_1, C_4 = 4.7 pF, ceramic disc
C_2, C_5, C_8 = 0.01 μF, ceramic disc
C_3, C_6 = 1000 pF, ceramic disc, 1000 V
C_7 = 5 pF, ceramic disc
C_9 = 1.0 pF, ceramic disc
C_{10}, C_{11}, C_{12} = 330 pF, ceramic disc
C_{13} = 0.05 μF, ceramic disc
C_{14} = 0.02 μF, ceramic disc

13-4 HIGH-QUALITY FM TUNER (cont'd)



NOTE: Type 1N542 diodes are a matched pair.

IF SECTION

Parts List for IF Section (cont'd)

C_{15} = 5 µF, electrolytic, 10 V.
R_1, R_5, R_9 = 12000 ohms, 0.5 watt
R_2, R_6, R_{10} = 2700 ohms, 0.5 watt
R_3, R_4, R_7, R_8, R_{11} = 220 ohms, 0.5 watt
R_{12} = 470 ohms, 0.5 watt
R_{13} = 68 ohms, 0.5 watt
R_{14} = 22000 ohms, 0.5 watt
R_{15} = 3900 ohms, 0.5 watt
R_{16} = 1000 ohms, 0.5 watt
R_{17} = 1500 ohms, 0.5 watt
R_{18}, R_{19} = 6800 ohms, 0.5 watt
T_1 = second if (10.7-MHz) transformer, Thompson-Ramo-Wooldridge No. E019310-R2 or equiv.
T_2 = third if (10.7-MHz) transformer, Thompson-Ramo-Wooldridge No. E019311-R1 or equiv.
T_3 = ratio-detector transformer, Thompson-Ramo-Wooldridge No. E019312-R3 or equiv.

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 MHz for a 300-ohm source impedance). These transistors pro-

13-4 HIGH-QUALITY FM TUNER (cont'd)

Circuit Description (cont'd)

vide excellent amplification in the FM band and are capable of sustained oscillation at frequencies up to 1100 MHz.

RF section—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_{18} to the base of the mixer transistor from the oscillator resonant circuit C_{17}, C_{20}, C_{21} and T_4. 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.

IF section—The three stage if-amplifier strip uses three 40245 or 40246 transistors in a common-emitter circuit configuration to provide 23.4 dB of stable gain per stage. The three double-tuned if transformers T_1, T_2, and T_3 provide a 6-dB bandwidth of 300 kHz, which is adequate for reproduction of stereo signals.

The 1N295 diode and associated components in the collector circuit of the third if amplifier develops a negative voltage proportional to the rf input signal. This voltage is used to drive a schmitt trigger stage associated with the noise immunity circuit of the FM stereo demodulator (refer to discussion of the demodulator, circuit 13-5). If desired, the negative voltage may also be applied to the base of the 40242 transistor in the rf amplifier as agc bias. 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 a matched pair of IN542 diodes and associated components. The detector transformer T_3 is designed to provide the wide peak-to-peak separation (450 kHz) required for good stereo multiplex operation. R_{15} and C_{14} in the output circuit of the ratio detector form a standard FM de-emphasis network for high audio frequencies.

NOTE: See general considerations for construction of high-frequency and broadband circuits on page 462.

13-5 FM STEREO MULTIPLEX DEMODULATOR

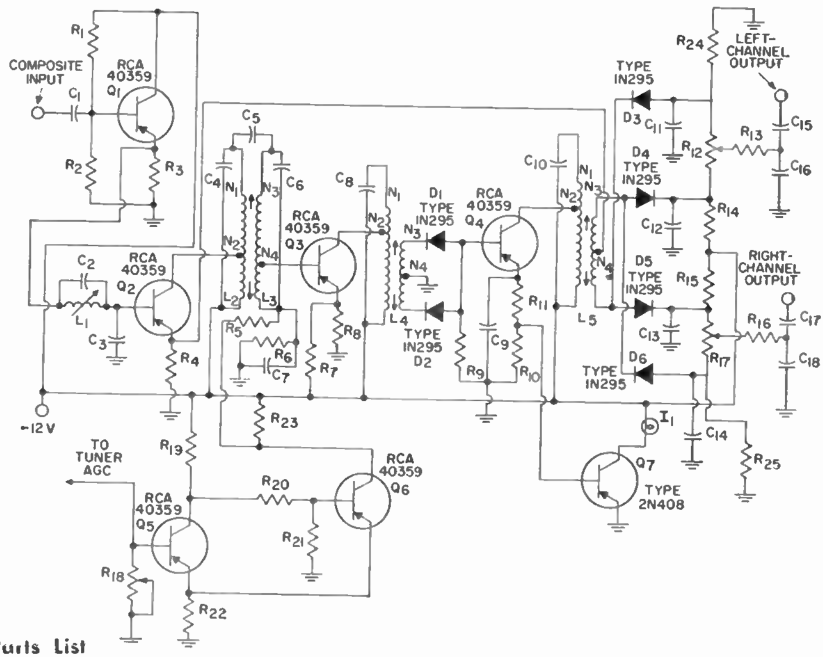
Circuit Description

This FM stereo multiplex demodulator separates complex signals supplied by an FM tuner into right- and left-channel inputs for stereo audio output stages. The demodulator features a high input impedance, a noise immunity circuit, and automatic switching for stereophonic or monaural reception.

Operation of an FM tuner in the stereo mode may be unsatisfactory under weak-signal conditions because the signal-to-noise ratio is poorer for stereo reception than for monaural reception. In addition, if switching is permitted on weak signals the 19-kHz component of noise which is present between stations may cause undesired operation.

The demodulator incorporates circuits that sense the presence of adequately strong FM signals and provide automatic switching in the presence of 19-kHz pilot signal. It has a separation at 1 kHz of 36.5 dB, S.C.A. rejection of 59.4 dB, residual 38-kHz subcarrier rejection of 60 dB, insertion loss at 1 kHz of 2.5

13-5 FM STEREO MULTIPLEX DEMODULATOR (cont'd)



Parts List

C_1 = 0.33 μF
C_2 = 560 pF
C_3 = 300 pF (adjust for optimum separation)
C_4 = 1000 pF, part of L_2
C_5 = 10 pF
C_6 = 1000 pF, part of L_3
C_7, C_9, = 0.47 μF
C_8 = 1000 pF, part of L_4
C_{10} = 390 pF, part of L_5
C_{11}, C_{12}, C_{13}, C_{14} = 7500 pF, ± 5%
C_{15}, C_{17} = 1.0 μF
C_{16}, C_{18} = 0.02 μF
I_1 = stereo lamp, 14 mA at 10 V
L_1 = 10 mH, Q = 46 at 67 kHz; Thompson-Ramo-Wooldridge No. E0-14039-R1 or equivalent
L_2 = 69 mH, Q = 93 at 19 kHz; N_1/N_2 = 5.66; Thompson - Ramo - Wooldridge No. E0-15485-R3 or equivalent (includes C_4)
L_3 = 69 mH, Q = 93 at 19 kHz, N_1/N_2 = 40.2; Thompson - Ramo - Wooldridge No. E0-15486-R3 or equivalent (includes C_6)
L_4 = 69 mH, Q = 88 at 19 kHz, N_1/N_2 = 5.24, N_1/N_3 = 5.21, N_3/N_4 = 2; Thompson - Ramo - Wooldridge No. E0-15360-R9 or equivalent (includes C_8)
L_5 = 41 mH, Q = 108 at 38 kHz, N_1/N_2 = 11.62, N_1/N_3 = 19.8, N_3/N_4 = 2; Thompson-Ramo-Wooldridge No. E0-15361-R7 or equivalent (includes C_{10})
R_1 = 91,000 ohms, 0.5 watt
R_2 = 120,000 ohms, 0.5 watt
R_3 = 6800 ohms, 0.5 watt
R_4 = 1000 ohms, 0.5 watt
R_5 = 18,000 ohms, 0.5 watt
R_6, R_{13}, R_{16}, R_{21} = 3300 ohms, 0.5 watt
R_7, R_9, R_{14}, R_{15}, R_{23}, R_{24}, R_{25} = 10,000 ohms, 0.5 watt
R_8 = 510 ohms, 0.5 watt
R_{10} = 220 ohms, 0.5 watt
R_{11} = 1500 ohms, 0.5 watt
R_{12}, R_{17} = potentiometer, 5000 ohms, 0.5 watt
R_{18} = potentiometer, 10,000 ohms, 0.5 watt
R_{19} = 8200 ohms, 0.5 watt
R_{20} = 15,000 ohms, 0.5 watt
R_{22} = 820 ohms, 0.5 watt

Circuit Description (cont'd)

dB, and total harmonic distortion at 1 kHz of 0.4 per cent. Six RCA-40359 transistors and one 2N408 transistor are used to provide the automatic switching and noise immunity. The demodulator is designed for use with a high-quality FM tuner, such as that shown by circuit 13-4, which provides an audio output of 400 millivolts with 75-kHz deviation under strong signal conditions. If a tuner that provides less audio output is used, the gain in the subcarrier amplifier can be increased by bypassing R_8. If a tuner of higher output is used, it may be necessary to use a voltage divider at the input.

The composite multiplex signal from the ratio detector of the FM tuner is applied to the base of transistor Q_1. Transistor Q_1 is an isolation stage which provides a high-

13-5 FM STEREO MULTIPLEX DEMODULATOR (cont'd)

Circuit Description (cont'd)

impedance load for the ratio detector and a low-impedance source for the S.C.A. filter. The parallel resonant circuit L_1C_2 is tuned to 72 kHz to provide maximum S.C.A. rejection at low beat frequencies.

Transistor Q_2 is a 19-kHz amplifier which also serves to separate the pilot from the composite signal. L_2, L_3, and C_5 constitute a top-coupled double-tuned circuit which resonates at 19 kHz and thus passes only the 19-kHz portion of the composite signal to transistor Q_3. The remainder of the signal is taken from the emitter resistor R_4 and fed into the balanced demodulator at the secondary winding of L_5. Capacitor C_3 compensates for the degradation of the composite signal as it passes through the S.C.A. filter.

Transistors Q_5 and Q_6 comprise a Schmitt trigger used as a noise-immunity circuit. A negative agc voltage obtained from the if amplifier of the tuner is applied to the base of Q_5. When no agc voltage is present Q_5 is turned off and Q_6 is turned on. In this state, which occurs under weak signal conditions, resistor R_5 is returned to a low-voltage point, and, therefore, transistor Q_3 is turned off. When a preset agc voltage is reached, Q_6 is turned off, R_5 is returned to the supply voltage through R_{23}, and Q_3 is turned on.

The agc circuit of the FM tuner drives the Schmitt trigger. The "on" trigger level can be adjusted by variation of R_{18}. The "off" trigger level is then determined by the hysteresis of the Schmitt-trigger circuit. Hysteresis is desirable because it prevents intermittent switching caused by slight signal variations in the vicinity of the trigger point. The hysteresis can be changed by adjustment of R_{19}.

Transistor Q_3 serves as a 19-kHz pilot amplifier and limiter when it is turned on by Q_6. When Q_3 is turned off, it acts as an open switch which stops the pilot signal. The emitter of Q_3 is reverse-biased by the current through R_7. Because this reverse bias exceeds the 19-kHz level at the base of Q_3, it prevents the 19-kHz pilot signal of a weak station from turning on Q_3 and thereby over-riding the noise-immunity circuit.

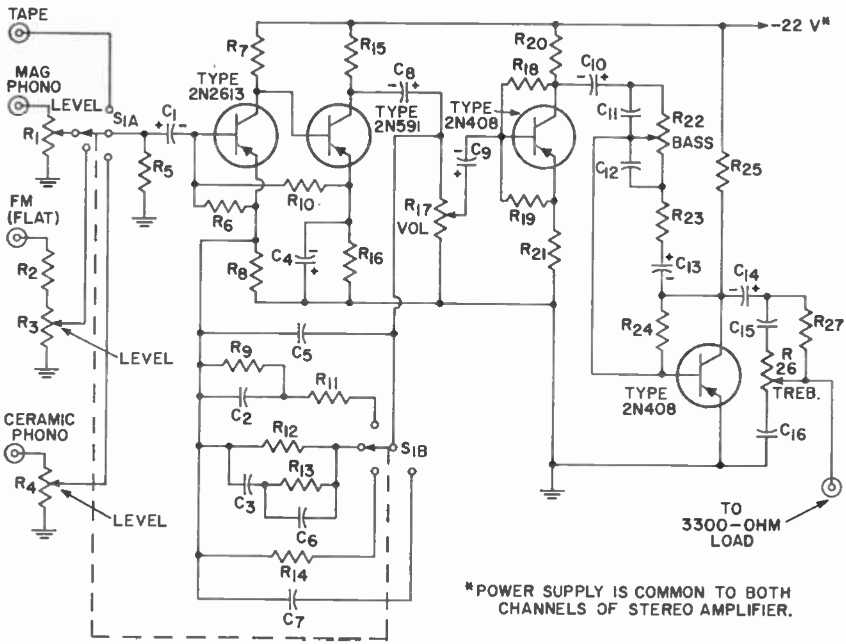
The output of the pilot amplifier Q_3 is fed to a balanced full-wave rectifier which consists of D_1, D_2, and the secondary winding of L_4. The output of the rectifier is unfiltered and develops both a dc component and a 38-kHz component. The dc component is used to bias transistor Q_4 on. The 38-kHz component is amplified by Q_4 (which also acts as a limiter), and appears at the secondary winding of L_5. In the absence of a pilot signal, Q_4 is turned off because there is no 19-kHz output from Q_3 to be rectified.

The composite signal taken from the emitter resistor R_4 is added to the 38-kHz subcarrier in the secondary winding of L_5. When the subcarrier has the proper phase with respect to the composite signal, a 38-kHz amplitude-modulated signal is formed in which one side of the envelope contains right-channel information and the other side contains left-channel information.

Diodes D_3 and D_4 form a balanced detector which permits one side of the envelope to pass. Resistor R_{12} is adjusted for minimum 38-kHz residual signal at the output. When Q_4 is off and no subcarrier is present in the secondary winding of L_5, the left-plus-right portion of the composite is passed by the detector circuit, and the left-minus-right portion is filtered out. Diodes D_5 and D_6 form the balanced detector for the other channel. R_{13}, C_{16}, R_{14}, and C_{18} form de-emphasis networks. Q_7 acts as a switch which lights a stereo indicator lamp when Q_4 is turned on.

NOTE: See general considerations for construction of high-frequency and broadband circuits on page 462.

13-6 HIGH-QUALITY PREAMPLIFIER FOR PHONO, FM, OR TAPE PICKUP



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

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

13-6 HIGH-QUALITY PREAMPLIFIER (cont'd)

Circuit Description (cont'd)

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. For a given input level, the output response of the preamplifier (with controls flat) is constant within ±1 dB from 10 to 20,000 Hz.

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.

Sensitivity (at full volume):

Tape input = 1-mV rms input for 42-mV output at 1000 Hz
FM (flat) input = 100-mV rms input for 42-mV output at 1000 Hz
Magnetic-phono input = 2-mV rms input for 42-mV output at 1000 Hz
Ceramic-phono input = 100-mV rms input fed in through 1000 pF (equivalent capacitance of crystal cartridge) for 42-mV output at 1000 Hz

Overload = more than 30 dB above full-volume input
Output response (tone controls flat) = ±1 dB from 10 Hz to 22 kHz
Tone-control range:

Treble (at 20 kHz) = −21 dB cut to +17 dB boost
Bass (at 20 Hz) = −25 dB cut to +18 dB boost

13-7 1-WATT AC/DC PHONOGRAPH AMPLIFIER

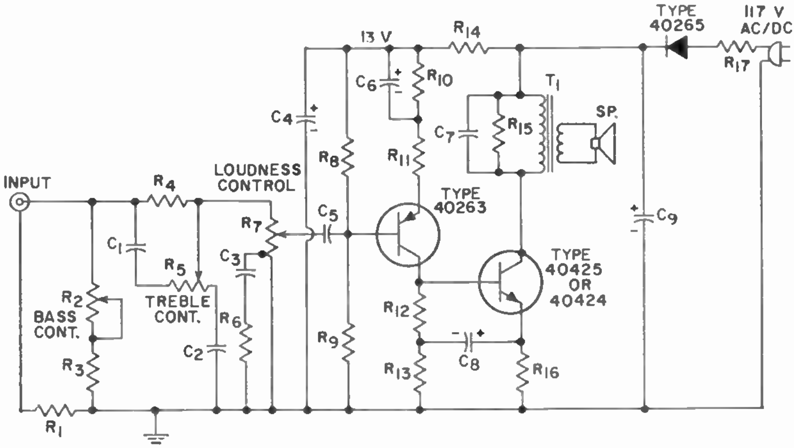
IHFM Music Power Rating, 2.5 W

Circuit Description

This two-transistor amplifier delivers an rms power output of more than 1 watt to a 4-ohm speaker; its IHFM music power rating is 2.5 watts. The input to the amplifier is obtained from a conventional 0.5-volt, 1000-picofarad ceramic phonograph cartridge; 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 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. The circuit operates directly from either an ac power line or a dc power supply of 117 volts. AC inputs are converted to dc power by the 40265 half-wave rectifier circuit.

The input stage of the phonograph amplifier consists of a 40263 n-p-n transistor operated in essentially a collector-follower circuit configuration. The signal developed at the collector of the 40263 directly drives the 40425 or 40424 p-n-p transistor used in the output stage. The output stage is basically a common-emitter class A power amplifier that is transformer coupled to the speaker. Output transformer T_1 matches the

13-7 1-WATT AC/DC PHONOGRAPH AMPLIFIER (cont'd)



Parts List

C_1, C_2 = 1200 pF, ceramic disc
C_3 = 0.005 μF, ceramic disc
C_4 = 80 μF, electrolytic, 25 V
C_5 = 0.1 μF, ceramic disc
C_6, C_8 = 25 μF, electrolytic, 6 V
C_7 = 0.01 μF, ceramic disc
C_9 = 80 μF, electrolytic, 150 V
R_1 = 56000 ohms, 0.5 watt
R_2 = base control, potentiometer, 3 megohms, 0.5 watt, audio taper
R_3 = 68000 ohms, 0.5 watt
R_4 = 0.33 megohm, 0.5 watt
R_5 = treble control, potentiometer, 1 megohm, 0.5 watt, audio taper
R_6 = 10000 ohms, 0.5 watt
R_7 = loudness control, potentiometer, 2 megohms, tapped at 1 megohm, 0.5 watt, linear taper
R_8, R_{11} = 18000 ohms, 0.5 watt
R_9 = 33000 ohms, 0.5 watt
R_{10}, R_{15} = 1000 ohms, 0.5 watt
R_{11} = 68 ohms, 0.5 watt
R_{12} = 470 ohms, 0.5 watt
R_{13} = 820 ohms, 0.5 watt
R_{14} = 120 ohms, 0.5 watt
R_{17} = 250 ohms, 4 watts
T_1 = audio output transformer; matches collector load impedance of 2500 ohms to speaker voice-coil impedance of 3.2 ohms; Freed No. RCA-8, Triad No. S-12X, or equiv.

Circuit Description (cont'd)

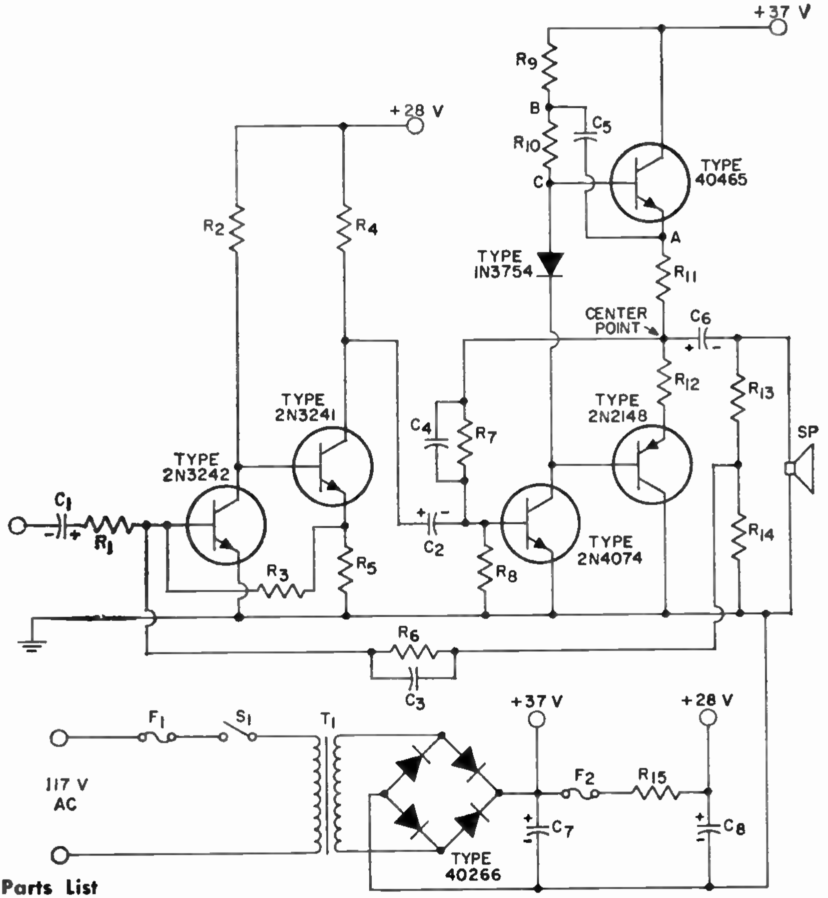
collector impedance of the output transistor to the speaker.

The phonograph amplifier provides an over-all power gain of 72 dB. The input impedance of the circuit is typically 3000 ohms. An rms input of 3 millivolts, therefore, results in an rms output of 50 milliwatts. An rms input of 16 millivolts is required to obtain the rated output of 1 watt. The stability of the amplifier is excellent, and the sensitivity remains essentially constant at temperatures up to 55°C. The total harmonic distortion is less than 1 per cent for output below 50 milliwatts and is approximately 10 per cent for outputs at the 1-watt level. The hum and noise level is 70 dB below the rated output of 1 watt at the zero volume setting and 58 dB below the rated output at the maximum volume setting. The frequency response of the amplifier is flat within 3 dB from 120 Hz to 7.6 kHz.

If a 40264 transistor is used in the output stage of the phonograph amplifier, it should be mounted on a suitable heat sink. A vertical heat sink made of 1/16-inch-thick aluminum that provides a total effective cooling-surface area of 28 square inches will provide adequate heat-sink protection. If a 40265 transistor is used in the output stage, it may be mounted directly on the circuit board without use of any additional heat sink for operation at ambient temperatures up to 55°C.

13-8 HIGH-QUALITY, 8-WATT, COMPLEMENTARY-SYMMETRY AUDIO POWER AMPLIFIER

IHFM Music Power Rating, 15 W



Parts List

C_1 = 5 μF, electrolytic, 15 V
C_2 = 250 μF, electrolytic, 15 V
C_3 = 10 pF, NPO ceramic disc
C_4 = 100 pF, NPO ceramic disc
C_5 = 250 μF, electrolytic, 15 V
C_6 = 1000 μF, electrolytic, 25 V
C_7 = 2500 μF, electrolytic, 40 V
C_8 = 1000 μF, electrolytic, 30 V
F_1 = fuse, 1-ampere, slo-blo
F_2 = fuse, 3-ampere
R_1 = 3300 ohms, 0.5 watt
R_2 = 33000 ohms, 0.5 watt
R_3, R_6 = 0.1 megohm, 0.5 watt
R_4 = 1000 ohms, 0.5 watt
R_5, R_8 = 100 ohms, 0.5 watt
R_7 = 2200 ohms, 0.5 watt
R_9, R_{10} = 120 ohms, 2 watts
R_{11}, R_{12} = 0.51 ohm, 1 watt
R_{13}, R_{14} = 560 ohms, 0.5 watt
R_{15} = 180 ohms, 0.5 watt
S_1 = ON-OFF switch, single-pole single throw
SP = speaker; 4-, 8-, or 16-ohm
T_1 = power transformer, Better Coil and Transformer Co. No. 99 P 11, CP Electronics No. 9999, or equiv.

This high-quality, low-cost audio power amplifier features a transformerless, direct-coupled complementary-symmetry driver-output circuit. The class B output stage develops an rms power output of 5

13-8 HIGH-QUALITY, 8-WATT, COMPLEMENTARY-SYMMETRY AUDIO POWER AMPLIFIER (cont'd)

Circuit Description (cont'd)

watts into an 8-ohm load impedance or 8 watts into a 4-ohm load impedance. A stereo system which uses this amplifier with a 4-ohm load impedance in each channel has an IHFM music-power rating of 15 watts per channel or 30 watts total. The circuit operates from a 117-volt ac power line. AC power inputs are converted to dc power by the 40266 full-wave bridge rectifier circuit. This rectifier circuit can supply the dc power required for both channels in a stereo system.

Harmonic-distortion levels in the amplifier typically are below 0.15 per cent from 40 to 20,000 Hz both at full power output of 8 watts and at low power outputs. Intermodulation distortion is typically 0.1 per cent at power levels of 8 watts or less. The hum and noise level of the amplifier is 94 dB below rated output, and the frequency response is flat within 3 dB from 8 Hz to 90 kHz.

Use of the right type of transformerless circuitry makes it possible to eliminate two major problems associated with capacitive coupling to the speaker. One problem is that the natural unbalance of the system prevents ripple cancellation at the speaker. The second problem is that the center voltage may go off-center under drive and cause premature clipping because there is no direct control over this voltage. Both problems are eliminated in the complementary-symmetry system when a high level of dc feedback is used to hold the center voltage at the proper point and a high level of ac feedback is used to cancel the ripple signal.

The idling current in the complementary-symmetry output stage is established by the voltage drop across the 1N3754 silicon bias diode and is stabilized by two 0.51-ohm emitter resistors, R_{11} and R_{12}. The dc drop across the bias diode is virtually independent of changes in the current through it (i.e., the diode has a low dynamic impedance). This voltage decreases, however, with increases in temperature and partially compensates for changes in the base-to-emitter voltage of the output transistors. As a result, the idling current is extremely stable. With the output transistors used, the single bias diode provides an output idling current of about 10 to 20 milliamperes. This low idling current does not create a crossover distortion problem because the output stage is driven from a high ac impedance. The result is cool and stable operation in the output stage.

The idling current in the driver stage (which must at least equal the maximum peak base current required by the n-p-n output transistor) is established by two 120-ohm bias resistors, R_9 and R_{10}. The driver current is equal to the difference between the supply voltage and the center voltage divided by the series resistance (R_9 + R_{10}), and is about 92 milliamperes.

For proper operation of the circuit, the current through bias resistor R_{10} must remain essentially constant during ac excursions of output voltage. For this reason, a 250-microfarad "bootstrap" capacitor C_5 is connected between the bias resistors and the emitter of the 40465 n-p-n output transistor. Because the voltage across the capacitor does not change during ac output-voltage excursions, the change in voltage at point B is the same as the change in voltage at point A. The change in voltage at point C is almost the same as that at point A, and differs only by the small change in the base-to-emitter voltage of the 40465 transistor. Therefore, the voltages at points B and C change by essentially the same amount, the voltage across the 120-ohm resistor R_{10} remains constant and a constant current results.

The "bootstrap" capacitor C_5 is returned to point A rather than to

13-8 HIGH-QUALITY, 8-WATT, COMPLEMENTARY-SYMMETRY AUDIO POWER AMPLIFIER (cont'd)

Circuit Description (cont'd)

the center point (as is the usual practice) to keep the change in voltage across the 0.51-ohm emitter resistor R_{11} from appearing across resistor R_{10}. When the change in voltage across R_{11} appears across R_{10}, a slight variation in the current through R_{10} occurs, and the dynamic-range requirements of the driver transistor are increased.

Bias for the base of the 2N4074 driver stage is derived from the center point of the output stage. As a result, dc and ac feedback proportional to the center voltage is fed to the base of the driver stage. The actual dc center voltage which the feedback establishes depends on the ratio of resistors R_7 and R_8 and on the base-to-emitter voltage and base current of the driver transistor. If a heavy direct current flows through R_7, changes in the base current become insignificant. The dc voltage at the center point is then determined by the base-to-emitter voltage. Because the percentage variation in the base-to-emitter voltage of a silicon transistor is small, the center-point dc voltage is held close to the desired value. The values of resistors R_7 and R_8 are chosen so that (1) the bleeder current in R_8 is large compared to the base current in the driver transistor, (2) the ratio of the resistors provides the desired center-point voltage, and (3) the desired amount of ac feedback current is obtained.

The front end of the power amplifier consists of a pair of n-p-n silicon transistors, a 2N3242 and a 2N3241, in a direct-coupled input circuit. The feedback from the emitter of the 2N3241 to the base of the 2N3242 serves primarily to hold the dc operating point of the 2N3241 within the limits necessary to prevent a dynamic-range limitation, despite variations in individual transistors or in temperature. The loop feedback resistor R_6 also serves as the dc bias resistor from the base of the 2N3242 input transistor to ground (the resistor returns to ground through the output voltage-divider resistors R_{13} and R_{14}).

Because the value of resistor R_6 is established by the dc bias considerations for the front end, the proper amount of ac loop feedback is established by deriving the feedback from a voltage divider across the output. Resistors R_{13} and R_{14} divide the output voltage down to a level which provides the desired feedback current through R_6. R_{13} and R_{14} also serve as an output termination when there is no speaker load.

The high degree of feedback (about 32 dB local in R_7 and 34 dB loop in R_6, for a total of 66 dB) results in an extremely low output impedance and a high degree of speaker damping. This large amount of feedback is the main reason for the extremely low hum and distortion levels in the amplifier. In spite of the large amount of feedback, the stability is excellent. This stability results from elimination of the driver transformer and careful observation of the rules of feedback stability.

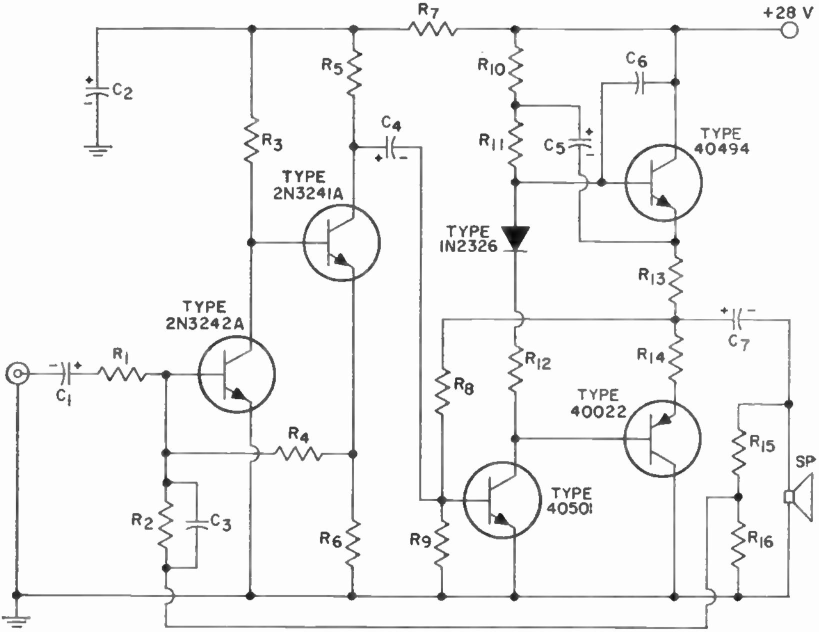
13-9 9.5-WATT COMPLEMENTARY-SYMMETRY AUDIO POWER AMPLIFIER

IHFM Music Power Rating, 19 W

Circuit Description

This 4-stage audio power amplifier delivers 9.5 watts of rms power output to a 8-ohm load impedance with less than 100 millivolts of input signal. Two of these amplifiers can be used in a dual-channel (stereo) sys-

13-9 9.5-WATT COMPLEMENTARY-SYMMETRY AUDIO POWER AMPLIFIER (cont'd)



NOTE: The 40022 and 40494 output transistors and the 1N2326 compensating diode should be mounted on a common heat sink that has a thermal resistance of 1.8°C per watt or less.

Parts List

C_1 = 50 μF, electrolytic, 15 V
C_2, C_4 = 1000 μF, electrolytic, 25 V
C_3 = 18 pF, ceramic
C_5 = 100 μF, electrolytic, 12 V
C_6 = 0.0056 μF, NPO ceramic disc
C_7 = 500 μF, electrolytic, 30 V
R_1 = 3300 ohms, 0.5 watt
R_2, R_4 = 0.1 megohm, 0.5 watt
R_3 = 33000 ohms, 0.5 watt
R_5 = 680 ohms, 0.5 watt
R_6, R_{10}, R_{11} = 120 ohms, 0.5 watt
R_7 = 560 ohms, 0.5 watt
R_8 = 1800 ohms, 0.5 watt
R_9 = 82 ohms, 0.5 watt
R_{12} = 5.6 ohms, 0.5 watt
R_{13}, R_{14} = 0.68 ohm, 1 watt
R_{15} = 820 ohms, 0.5 watt
R_{16} = 180 ohms, 0.5 watt

Circuit Description (cont'd)

tem to provide 19 watts of IHFM music power per channel or 38 watts total. The amplifier uses a direct-coupled complementary-symmetry output stage with conventional "bootstrap" drive to provide excellent frequency response. The large amounts of negative feedback employed assure low distortion. The amplifier operates from a dc power supply of 28 volts. (The power supply shown in circuit 13-8 can be used to supply the 28 volts dc required for this amplifier.)

The amplifier employs a 2N3242A transistor in the input stage, a 2N3241A transistor in the predriver stage, a 40501 transistor in the driver stage and a 40022 p-n-p transistor and a 40494 n-p-n transistor in the complementary-symmetry output stage. The direct-coupled input and predriver stages provide good dc stability and local feedback. The 40501 driver transistor has an integral heat radiator to provide the

13-9 9.5-WATT COMPLEMENTARY-SYMMETRY AUDIO POWER AMPLIFIER (cont'd)

Circuit Description (cont'd)

high dissipation capability that is required. The 1N2326 compensating diode is used to provide thermal stability. This diode, which is thermally connected to the heat sink of the output transistors, must be used if the output stage is to operate reliably at an ambient temperature of 55°C.

The 0.0056-microfarad capacitor C_6 from collector to base of the 40494 transistor reduces the high-frequency response of this n-p-n silicon transistor to approximately that of the 40022 p-n-p germanium transistor. Both halves of the output stage thus have substantially the same frequency response characteristics—a feature which simplifies the addition of negative feedback.

The resistor voltage divider across the speaker terminals provides the proper amount of voltage for the loop feedback network (0.1 megohm and 18 picofarads) and acts as a load impedance both when the speaker is removed and at high frequencies.

13-10 HIGH-QUALITY 10-WATT AUDIO POWER AMPLIFIER IHFM Music Power Rating, 20 W

Circuit Description

This high-quality audio power amplifier can supply 10 watts of rms power or 20 watts of IHFM music power to an 8-ohm speaker for an input of 1 volt rms. The amplifier employs a 40314 n-p-n silicon transistor and a 40319 p-n-p silicon transistor as complementary drivers for the pair of series-connected 40310 n-p-n silicon transistors used in the output stage. The absence of both driver and output transformers helps to provide exceptional frequency response at low cost without the hum pick up and feedback problems often encountered in the design of audio power amplifiers.

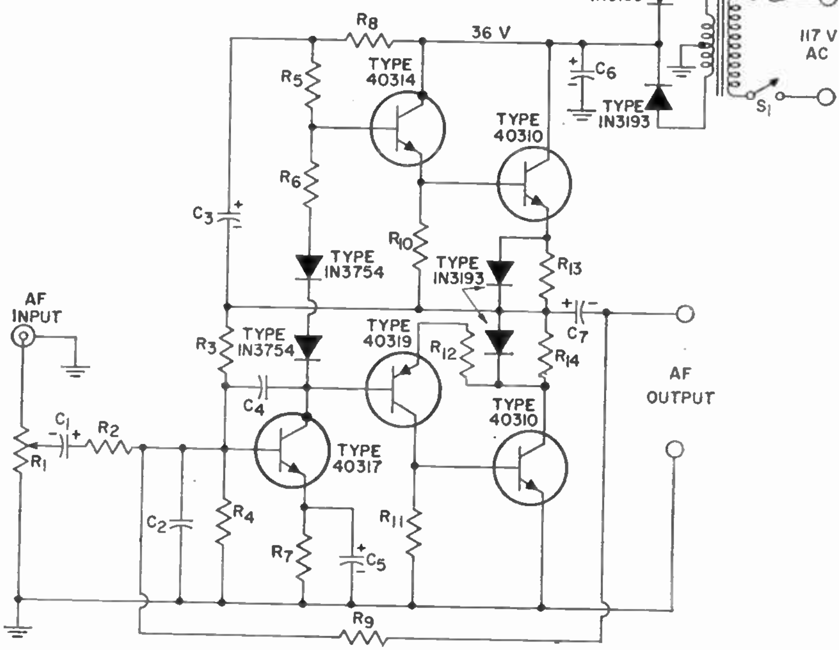
The use of direct coupling between stages and local dc feedback for each stage makes possible very stable quescent operation at all temperatures up to 71°C. The use of an over-all negative feedback of 6 dB helps to provide a frequency response that is flat within 3 dB from 15 Hz to 100 kHz. For operation at the rated output, the amplifier provides a total harmonic distortion of less than 0.7 per cent at 1000 Hz. The amplifier provides more than 48 dB of power gain and has a quiescent dissipation of less than 1 watt.

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 IN3754 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 crossover 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 effec-

13-10 HIGH-QUALITY 10-WATT AUDIO POWER AMPLIFIER (cont'd)



NOTE: The 1N3754 diodes in the driver stage are thermally connected to the heat sink of the 40310 output transistors.

Parts List

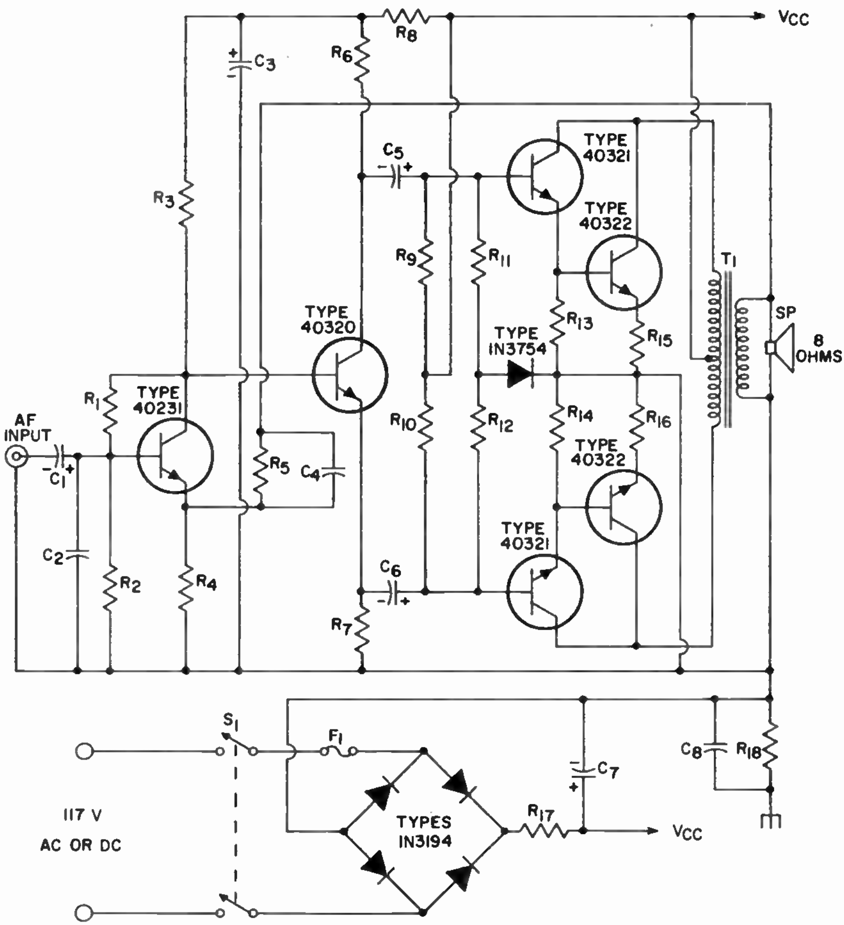
C_1 = 50 μF, electrolytic, 6 V
C_2 = 180 pF, ceramic
C_3 = 50 μF, electrolytic, 25 V
C_4 = 68 pF, ceramic
C_5 = 100 μF, electrolytic, 6 V
C_6 = 1000 μF, electrolytic, 50 V
F_1 = fuse, 1 ampere
R_1 = volume control, potentiometer, 10000 ohms, 0.5 watt (part of assembly with ON-OFF switch S_1)
R_2 = 3300 ohms, 0.5 watt
R_3 = 47000 ohms, 0.5 watt
R_4 = 5600 ohms, 0.5 watt
R_5, R_{12} = 4700 ohms, 0.5 watt
R_6, R_{10}, R_{11} = 220 ohms, 0.5 watt
R_7 = 270 ohms, 0.5 watt
R_8 = 1000 ohms, 0.5 watt
R_9 = 0.1 megohm, 0.5 watt
R_{13}, R_{14} = 1 ohm, 1 watt
S_1 = ON-OFF switch (part of assembly with volume-control potentiometer R_1)
T_1 = power transformer; primary, 117 volts rms; secondary, center-tapped, 28 volts rms from center tap to each end at 500 mA dc; Triwec Transformer Co. No. RCA-111, or equiv.

Circuit Description (cont'd)

tively operated in a common-emitter configuration. As a result, both output transistors provide equal voltage gain. The small amount of degenerative feedback developed across resistors R_{13} and R_{14} helps to stabilize the output stage. The limiting action of the 1N3193 diodes connected in shunt with these resistors prevents excessive power losses across them 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. This rectifier circuit can provide the dc power requirements for both channels of a stereo system that uses the 10-watt amplifier.

13-11 25-WATT AC/DC AUDIO POWER AMPLIFIER



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.

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

13-11 25-WATT AC/DC AUDIO POWER AMPLIFIER (cont'd)

Circuit Description (cont'd)

Hz. 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. This power supply circuit is common to both channels of a stereo system that uses the 25-watt amplifier.

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.

13-12 A 25-WATT COMPLEMENTARY-SYMMETRY AUDIO POWER AMPLIFIER

IHFM Music Power Rating, 50 W

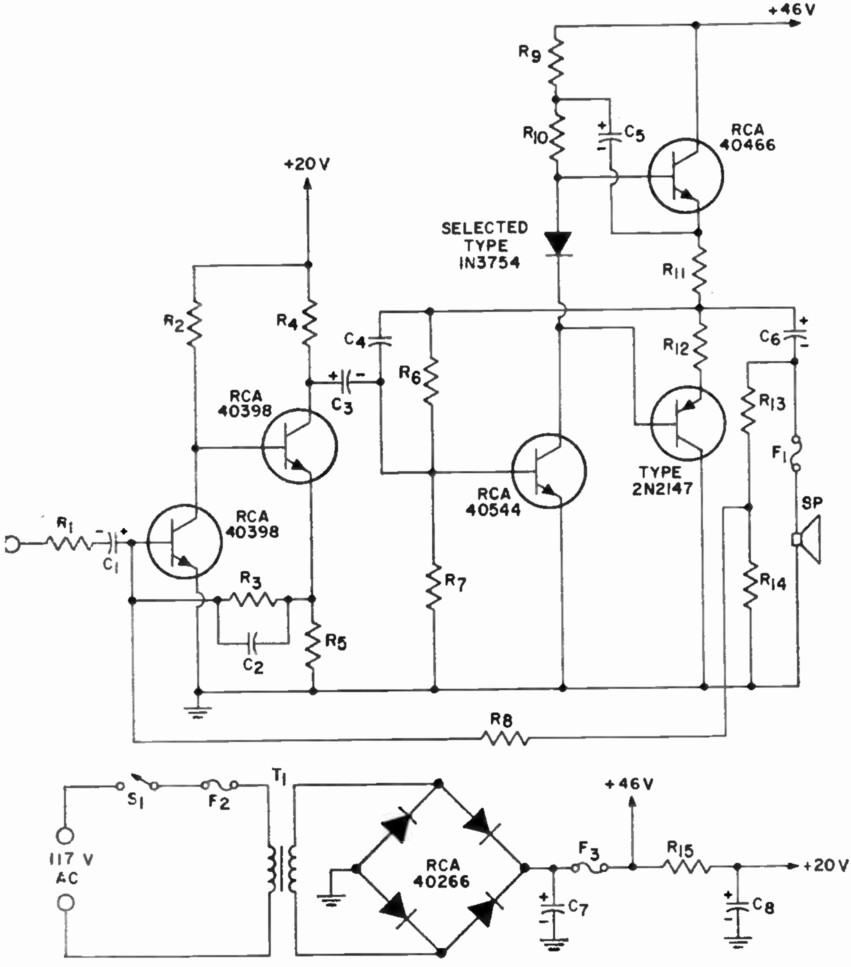
Circuit Description

This 4-stage complementary-symmetry audio power amplifier delivers 25 watts of rms power into a 4-ohm load and 17 watts of rms power into an 8-ohm load. This amplifier is similar to the 8-watt amplifier, circuit 13-8, described previously. The main differences are the use of higher-voltage driver and output transistors, and a higher-supply voltage (46 volts).

The complementary output stage employs a 40466 n-p-n transistor and a 2N2147 p-n-p transistor biased by a 1N3754 silicon bias diode. The driver stage consists of a 40544 transistor operated in a common emitter circuit configuration. The 1N3754 diode in the collector circuit of the driver stage provides temperature compensation for the output transistors.

The front end consists of two 40398 transistors. High-frequency

13-12 25-WATT COMPLEMENTARY-SYMMETRY AUDIO POWER AMPLIFIER (cont'd)



NOTES: 1. The 40466 and 2N2147 output transistors should be mounted on heat sinks that have a thermal resistance of 1.5°C per watt or less. 2. The 1N3754 temperature-compensating diode is selected on the basis of a maximum forward-voltage drop of 0.8 volt. This diode should be mounted on the same heat sink as the 40466 output transistor.

Parts List

C_1 = 5 μF, 15 V
C_2 = 500 pF
C_3 = 250 μF, 50 V
C_4 = 1000 pF
C_5 = 250 μF, 15 V
C_6 = 1000 μF, 50 V
C_7 = 3500 μF, 50 V
C_8 = 1000 μF, 25 V
F_1, F_2 = fuse, 2 ampere, slo-blo type
F_3 = fuse, 5 ampere

R_1 = 2200 ohms, 0.5 watt
R_2 = 12,000 ohms, 0.5 watt
R_3 = 100,000 ohms, 0.5 watt
R_4 = 390 ohms, 0.5 watt
R_5 = 68 ohms, 0.5 watt
R_6 = 1200 ohms, 1 watt
R_7 = 33 ohms, 0.5 watt
R_8 = 75,000 ohms, 0.5 watt
R_9 = 82 ohms, 2 watts
R_{10} = 100 ohms, 2 watts
R_{11}, R_{12} = 0.39 ohms, 1 watt

R_{13} = 130 ohms, 0.5 watt
R_{14} = 560 ohms, 0.5 watt
R_{15} = mono: 680 ohms, 1 watt; stereo: 330 ohms, 2 watts
S_1 = ON-OFF switch; single-pole, single-throw
T_1 = transformer; CP Electronics Type X-10307 or equivalent

13-12 25-WATT COMPLEMENTARY-SYMMETRY AUDIO POWER AMPLIFIER (cont'd)

Circuit Description (cont'd)

roll off is provided by capacitor C_2 in the feedback loop from the emitter of the output-side 40398 to the base of the input-side 40398. Low-frequency roll off is provided by the output coupling capacitor.

A conventional full-wave bridge rectifier using four 40266 diodes rectifies the 117-volt ac input power to obtain the 46 volts used as the collector supply voltage for the driver and output-stage transistors and the 20 volts for the front-end stages. In a stereo system, this power supply is common to both channels.

Typical performance for the 25-watt amplifier (with an 8-ohm load impedance) is as follows:

Distortion at 22 watts output = 0.5% at 1000 Hz
Distortion at 11 watts output = 1.0% at 20 Hz and 20 kHz
IHFM music power = 50 watts
Sensitivity = 75 millivolts into 2200-ohm input for 20-watt output
Hum and Noise = more than 100 dB below 25 watts
Frequency response (3-dB down points) = 10 Hz to 80 kHz
Intermodulation distortion (with 60 and 7,000-Hz signals mixed 4:1; output equivalent to 10 watts) = 0.05%

13-13 HIGH-QUALITY 35-WATT AUDIO POWER AMPLIFIER IHFM Music Power Rating, 75 W

Circuit Description

This high-power audio amplifier is typical of the type used in "top-of-the-line" commercial high-fidelity equipment. The power amplifier of this audio system delivers 35 watts rms power output at low distortion and 50 watts rms power output at 5 per cent distortion. The IHFM music power rating of a stereo system that uses this amplifier is 75 watts per channel or 150 watts total. Full 35-watt rms power output is attained from 20 Hz to 20 kHz, and the frequency response is flat within 1 dB from 20 Hz to 20 kHz. Other features of the power amplifier include low hum and noise level, good transient response and electrical stability, and excellent thermal stability.

The amplifier operates from a 117-volt ac power line. The ac power inputs are converted to dc power by four 40267 rectifier diodes connected in a conventional four-diode full-wave center-tapped bridge which provides a plus and minus 35-volt supply. This balanced type of supply is preferred for two reasons. Because ripple components cancel at the speaker, a low hum level is obtained. In addition, because no speaker coupling capacitor is necessary, full power output can be attained at very low frequencies. In a stereo system, this power supply can be used to provide the required dc power to both channels.

The output stage of the power amplifier is basically a four-transistor totem-pole arrangement driven by a split-secondary driver transformer T_1. The four-transistor method provides three major advantages. First, the required 80-volt reverse breakdown rating can be attained by sharing of the voltage between two transistors. Second, the necessary 35 watts of total possible dissipation can be handled by use of four transistors to share the dissipation. Finally, the necessary transient breakdown performance can be attained, even under many abnormal conditions, because the instantaneous dissipation conditions are divided between two transistors.

The characteristics of the common-emitter-operated 2N2147 output transistors determine both the driver-stage requirements and the frequency response and distortion level of the output stage. The high

13-13 HIGH-QUALITY 35-WATT AUDIO POWER AMPLIFIER (cont'd)

Circuit Description (cont'd)

gain of the 2N2147 drift-field power transistors (minimum beta is 100) reduces the size of the driver transformer and the dissipation requirement in the driver stage. The wide-band response of the transistors (beta cutoff frequency greater than 20 kHz) ensures no increase in driver requirements for full power output at high frequencies. The excellent linearity of the 2N2147 ensures low inherent distortion in the output stage.

The two 40051 transistors used in the output stage are operated in a common-base arrangement and therefore are not so critical with regard to gain, response, and linearity. The only criterion for these transistors is that enough base drive current be made available to allow them to become saturated. However, the 40051 is an alloy transistor, and the minimum beta in alloy transistors at 20 kHz and high current levels is considerably less than the specified dc value at 1 ampere. Because it is impractical to provide sufficient base drive current through the 68-ohm bias resistors R_{11} and R_{11} under these conditions, 0.2-microfarad capacitors, C_7 and C_9, are placed across the bias resistors to provide extra base drive current at high frequencies. Elimination of these capacitors would result in reduced power output at high frequencies because the 40051 transistors would fail to saturate.

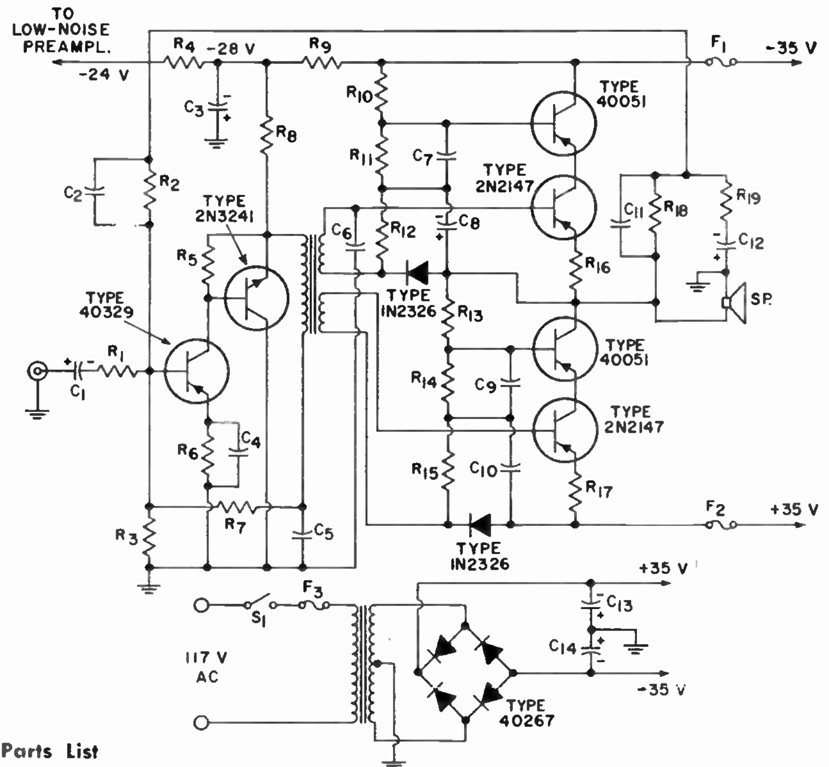
The idling current in the output stage is established by the voltage drop across the temperature-compensating 1N2326 reference diodes. The use of diode bias offers several advantages. First, thermal stability is excellent, even with low values of emitter resistance. Second, because idling current remains fairly constant over a wide range of ambient temperatures, cross-over distortion performance is relatively independent of ambient temperature. Third, line-voltage variations have very little effect on idling current. Fourth, when the diode is thermally connected to the heat sink it is possible to reduce the heat-sink size.

A pair of direct-coupled stages and a good-quality driver transformer T_1 are used to supply the drive power for the output stage. The driver-transformer phase characteristics are of prime importance in determining the stability of the feedback in the amplifier. To provide a high enough frequency response for good stability, it is necessary to use as few turns as possible, and to wind the transformer in a manner which provides a very high primary resonance frequency. However, a low number of turns cannot be used unless there is no air gap, and the air gap cannot be eliminated unless there is no direct current in the transformer. Therefore, the primary winding of the transformer is shunt-fed so that it carries no direct current.

The driver-stage transistor, is required to have high dissipation capability, good linearity over wide ranges of current and voltage swing, and high frequency response. The hermetically sealed epitaxial n-p-n silicon planar 2N3241 transistor is used to meet these requirements. The 2N3241 features a free-air dissipation rating of 400 milliwatts at 55°C ambient, excellent linearity and high gain to 100 milliamperes, and a typical gain-bandwidth product of 80 MHz.

The 40329 noise-controlled p-n-p germanium transistor is used in the predriver, stage because (1) a relatively low high-frequency response is needed in this stage; (2) a p-n-p transistor can easily be direct-coupled to an n-p-n transistor in the manner shown; and (3) some noise control is needed in this stage to keep zero-volume noise level at a minimum. The 40329 has a maximum equivalent noise current of 0.02 microampere from 20 Hz to 20

13-13 HIGH-QUALITY 35-WATT AUDIO POWER AMPLIFIER (cont'd)



Parts List

C_1 = 5 μF, electrolytic, 3 V
C_2, C_{11} = 39 pF, ceramic disc
C_3, C_{13}, C_{14} = 2500 μF, electrolytic, 35 V
C_4 = 200 μF, electrolytic, 3 V
C_5 = 250 μF, electrolytic, 15 V
C_6 = 0.001 μF, ceramic disc
C_7, C_9 = 0.2 μF, ceramic disc
C_8, C_{10} = 100 μF, electrolytic, 15 V
C_{12} = 10 μF, electrolytic, 3 V
F_1, F_2 = fuse, 3-ampere
F_3 = fuse, 2-ampere, slo-blo
R_1 = 1500 ohms, 0.5 watt
R_2, R_3 = 22000 ohms, 0.5 watt
R_4, R_5 = 270 ohms, 0.5 watt
R_6, R_{19} = 1000 ohms, 0.5 watt
R_7 = 56000 ohms, 0.5 watt
R_8 = 470 ohms, 1 watt
R_9 = 82 ohms, 1 watt
R_{10}, R_{13} = 220 ohms, 2 watts
R_{11}, R_{14} = 68 ohms, 1 watt
R_{12}, R_{15} = 150 ohms, 1 watt
R_{16}, R_{17} = 0.33 ohm, 1 watt
R_{18} = 33000 ohms, 0.5 watt
S_1 = ON-OFF switch, single-pole, single-throw
T_1 = consists of 5 pentafilar-wound coils of 110 turns each; wound from No. 28 heavy Formvar insulated wire on grain-oriented silicon-steel, ½-inch EI square stack, interleaved, with no air gap; 3 windings are connected in series to form primary; other two windings form the split secondary; secondary dc resistance, 2 ohms per secondary winding; primary dc resistance, 6 ohms
T_2 = power transformer; Better Coil and Transformer Co. No. 99P6, Columbus Process Co. No. X8300, or equiv.

Circuit Description (cont'd)

kHz, good linearity over the current and voltage range used in the predriver stage, and a response relatively lower than that of other stages in the feedback loop.

The 250-microfarad capacitor C_5 used to couple the driver-transformer primary is also used to decouple the dc feedback around the direct-coupled stages. This feedback is used in conjunction with the bypassed emitter resistor R_6 for the 40329 predriver transistor to provide excellent dc stability. Variations in transistor gain or temperature do not materially affect the driver

13-13 HIGH-QUALITY 35-WATT AUDIO POWER AMPLIFIER (cont'd)

Circuit Description (cont'd)

operating point. It is essential to hold this operating point fairly constant so that the driver stage will not be limited for dynamic range.

AC feedback is taken from a voltage divider R_{18} and R_{19} across the speaker and applied to the base of the 40329 predriver transistor. If oscillation is to be avoided, the base signal current of the predriver transistor and the feedback signal current cannot be in phase at any frequency at which loop gain (defined as feedback-signal-current amplitude divided by base-signal-current amplitude) is unity (or, in practice, greater than unity). If ringing in the square-wave response is to be avoided, the phase relationship between these two currents must be greater than 90 degrees when loop gain is equal to or greater than unity. The normal phase relationship between these two currents for degenerative feedback is, of course, 180 degrees. The effect of various types of speaker impedance (including infinite impedance) must be considered when this analysis is made.

Because loop gain cannot be reduced without the introduction of phase shift, the best stability is achieved when one roll-off time constant is allowed to occur much sooner in the loop response (defined as frequency response between predriver base signal current and the feedback signal current) than all other roll-off time constants. If the first roll-off time constant is sufficiently different from the other roll-off time constants, loop gain ultimately decreases at 6 dB per octave and phase shift approaches 90 degrees. Loop gain eventually becomes less than unity before any other phase shift occurs, and unconditional stability is achieved.

In the 35-watt amplifier, the relatively lower high-frequency response of the predriver stage is used to reduce the loop gain below unity at a loop phase of 90 degrees and thus to stabilize the high-frequency feedback. (If possible, it is desirable to put the limiting element in the first stage of the feedback loop so that the limited response will not affect the dynamic range of some other stage.) Because the other roll-off time constants are not sufficiently different than the response of the predriver stage, correction elements must be used which act in a direction to roll up the loop response where these other time constants would be rolling it off and thus create phase shift in the correcting direction so that the loop phase shift will be held to 90 degrees. Two of these elements are used for high-frequency stabilization, the 39-picofarad capacitors C_{11} and C_2 across the 33000-ohm and 22000-ohm feedback resistors R_{18} and R_2 respectively.

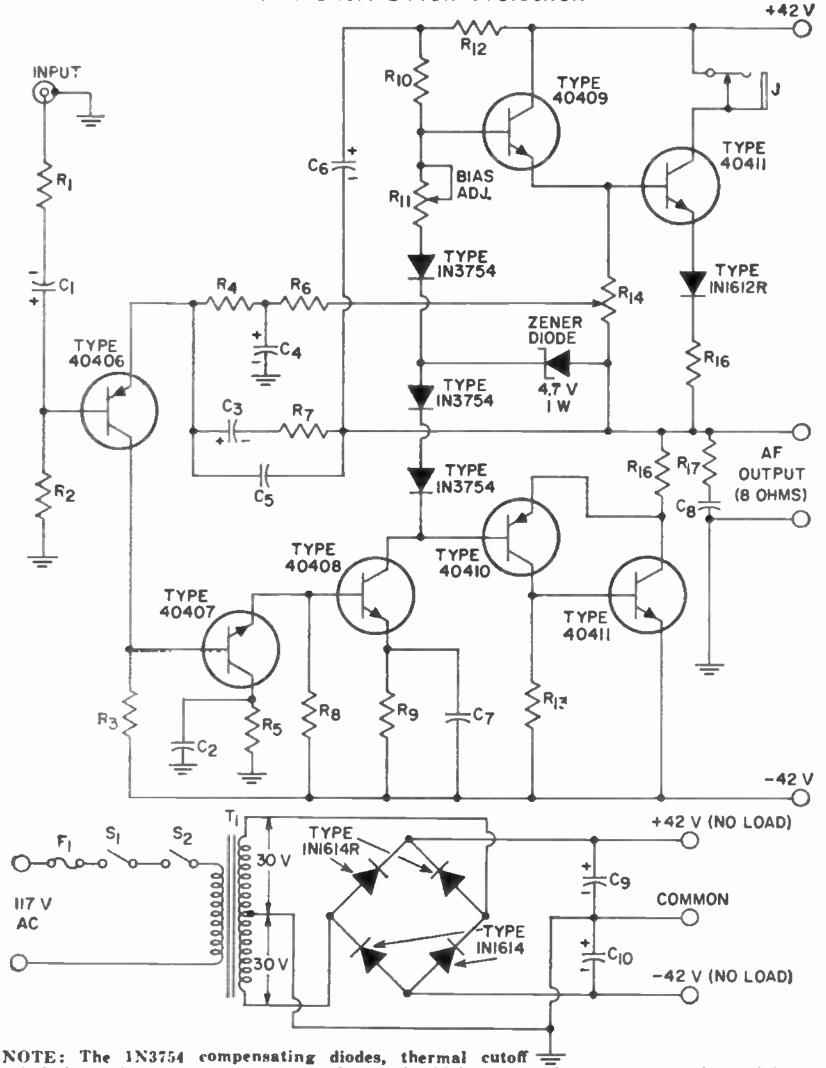
A low-frequency phase-correction element is also used. The 10-microfarad capacitor C_{12} in series with the 1000-ohm resistor R_{19} in the feedback network serves the same purpose at low frequencies as the 39-picofarad capacitors at high frequencies; it acts in a direction to roll up the loop response at low frequencies to compensate for a roll-off in the forward gain of the amplifier (and thus corrects loop phase shift).

One additional element used in the amplifier for feedback stabilization is the 0.001-microfarad capacitor C_{4}. This capacitor minimizes the increase in high-frequency loop gain when the speaker load is removed, i.e., it feeds current into the transformer secondary at high frequencies so that secondary signal current does not drop near zero when the load is removed.

The result of this careful application of loop feedback is that the degree of feedback stability in the amplifier is excellent with a resistive load, a very reactive speaker load, or an open load.

13-14 HIGH-FIDELITY 70-WATT AUDIO POWER AMPLIFIER

With Short-Circuit Protection



NOTE: The 1N3754 compensating diodes, thermal cutoff switch S_2, and the 40411 output transistors should be mounted on a common heat sink.

Parts List

C_1 = 5 μF, electrolytic, 6 V
C_2 = 0.01 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 = 0.1 μF, ceramic
C_9, C_{10} = 3000 μF, electrolytic, 75 V
F_1 = fuse, 3-ampere
J = monitor jack
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, linear taper
R_{15}, R_{16} = 0.3 ohm, 10 watts
R_{17} = 20 ohms, 5 watts
S_1 = ON-OFF switch, single-pole, single-throw
S_2 = thermal cutout switch,

13-14 HIGH-FIDELITY 70-WATT AUDIO POWER AMPLIFIER (cont'd)

Parts List (cont'd)

opens automatically when temperature rises above 100°C. Elmwood Sensor Co., Part No. 2455-88-4, or equiv.

T_1 = power transformer; primary, 117 volts rms; secondary, center-tapped, 30 volts from center tap to each end at 1.5 A dc (with no external load on power supply). Triwec Transformer Co., No. RCA-113, or equiv.

Circuit Description

This amplifier has a frequency response that is flat within 1 dB from 5 to 25,000 Hz. Total harmonic distortion at the full rated output of 70 watts is less than 0.25 per cent at 1000 Hz. 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_7 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_{11} (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 prevented. In this way, both the driver and the output transistors are protected from high currents and excessive power dissipation such as

13-14 HIGH-FIDELITY 70-WATT AUDIO POWER AMPLIFIER (cont'd)

Circuit Description (cont'd)

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.

13-15 2-WATT-PER-CHANNEL AC/DC STEREO AMPLIFIER IHFM Music Power Rating, 4 W Per Channel

Circuit Description

This low-cost, three-stage, direct-coupled stereo amplifier is designed for use with ceramic or crystal pickups that have an output voltage of 500 millivolts and an output capacitance of 800 picofarads or more per channel. The amplifier delivers a power output of 2 watts rms or more per channel at a total harmonic distortion of 10 per cent; its IHFM music power rating is 4 watts per channel, or 8 watts total. The circuit operates directly from either an ac power line or dc power supply of 115 volts. AC power inputs are converted to dc power by the 40265 half-wave rectifier circuit.

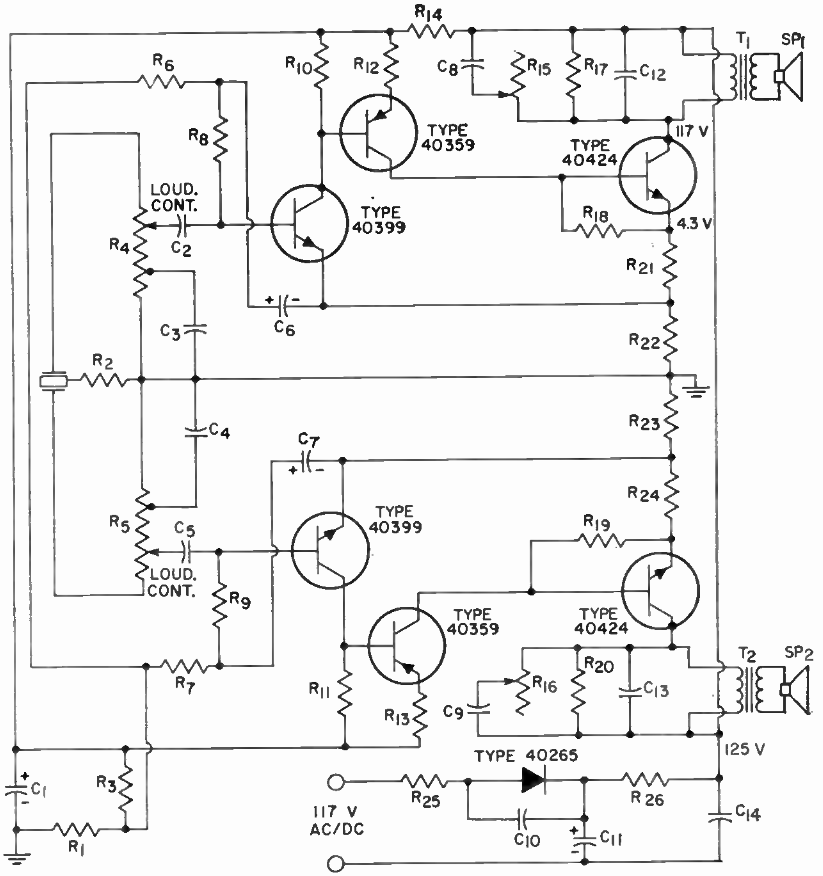
Each channel uses a 40424 high-voltage n-p-n silicon transistor in a common-emitter class A transformer-coupled output stage. The 40424 output transistor is direct-coupled to a 40359 p-n-p germanium common-emitter driver. The 40399 n-p-n silicon predriver maintains the high input impedance of the amplifier and controls the dc operating point of the 40424 output stage. The emitter current of the 40424 output transistor is determined by the resistor voltage divider network R_1 and R_3. The voltage across the emitter resistors of the output transistor is proportional to this emitter current, and a portion of this voltage is degeneratively fed back to the emitter of the 40399 predriver. The operating point of the 40424 output transistor is, therefore, insensitive to changes in the current transfer ratios of all three stages within the design limits, as well as to changes in the voltages across the emitter-base diodes of the 40359 and the 40424. Because an ac voltage proportional to the output current appears across the emitter resistors, this connection also provides negative ac feedback to control distortion and improve interchangeability.

In each channel, the only electrolytic capacitor used outside the power supply is the "bootstrap" capacitor in the base-to-emitter circuit of the first stage which is used to raise the input impedance of the first stage. In this configuration, the bias network is ac-coupled to the emitter of the 40399 to eliminate shunting by the bias network.

The stereo amplifier has a sensitivity of about 500 millivolts for a power output of 2 watts per channel. The distortion at this power level is approximately 7.5 per cent at room temperature and a line voltage of 120 volts. Feedback from the emitter circuit of the output stage provides nearly constant voltage sensitivity independent of the composite current transfer ratio of the transistor complement. The change in sensitivity from all high-gain to all low-gain transistors is less than 2 dB. The power output at a total harmonic distortion of 10 per cent and the sensitivity remain essentially constant at 65°C.

The tapped volume-control potentiometer in each channel provides

13-15 2-WATT-PER-CHANNEL AC/DC STEREO AMPLIFIER (cont'd)



Parts List

C_1 = 100 μF, electrolytic, 15 V
C_2, C_5 = 0.01 μF, ceramic disc
C_3, C_4 = 0.0022 μF, ceramic disc
C_6, C_7 = 5 μF, electrolytic, 3 V
C_8, C_9 = 0.1 μF, ceramic disc, 1200 V
C_{10} = 0.047 μF, ceramic disc, 400 V
C_{11}, C_{14} = 100 μF, electrolytic, 15 V (dual electrolytic capacitor may be used)
C_{12}, C_{13} = 0.005 μF, ceramic disc
R_1 = 82 ohms, ± 5 per cent, 0.5 watt
R_2 = 68000 ohms, 0.5 watt (This resistor may be replaced by 0.047-μF, 400-V capacitor)
R_3 = 1000 ohms, ± 5 per cent, 0.5 watt
R_4, R_5 = loudness control, potentiometer, 5 megohms, tapped at 1.5 megohms, 0.5 watt, linear taper
R_6, R_7 = 8200 ohms, 0.5 watt
R_8, R_9 = 47000 ohms, 0.5 watt
R_{10}, R_{11} = 8200 ohms, 0.5 watt
R_{12}, R_{13} = 1000 ohms, 0.5 watt
R_{14} = 6800 ohms, 2 watts
R_{15}, R_{16} = tone control, potentiometer, 50000 ohms, 0.5 watt, audio taper
R_{17}, R_{20} = 18000 ohms, 0.5 watt
R_{18}, R_{19} = 1000 ohms, 0.5 watt
R_{21}, R_{24} = 82 ohms, 0.5 watt
R_{22}, R_{23} = 11 ohms, ± 5 per cent, 0.5 watt
R_{25} = 6.8 ohms, 2 watts
R_{26} = 200 ohms, 4 watts
T_1, T_2 = audio output transformer; primary impedance, 2500-ohms; secondary impedance, 3.2 ohms; Freed No. R6A-8, Triad No. S-12X, or equiv.

13-15 2-WATT-PER-CHANNEL AC/DC STEREO AMPLIFIER (cont'd)

Circuit Description (cont'd)

bass boost of about 12 dB at 100 hertz at low volumes. Treble cut is provided by the RC tone-control network across the primary of the output transformer. The over-all useful response has a range from about 50 Hz to 12 kHz, depending on the cartridge and speakers used.

The pi filter used for the high-voltage supply results in an over-all level of hum and noise more than 60 dB below full power output.

13-16 5-STAGE, 3-WATT-PER-CHANNEL STEREO AMPLIFIER WITH COMPLEMENTARY-SYMMETRY OUTPUT STAGE

Circuit Description

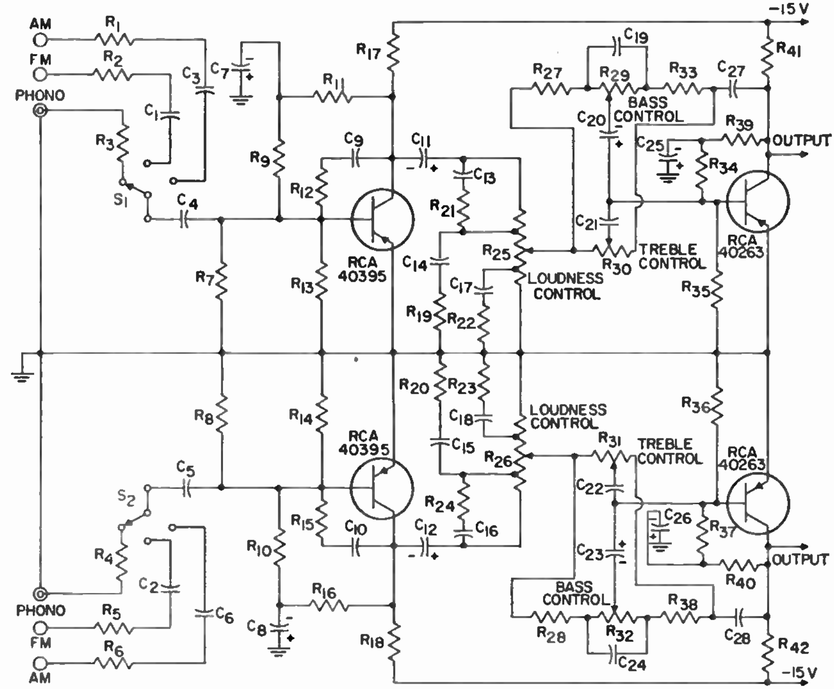
This low-cost 5-stage stereo amplifier delivers an IHFM music power output of 3.1 watts per channel, or 6.2 watts total, to a 16-ohm load impedance. The sine-wave power developed per channel is 2.7 watts. The amplifier includes a two-stage preamplifier with full tone controls and a complementary-symmetry power amplifier. The preamplifier is designed for use with either ceramic phonograph cartridges or tuner/multiplex inputs. The power amplifier uses a direct-coupled complementary-symmetry output stage with conventional "bootstrap" drive to provide excellent frequency response. Elimination of a driver transformer simplifies the feedback network. Although the speaker is not grounded, the maximum voltage on the "hot" side of only 25 volts dc should present no problem because this type of amplifier is generally used in applications where the speaker is an integral part of the system. (In the following paragraphs, only the upper channel on the stereo-amplifier circuit diagram is described because the two channels are identical and corresponding parts perform the same functions.)

Preamplifier—Each channel of the preamplifier employs a 40395 transistor in the input stage and a 40263 transistor in the second stage. This two-stage circuit has full tone controls, as well as a tapped loudness (volume) control for bass and treble boosting at low volume settings. It provides the following outstanding features:

(1) good high-level signal-handling capability (dynamic range of the first stage is 25 dB above sensitivity);
(2) tone compensation for the Fletcher-Munson effect;
(3) low noise at high frequencies; and
(4) a low power-supply-voltage requirement.

The phonograph input is equalized for a ceramic cartridge which has a capacitance of 1000 picofarads and an output of 0.3 volt. Equalization of the phonograph input is accomplished by matching the electrical time constants of the circuit with the playback characteristic of the phonograph cartridge. The mid-frequency compensation of the playback characteristic is provided by the series combination of R_{12} and C_9 between the collector and base of the 40395 input transistor. The high-frequency compensation is provided by the series combination of the cartridge capacitance and R_3. (Because the cartridge resonance boosts the pickup output at high frequencies, it may be desirable to increase the value of R_3 to obtain a "smoother" sound). No compensation of the low-frequency playback characteristic is provided so that some boost results in the low-bass region.

13-16 5-STAGE, 3-WATT-PER-CHANNEL STEREO AMPLIFIER (cont'd)



PREAMPLIFIER

Parts List for Preamplifier

C_1, C_2 = 5600 pF
C_3, C_6 = 6800 pF
C_4, C_5, C_{19}, C_{24} = 0.047 μF
C_7, C_8, C_{25}, C_{26} = 2 μF, 12 V
C_9, C_{10} = 3300 pF
C_{11}, C_{12} = 10 μF, 15 V
C_{13}, C_{16}, C_{21}, C_{22} = 0.01 μF
C_{14}, C_{15}, C_{17}, C_{18} = 0.22 μF
C_{20}, C_{23} = 10 μF, 6 V
C_{27}, C_{28} = 0.15 μF
R_1, R_6 = 47,000 ohms, 0.5 watt
R_2, R_5 = 56,000 ohms, 0.5 watt
R_3, R_4 = 120,000 ohms, 0.5 watt
R_7, R_8 = 1 megohm, 0.5 watt
R_9, R_{10}, R_{11}, R_{16}, R_{34}, R_{37}, R_{39}, R_{40} = 220,000 ohms, 0.5 watt
R_{12}, R_{15} = 100,000 ohms, 0.5 watt
R_{13}, R_{14}, R_{17}, R_{18}, R_{35}, R_{36}, R_{41}, R_{42} = 10,000 ohms, 0.5 watt
R_{19}, R_{20}, R_{22}, R_{23} = 1500 ohms, 0.5 watt
R_{21}, R_{24} = 3300 ohms, 0.5 watt
R_{25}, R_{26} = potentiometer, 15,000 ohms, linear; tapped at 5000 and 10,000 ohms, 0.5 watt
R_{27}, R_{28}, R_{33}, R_{38} = 5600 ohms, 0.5 watt
R_{29}, R_{32} = potentiometer, 50,000 ohms, linear, 0.5 watt
R_{30}, R_{31} = potentiometer, 25,000 ohms, linear, 0.5 watt
S_1, S_2 = switch, rotary type, 3-position

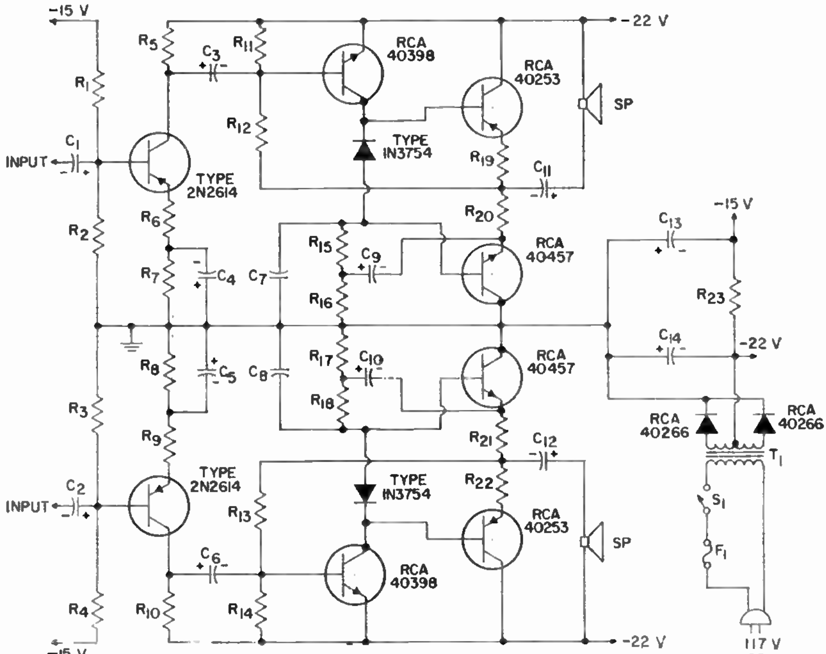
Circuit Description (cont'd)

To reduce the complexity of switching, it is desirable to retain the equalization circuits of the phonograph input for the tuner inputs. The nonuniform frequency response of the input stage must then be corrected to provide flat response from the tuner. This compensation is accomplished by the combination of R_1 and C_3 and R_2 and C_1 for the two tuner inputs.

The loudness (volume) control R_{25} is tapped to provide bass boost at low volume settings. This arrangement compensates for both the Fletcher-Munson effect and the poor bass response of the speaker systems generally used. The series RC combination of R_{21} and C_{13} between the top of the volume control and the first tap provides treble boost at low volume settings.

The feedback-type tone controls are incorporated in the second stage

13-16 5-STAGE, 3-WATT-PER-CHANNEL STEREO AMPLIFIER (cont'd)



POWER AMPLIFIER

Parts List for Power Amplifier

C_1, C_2 = 10 µF, 15 V
C_3, C_6 = 100 µF, 15 V
C_4, C_5 = 500 µF, 3 V
C_7, C_8 = 0.056 µF
C_9, C_{10} = 50 µF, 6 V
C_{11}, C_{12} = 500 µF, 25 V
C_{13} = 500 µF, 15 V
C_{14} = 2000 µF, 25 V
F_1 = fuse, 0.5 ampere, slo-blo
R_1, R_4 = 56,000 ohms, 0.5 watt
R_2, R_3 = 8200 ohms, 0.5 watt
R_5, R_{10} = 2200 ohms, 0.5 watt
R_6, R_9 = 27 ohms, 0.5 watt
R_7, R_8, R_{11}, R_{14} = 220 ohms, 0.5 watt
R_{12}, R_{13} = 3300 ohms, 0.5 watt
R_{15}, R_{16}, R_{17}, R_{18} = 180 ohms, 0.5 watt
R_{19}, R_{20}, R_{21}, R_{22} = 1 ohm, 1 watt
S_1 = ON-OFF switch, single-pole, single-throw
T_1 = power transformer; full-wave center-tapped; dc output voltage = 22 V at 95 mA, 20 V at 285 mA; Better Coil and Transformer Co. No. EX4744 P, C-P Electronics No. 8970, or equiv.

Circuit Description (cont'd)

because of the simplicity of the tone-control system. The operating points of the 40395 and 40263 are maintained by collector-to-base feedback through resistors R_9 and R_{11} and resistors R_{34} and R_{39}. The circuits are designed to provide adequate dynamic range for ambient temperatures up to 55°C. Capacitors C_7 and C_{25} decouple the dc feedback path to maintain high gain.

Power Amplifier—Each channel of the power amplifier employs a 2N2614 transistor in the predriver stage, a 40398 transistor in the driver stage, and a 40253 p-n-p transistor and a 40457 n-p-n transistor in the complementary-symmetry output stage. The predriver stage incorporates a partially bypassed emitter resistor to provide good dc stability with some ac feedback. The n-p-n silicon transistor driver has high dissipation capability and can be operated without a heat sink. The IN3754 diode is used to provide thermal stability. The diode need not be clamped to the output heat sink.

13-16 5-STAGE, 3-WATT-PER-CHANNEL STEREO AMPLIFIER (cont'd)

Circuit Description (cont'd)

This diode must be used if the output stage is to operate reliably in an ambient temperature of 55°C.

Capacitor C_7 reduces the frequency response of the 40457 n-p-n silicon output transistor to approximately that of the 40253 p-n-p germanium output transistor. Because the gain in both stages rolls off at the same frequency, a simple resistor R_{12} can be used for ac feedback. This resistor also provides dc bias for the driver stage.

The power-supply polarity is such that the collector (case) of the 40457 silicon transistor is at ground potential. This arrangement simplifies heat-sink requirements for the output transistors because the collector of the 40253 transistor is isolated from the case. The output transistors must be attached to a heat sink by means of clips such as the RCA SA2100 heat-sink attachment clip. The heat sink must have a thermal resistance of less than 8°C per watt from case to ambient.

13-17 3-STAGE, 5-WATT-PER-CHANNEL STEREO PHONOGRAPH AMPLIFIER

IHFM Music Power Rating, 10 W Per Channel

Circuit Description

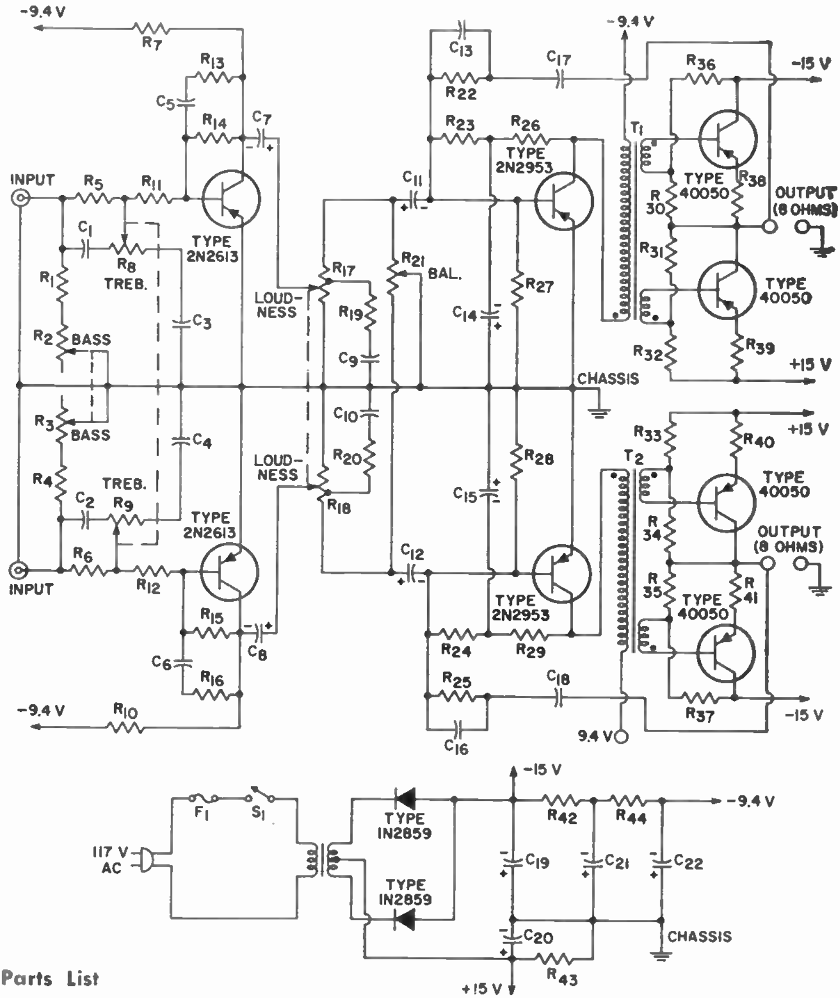
This three-stage amplifier delivers a sine-wave power output of 5 watts per channel to an 8-ohm speaker; its IHFM music power rating is 10 watts per channel, or 20 watts total. The amplifier develops full rated power output from each channel with very little distortion, and clips at a level of 8 watts for a 1-kHz input. At average record levels, full output of 5 watts per channel is obtained for a drive input provided by 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_3 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 kHz 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

13-17 3-STAGE, 5-WATT-PER-CHANNEL STEREO PHONOGRAPH AMPLIFIER (cont'd)



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

13-17 3-STAGE, 5-WATT-PER-CHANNEL STEREO PHONOGRAPH AMPLIFIER (cont'd)

Parts List (cont'd)

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.

Circuit Description (cont'd)

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.

13-18 27-MHz, 5-WATT CITIZENS-BAND TRANSMITTER

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, develops 3.5 watts of rf power output at 27 MHz. Both the driver and the power amplifier are modulated to achieve 100-per-cent amplitude modulation.

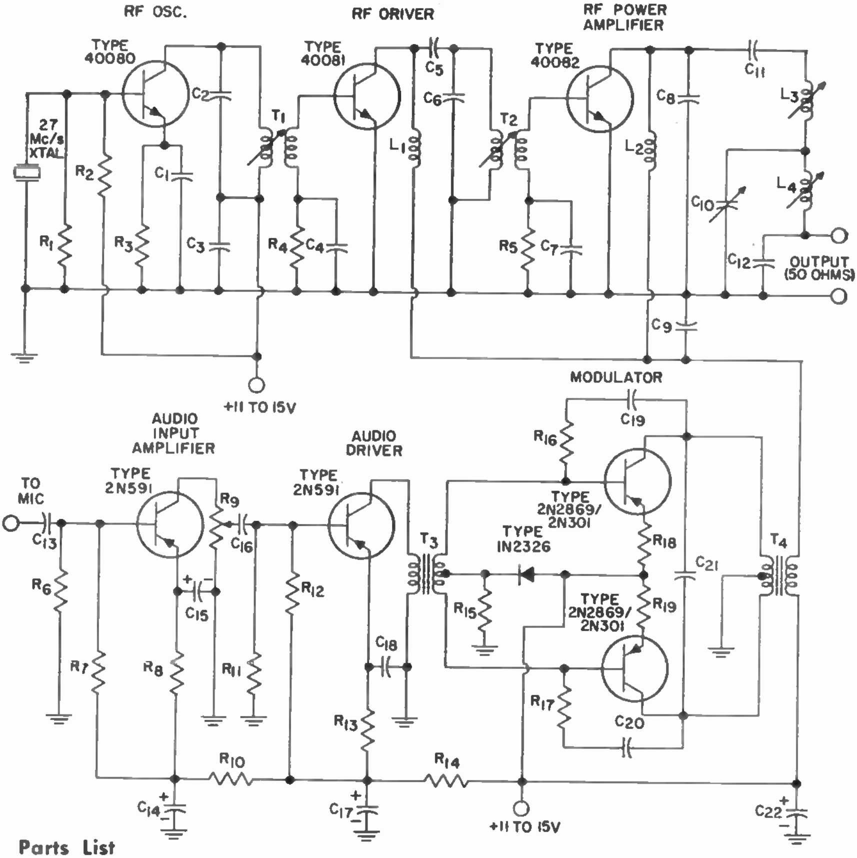
The 40080 crystal-controlled oscillator stage is a Colpitts type of circuit that provides excellent frequency stability with respect to collector supply voltage and temperature (well within the 0.005-per-cent tolerance permitted by F.C.C. regulations) and delivers a minimum rf power of 100 milliwatts 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_1 is designed to match the collector-to-collector load impedance of the modulator to the impedance of the rf driver and power-amplifier stages.

NOTE: See general considerations for construction of high-frequency and broadband circuits on page 462.

13-18 27-MHz, 5-WATT CITIZENS-BAND TRANSMITTER (cont'd)



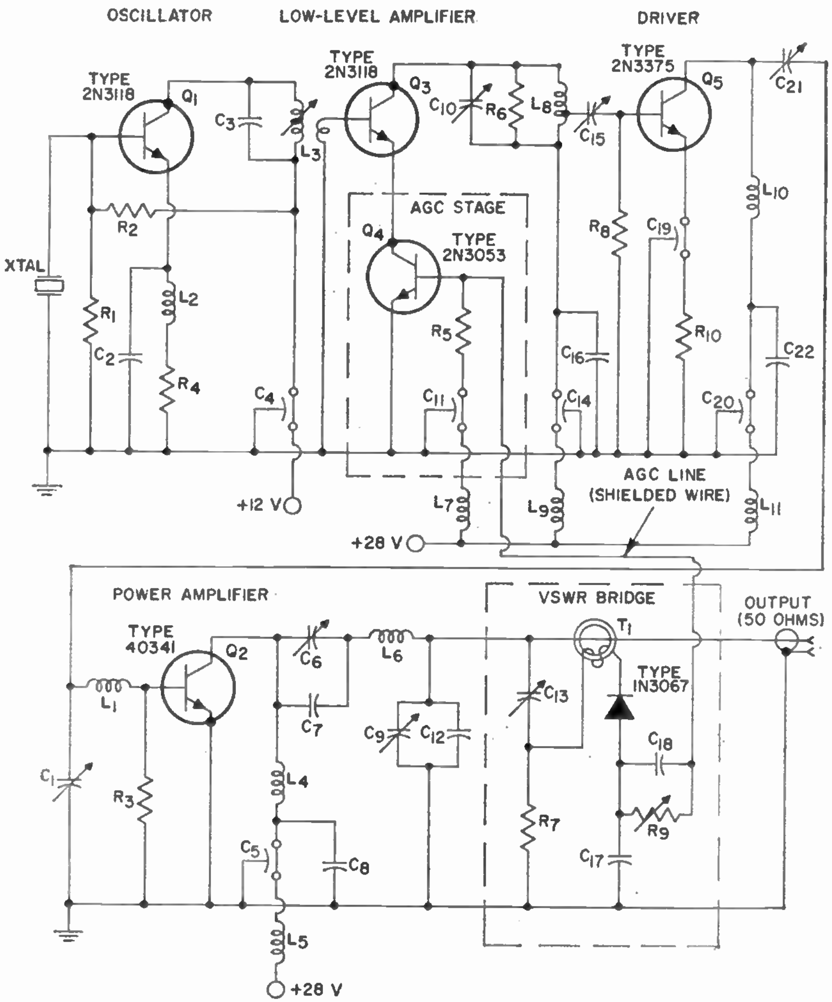
Parts List

C_1 = 75 pF, ceramic
C_2 = 30 pF, ceramic
C_3, C_7 = 0.01 μF, ceramic
C_4 = 0.001 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: The 40082 transistor used in the rf power amplifier should be mounted on a good heat sink.

13-19 50-MHz, 40-WATT CW TRANSMITTER

With Load-Mismatch Protection



Circuit Description

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

13-19 50-MHz, 40-WATT CW TRANSMITTER (cont'd)

Parts List (cont'd)

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, wire-wound, 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.

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.

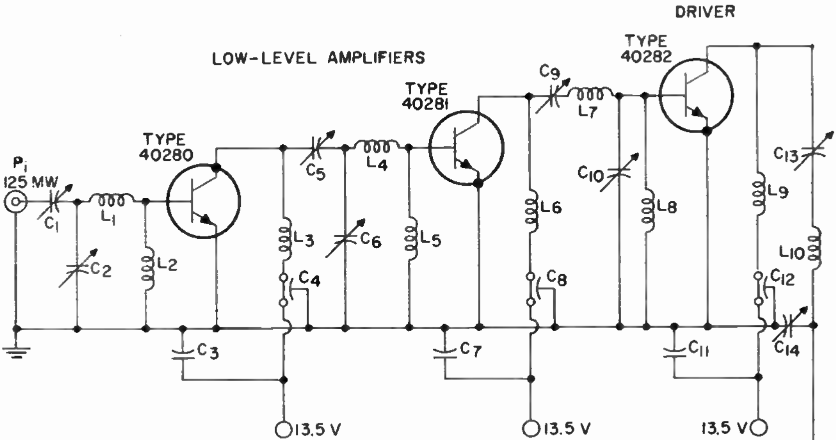
The 50-MHz crystal-controlled 2N3118 oscillator stage develops the low-level excitation signal for the transmitter. The 50-MHz output signal from the collector of the oscillator transistor is coupled by L_3 to the base of a second 2N3118 used in a predriver stage (low-level amplifier). This step-down 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 MHz. This signal is coupled from a tap on inductor L_6 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.

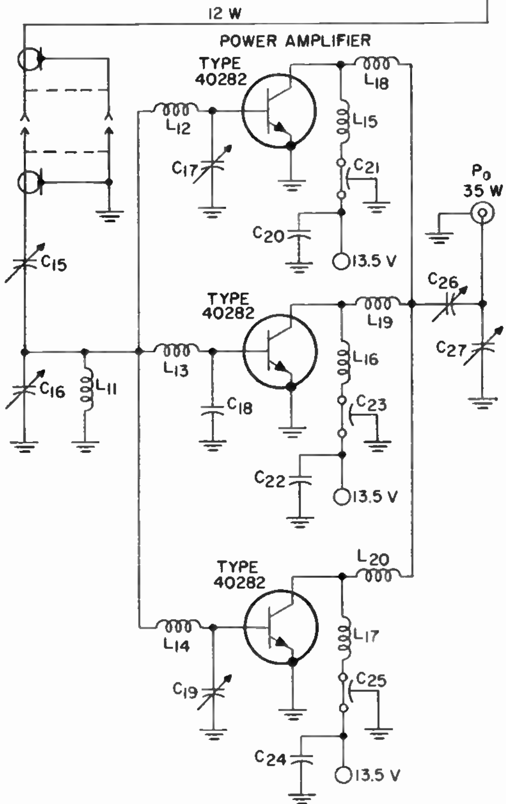
The 40341 overlay transistor used in the output stage develops 40 watts of power output at the transmitting frequency of 50 MHz. The driving power for the output stage is coupled from the collector of the driver transistor through a bandpass filter to the base of the output transistor. The filter networks in the collector circuit of the 40341 provide the required harmonic and spurious-frequency rejection. The 50-MHz 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_{18} 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.

NOTE: See general considerations for construction of high-frequency and broadband circuits on page 462.

13-20 175-MHz, 35-WATT AMPLIFIER





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

13-20 175-MHz, 35-WATT 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 MHz 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 MHz. The 40280 input stage develops 1 watt of power output when a 125-milliwatt 175-MHz 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_{16} and C_{18} 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 MHz. 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-MHz 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.

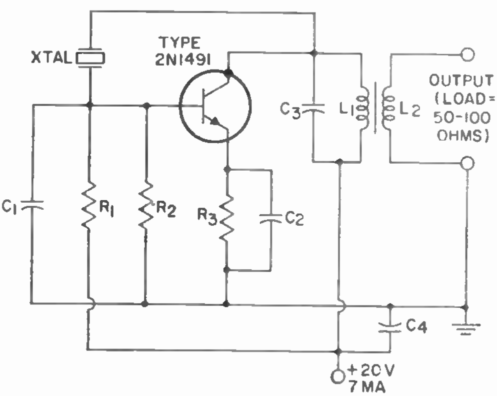
NOTE: See general considerations for construction of high-frequency and broadband circuits on page 391.

13-21 27-MHz CRYSTAL OSCILLATOR

Output 4 mW

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 MHz



Circuit Description

This crystal-controlled oscillator provides a stable 4-milliwatt output at 27 MHz. The circuit operates from a 20-volt, 7-milliampere dc supply.

A 2N1491 common-emitter circuit amplifies the signal from the 27-

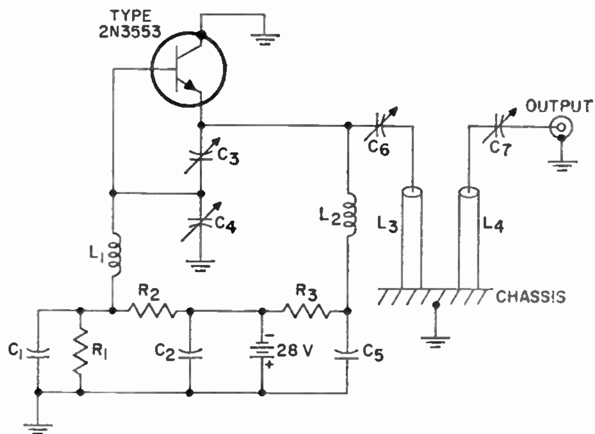
13-21 27-MHz CRYSTAL OSCILLATOR (cont'd)

Circuit Description (cont'd)

MHz 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 to sustain oscillations is selectively coupled from the collector to the base of the 2N1491 by the crystal which operates in the series-resonant mode.

The 27-MHz 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.

13-22 500-MHz, 1-WATT POWER OSCILLATOR



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

Circuit Description

This power oscillator operates from a portable battery supply of 28 volts and delivers 1 watt of rf power output at 500 MHz. 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-MHz 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

13-22 500-MHz, 1-WATT POWER OSCILLATOR (cont'd)

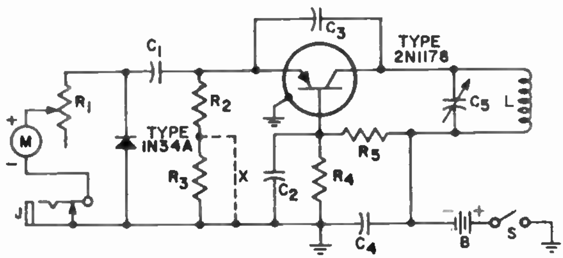
Circuit Description (cont'd)

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.

13-23 "GRID-DIP" METER

For Measuring Resonant Frequencies from 3.5 to 1000 MHz



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 MHz

Coil-Winding Data

Coil	Freq. Range	Wire Size	No. of Turns
1	3.4-6.9 MHz	#28, enamel	48¼, close wound
2	6.7-13.5 MHz	#24, enamel	22, close wound
3	13-27 MHz	#24, enamel	9⅛, close wound
4	25-47 MHz	#24, enamel	4⅛, close wound
5	46-78 MHz	#24, enamel	1½, close wound
6	74-97 MHz	#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 circuit, which is essentially a transistor version of the electron-tube grip-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

13-23 "GRID-DIP" METER (cont'd)

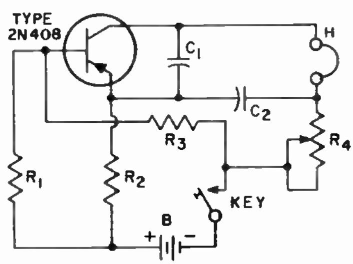
Circuit Description (cont'd)

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 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.

13-24 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 = 0.1 μF, paper, 150 V

H = Headphone, 2000-ohm, magnetic

R_1 = 2200 ohms, 0.5 watt

R_2 = 27000 ohms, 0.5 watt

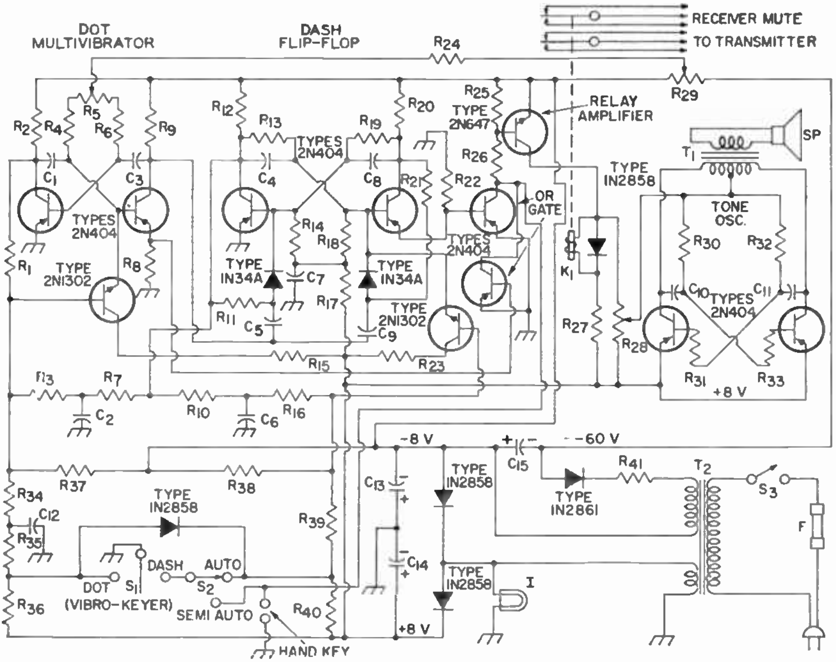
R_3 = 3000 ohms, 0.5 watt

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.

13-25 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.), Stancor No. A3496, or equiv.
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-

13-25 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.

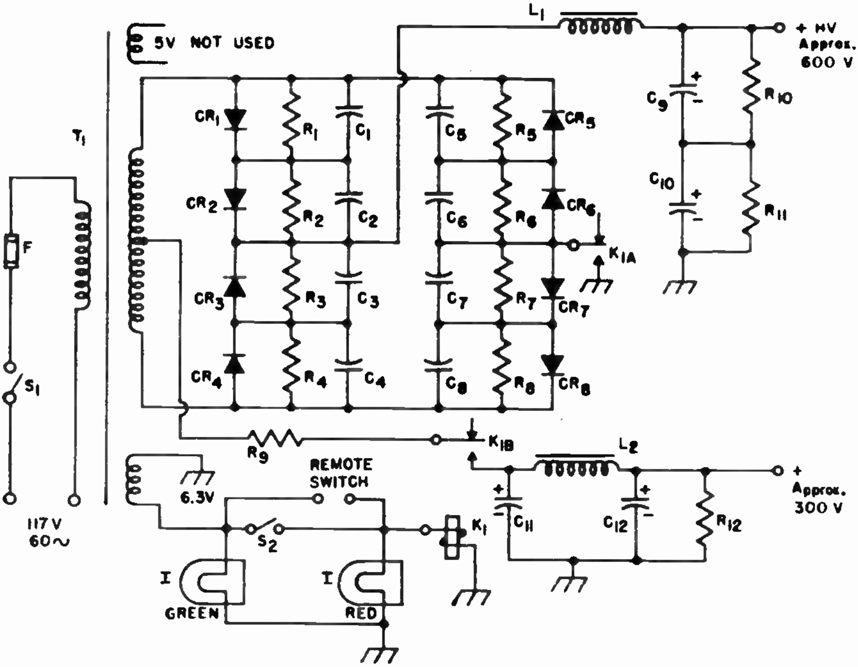
The keying speed of this electronic keyer is determined by the frequency of the dot multivibrator. This frequency is adjustable by means of potentiometer R_{20}, which varies the amplitude of the negative dc voltage. As the negative voltage at the armature of potentiometer R_5 is increased to a maximum 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-Hz 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_2 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.

13-26 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.

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

13-26 POWER SUPPLY FOR AMATEUR TRANSMITTER (cont'd)

Circuit Description (cont'd)

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.

13-27 VOLTAGE REGULATOR, SERIES TYPE

With Adjustable Output

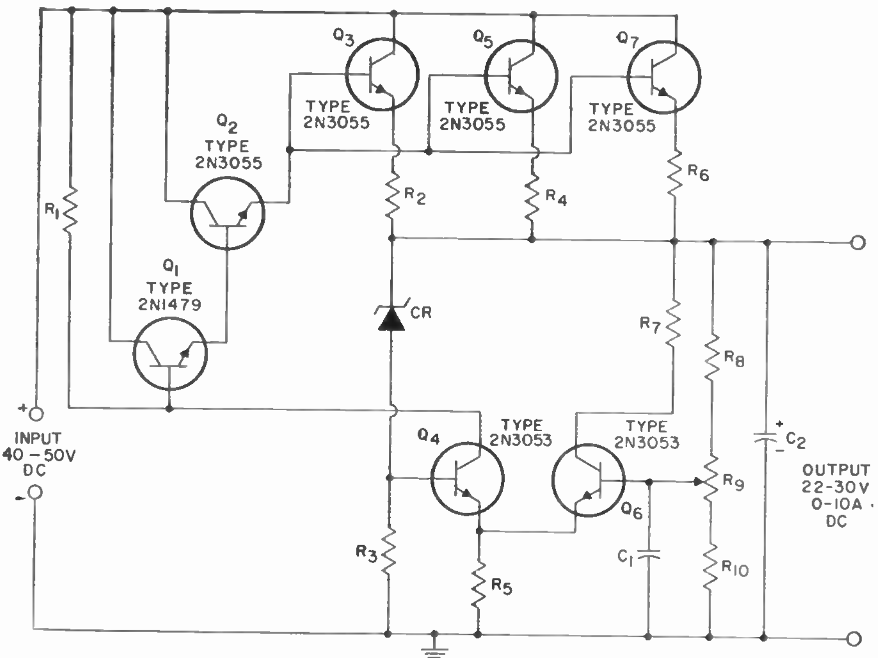
Line Regulation within 1.0% Load Regulation within 0.5%

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_5. 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

13-27 VOLTAGE REGULATOR, SERIES TYPE (cont'd)



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

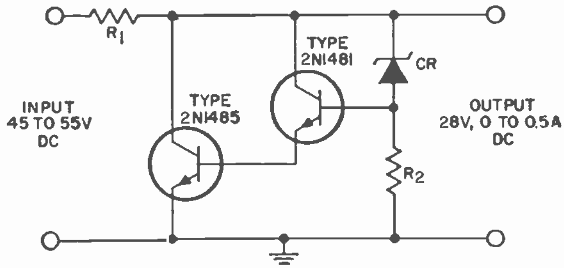
Circuit Description (cont'd)

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.

13-28 VOLTAGE REGULATOR, SHUNT TYPE

Regulation 0.5%



Parts List

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.

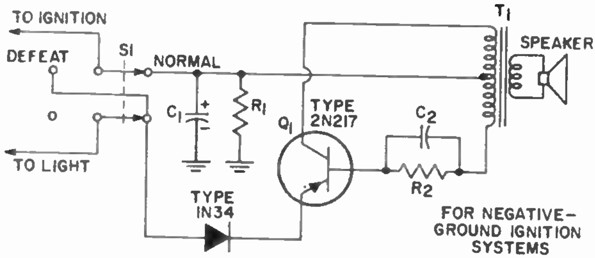
With a 28-volt output, the reverse-bias-connected reference diode, CR, operates in the breakdown-voltage region. In this region, the voltage drop across the diode remains constant (at the reference potential of 27 volts) over a wide range of reverse currents through the diode.

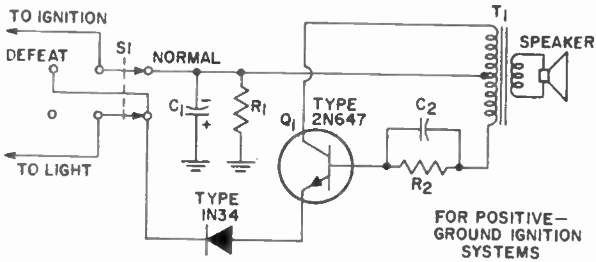
The output voltage tends to rise with an increase in either the applied voltage or the load-circuit impedance. The current through resistor R_2 and reference diode CR then increases. However, the voltage drop across CR remains constant at 27 volts, and the full increase in the output voltage is developed 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.

13-29 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

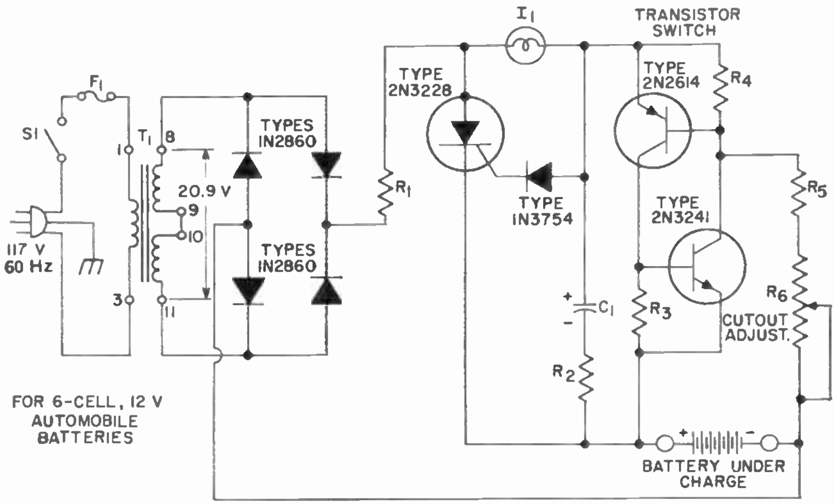
This light-minder circuit sounds an alarm if the lights of a car are left on when the ignition is turned off. The alarm stops when the lights are turned off. When the lights are intentionally left on for a period of time, the alarm can be defeated so that no warning sounds. The alarm then sounds when 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.

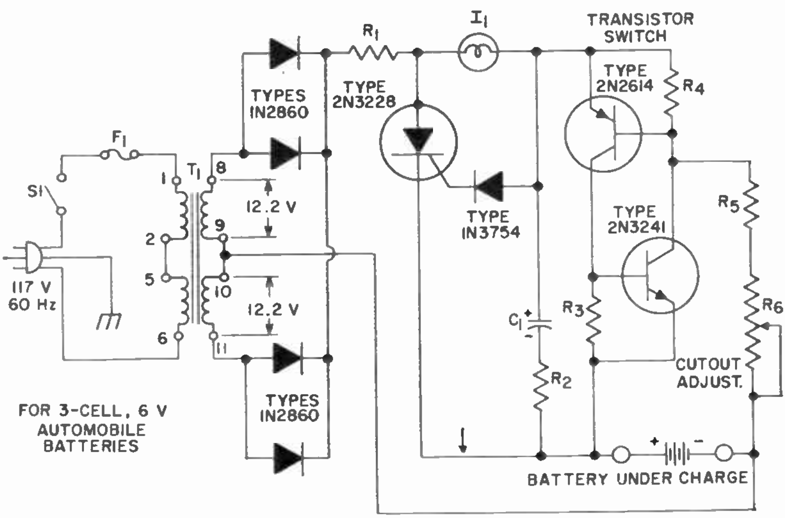
The circuit is essentially an oscillator that obtains its supply voltage from two possible sources, the ignition system or the light system of the car. In the "normal" mode of operation, the ignition system is connected to the collector circuit of the 2N217 (or 2N647) transistor, and the light system 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 R_1 and C_1, 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.

13-30 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.

13-30 BATTERY CHARGERS (cont'd)

Circuit Description

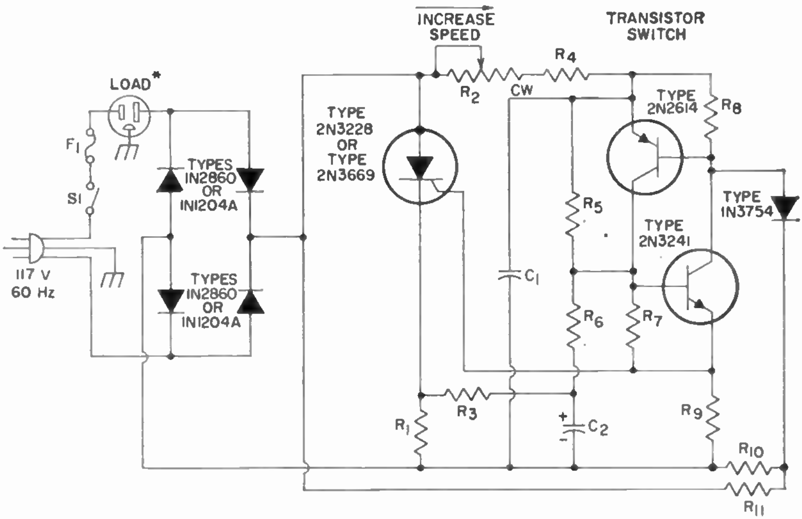
These battery chargers can be used to recharge run-down batteries in automobiles and other vehicles without removing them from their original mounting and without the need for constant attention. When the battery is fully charged, the charger circuits automatically switch from charging current to "trickle" 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.

13-31 UNIVERSAL MOTOR SPEED CONTROL OR LIGHT DIMMER



* Maximum load is 2 amperes when 2N3228 SCR and 1N2860 rectifiers are used or 12 amperes when 2N3669 SCR and 1N1204A rectifiers are used. Component values shown in parentheses in the parts list should be selected when the circuit is to be operated with loads greater than 2 amperes.

Parts List

C_1 = 1.0 μF (or 2 μF), paper, 200 V
C_2 = 50 μF (or 2 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 (or 50000 ohms), 2 watts, linear taper
R_3 = 100 ohms, 0.5 watt
R_4 = 1000 ohms (or 470 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_{10} = 1000 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 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 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 trig-

13-31 UNIVERSAL MOTOR SPEED CONTROL OR LAMP DIMMER (cont'd)

Circuit Description (cont'd)

gered 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_2 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.

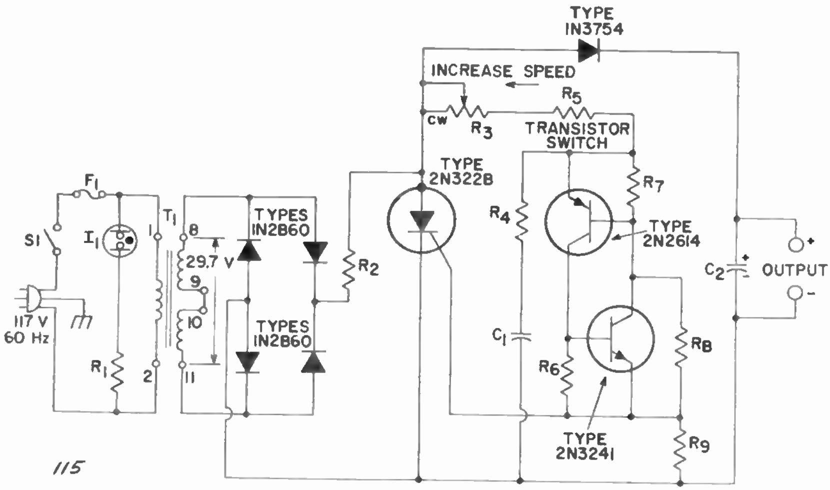
13-32 MODEL TRAIN AND RACE-CAR SPEED CONTROL

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 de-

13-32 MODEL TRAIN AND RACE-CAR SPEED CONTROL (cont'd)



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 (cont'd)

termined 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 adjustment of the potentiometer R_3. Because 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

13-32 MODEL TRAIN AND RACE-CAR SPEED CONTROL (cont'd)

Circuit Description (cont'd)

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.

13-33 ELECTRONIC TIMER

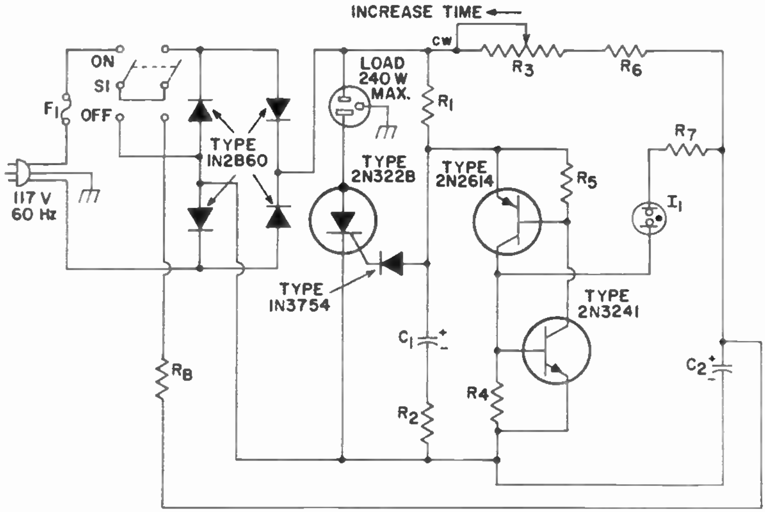
Circuit Description

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_4, 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 discharge path for capacitor C_1. The capacitor discharges through resistor R_2 and the two transistors to approximately one volt (the drop

13-33 ELECTRONIC TIMER (cont'd)



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
R_8 = 15 ohms, 0.5 watt
S_1 = toggle switch, double-pole, double-throw

Circuit Description (cont'd)

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.

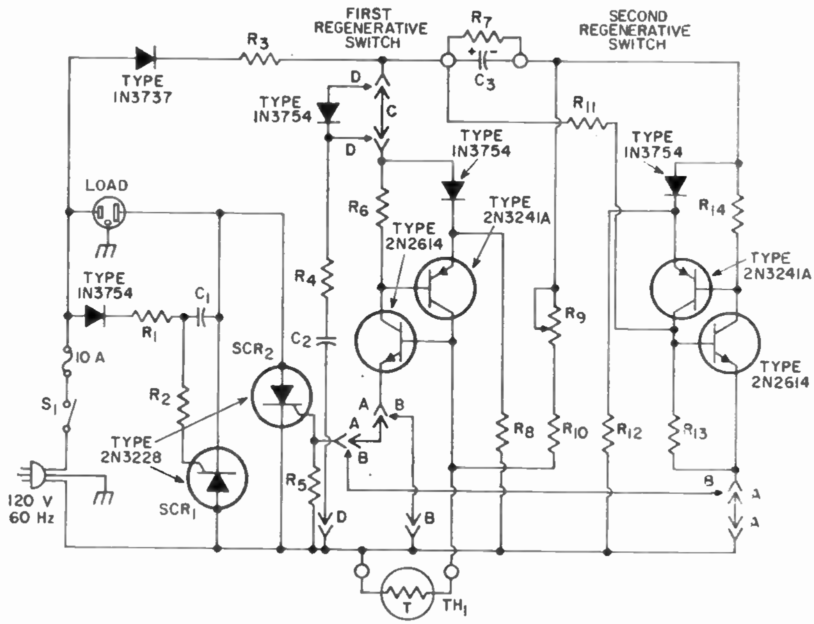
13-34 ELECTRONIC HEAT CONTROL

Circuit Description

This electronic heat control is useful for activating heaters, cooling fans, and warning alarms in food freezers; for switching on fire alarms, for controlling the temperature in fish tanks, incubators, and window greenhouses; or as safety devices for measuring the temperature in a furnace area or for shutting down hot or overheating motors. The circuit can also be used on farms to detect frost conditions.

The circuit can switch resistive loads that have power ratings up to 1 kilowatt or inductive loads that have power ratings up to 680 watts. It has an adjustable temperature range from −28° to +124°C (−18°

13-34 ELECTRONIC HEAT CONTROL (cont'd)



Parts List

C_1 = 10 μF, electrolytic, 15 V
C_2* = 50 μF, electrolytic, 15 V
C_3 = 200 μF, electrolytic, 6 V
R_1, R_3 = 4700 ohms, 2 watts
R_2 = 270 ohms, 0.5 watt
R_4* = 33 ohms, 0.5 watt
R_5 = 180 ohms, 0.5 watt
R_6, R_{14} = 150 ohms, 0.5 watt
R_7 = any resistance 0 to 250 ohms, 0.5 watt
R_8, R_{12} = 22000 ohms, 0.5 watt
R_9 = sensitivity control, potentiometer, 15000 ohms, 2 watts, linear taper
R_{10} = 680 ohms, 0.5 watt
R_{11} = 5600 ohms, 0.5 watt
R_{13} = 470 ohms, 0.5 watt
S_1 = ON-OFF switch, single-pole single-throw, toggle, 15-ampere, 125-volt type, 3-position
TH_1 = thermistor, negative temperature coefficient, resistance variation over desired operating temperature range from 150 to 1500 ohms

* Indicates optional latching-circuit components

Circuit Description (cont'd)

to +255°F) depending on the characteristics of the thermistor used. The manner in which the circuit is wired determines whether it turns the load ON or OFF with increasing temperature. Four different wiring arrangements may be used. Wiring A causes the circuit to the load to be opened as the temperature increases beyond a predetermined level; wiring B causes the opposite effect, i.e., the circuit to the load is opened when the temperature decreases below a preset value. When wiring C is used, the circuit does not lock in either mode. Wiring D "latches" or locks the heat control in the load-circuit open or closed position, depending upon whether wiring A or B is chosen. When wiring D (the latching circuit) is used, R_{11} and C_3 should be removed and replaced by a jumper.

Two 2N3228 SCR's are used in the circuit to provide full-wave power control. A pair of two-transistor regenerative switches are used to provide the turn-on signals for the SCR's. Each regenerative switch employs a 2N2614 n-p-n triggering transistor and a 2N3241A p-n-p out-

13-34 ELECTRONIC HEAT CONTROL (cont'd)

Circuit Description (cont'd)

put transistor. The thermistor TH_1 is the sensing element used to initiate the control function. The useful temperature range of the circuit depends on the characteristics of the thermistor used. This range can be varied by changing the values of potentiometer R_9 and resistor R_{10} in series with it. The total resistance of this combination should not exceed 18,000 ohms and the resistance of R_{10} should not be less than 680 ohms. Potentiometer R_9 is the sensitivity control for the circuit. The setting of this control determines the temperature at which the electronic heat control interrupts or applies power to the load circuit.

When power is applied to the circuit, a voltage is applied to the two regenerative switches that control the signal or gate voltage to the SCR's. The triggering level of the second regenerative switch is set by the fixed resistors R_{11} and R_{13}. The triggering level of the first switch is set by the thermistor and the series combination of R_{10} and the potentiometer R_9. The triggering level of the individual regenerative switches is determined by their associated resistances and not by the voltage across them. As a result, the switching of the circuit is independent of changes in line voltage.

When the ambient heat around the thermistor is high, the resistance of the thermistor is low and the voltage required to trigger the first regenerative switch is high. If this triggering voltage is higher than that required by the second regenerative switch, the second switch conducts. When wiring A is used, the signal from the second regenerative switch is short-circuited and there is an open circuit to the load. If differential resistor R_7 is used, the current through the second regenerative switch causes a voltage drop across R_7. This voltage drop results in a slight increase in the firing potential of the first regenerative switch. Because R_7 controls the firing potential of the first regenerative switch, it also controls the turn-on and turn-off temperatures of the circuit. With a decrease in temperature, the resistance of the thermistor increases and thus reduces the potential required to fire the switch. This switch turns on when its firing potential is lower than that of the second switch and applies a signal to the gate of SCR_1 to turn it on (when wiring A is used). A voltage is then applied to the load and to the network consisting of the 1N3754 diode D_1, R_1, and C_1, causing C_1 to charge.

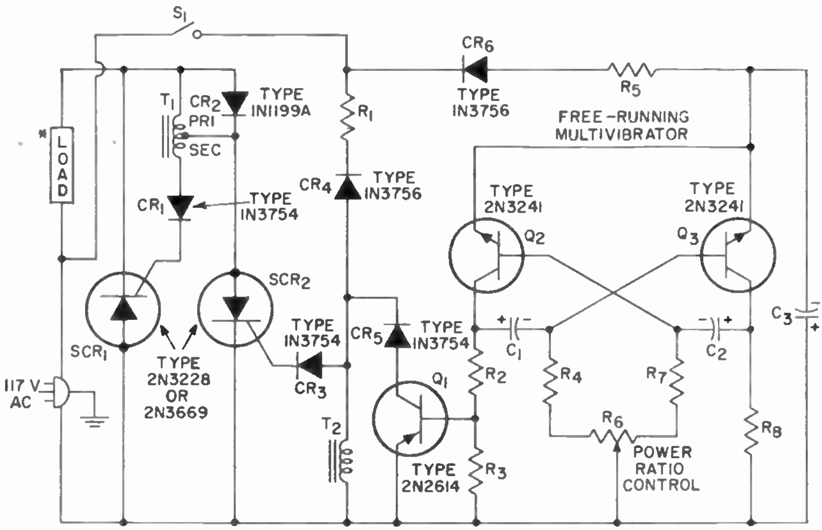
During the next half-cycle, the charge on C_1 is applied to the gate of SCR_2, causing it to conduct current to the load. If wiring A is used, this process repeats as long as the thermistor is cool; if wiring B is used, as long as the thermistor is warm.

13-35 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 Hz) multivibrator; the ratio of on time to off time during

13-35 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.

Circuit Description (cont'd)

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

13-35 INTEGRAL-CYCLE RATIO POWER CONTROL (cont'd)

Circuit Description (cont'd)

and the 1N3754 diode CR_3 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.

13-36 SERVO AMPLIFIER

Output, 6 W

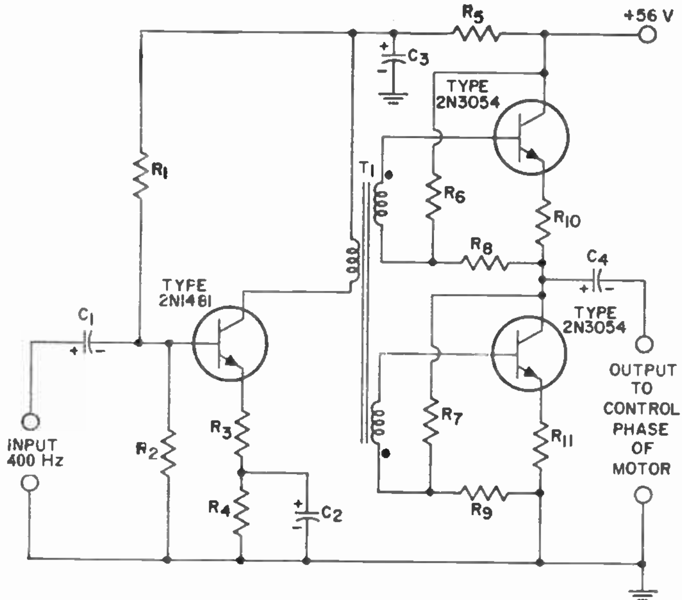
Circuit Description

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-Hz 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 13-10.

A 2N1481 common-emitter input stage amplifies the 400-Hz input to the level required to drive the 2N3054 output transistors. The amplified 400-Hz 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 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.

13-36 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_3 = 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)

13-37 SHIFT REGISTER OR RING COUNTER

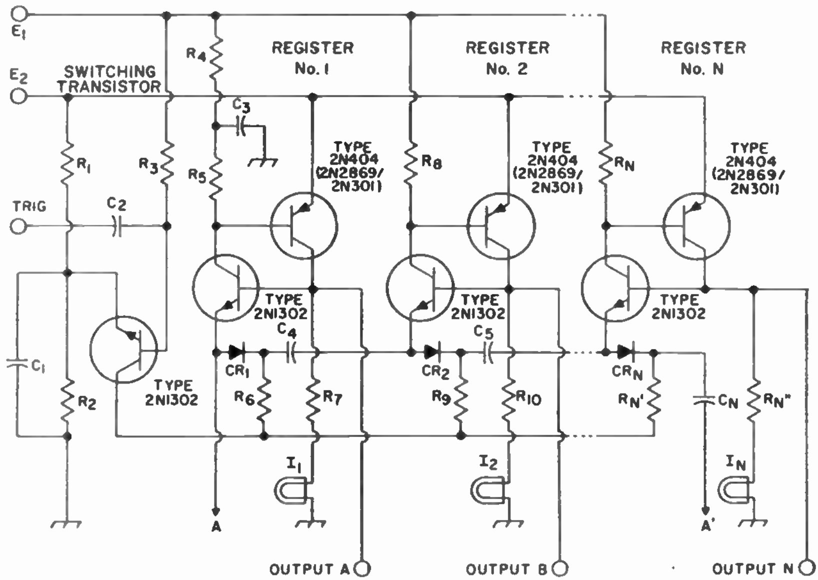
Circuit Description

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 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

13-37 SHIFT REGISTER OR RING COUNTER (cont'd)



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).

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)

Circuit Description (cont'd)

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 hrough any of the other register stages. When the power is first ap-

13-37 SHIFT REGISTER OR RING COUNTER (cont'd)

Circuit Description (cont'd)

plied, 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.

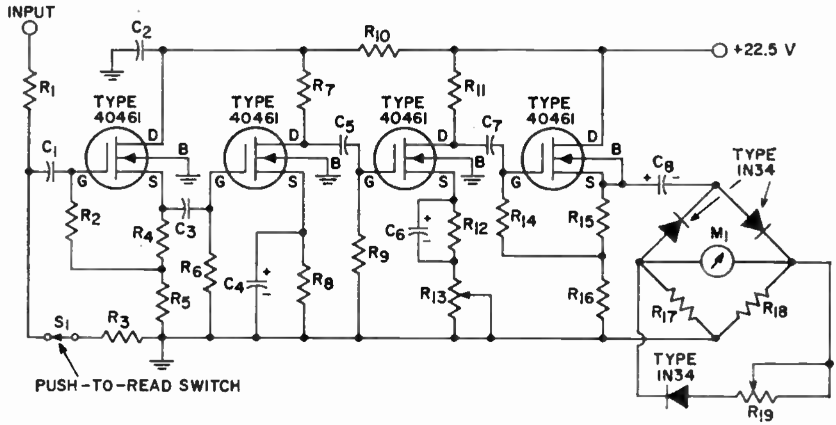
13-38 AC VOLTMETER

Circuit Description

This circuit illustrates the application of RCA-40461 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 Hz, and a low current drain which permits fully portable operation. The amplifier portion of the voltmeter circuit consists of four 40461 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 capaci-

13-38 AC VOLTMETER CIRCUIT (cont'd)



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; Micro Switch No. BZ2RQ1 or equiv.

Circuit Description (cont'd)

tor. 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 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.

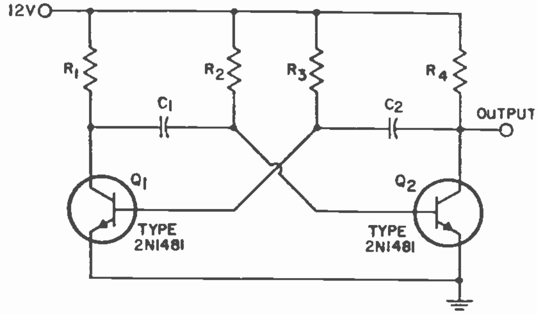
The meter rectifier uses two 1N34 diodes in a conventional meter-circuit bridge configuration. A third 1N34 diode is used in conjunction with a 10,000-ohm potentiometer to compensate for the nonlinear rectification characteristic of the rectifier diodes at the low end of the meter scale.

A 100-to-1 voltage divider is placed ahead of the input-coupling capacitor of the first stage to protect the gate of the 40461 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.

13-39 ASTABLE MULTIVIBRATOR

(Frequency = 7000 Hz)



$$f = \frac{1}{(0.7C_1R_2)(0.7C_2R_3)}$$

Parts List

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

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

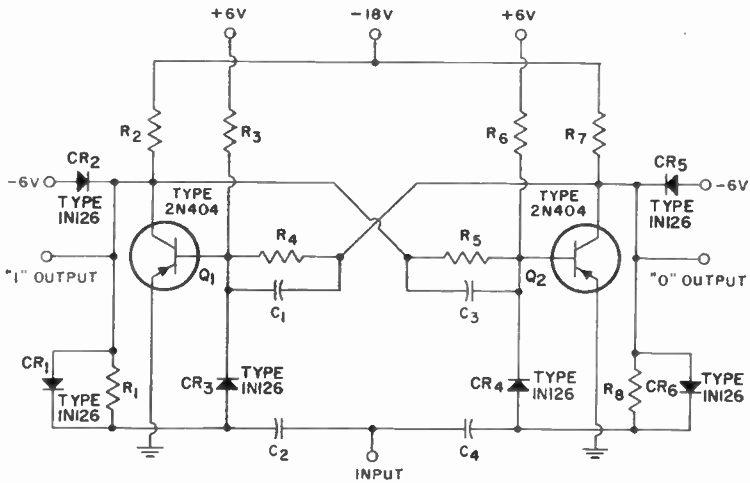
13-39 ASTABLE MULTIVIBRATOR (cont'd)

Circuit Description (cont'd)

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.

13-40 BISTABLE MULTIVIBRATOR

1-MHz "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 tran-

13-40 BISTABLE MULTIVIBRATOR (cont'd)

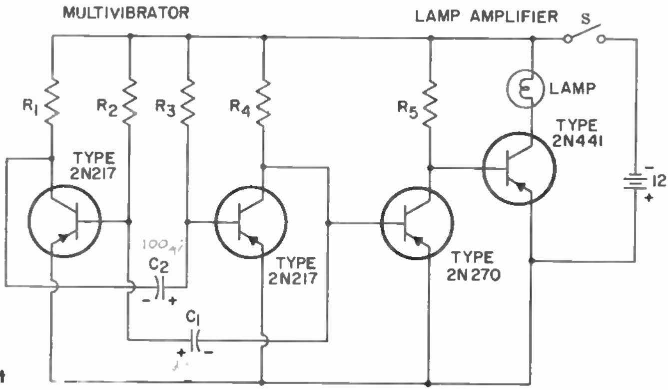
Circuit Description (cont'd)

sistor. 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.

13-41 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.

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TUNNEL DIODES
Charts on pages 446 and 447

COMPENSATING DIODES:
Pages 446 and 447

DAMPER DIODES:
Page 448

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