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POWER ELECTRONICS HANDBOOK

DEVICES, CIRCUITS, AND APPLICATIONS

Third Edition

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The Power Diode

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2.1 Diode as a Switch

Among all the static switching devices used in power electronics (PE), the power diode is perhaps the simplest. Its circuit symbol is shown in Fig. 2.1. It is a two terminal device, and terminal A is known as the anode whereas terminal K is known as the cathode. If terminal A experiences a higher potential compared to terminal K, the device is said to be forward biased and a current called forward current (I_F) will flow through the device in the direction as shown. This causes a small voltage drop across the device (<1 V), which in ideal condition is usually ignored. On the contrary, when a diode is reverse biased, it does not conduct and a practical diode do experience a small current flowing in the reverse direction called the leakage current. Both the forward voltage drop and the leakage current are ignored in an ideal diode. Usually in PE applications a diode is considered to be an ideal static switch.

The characteristics of a practical diode show a departure from the ideals of zero forward and infinite reverse impedance, as shown in Fig. 2.2a. In the forward direction, a potential barrier associated with the distribution of charges in the vicinity of the junction, together with other effects, leads to a voltage drop. This, in the case of silicon, is in the range of 1 V for currents in the normal range. In reverse, within the normal operating range of voltage, a very small current flows which is largely independent of the voltage. For practical purposes, the static characteristics is often represented by Fig. 2.2b. In the figure, the forward characteristic is expressed as a threshold voltage V_o and a linear incremental or slope resistance, r. The reverse characteristic remains the same over the range of possible leakage currents irrespective of voltage within the normal working range.

2.2 Properties of PN Junction

From the forward and reverse biased condition characteristics, one can notice that when the diode is forward biased, current rises rapidly as the voltage is increased. Current in the reverse biased region is significantly small until the breakdown voltage of the diode is reached. Once the applied voltage is over this limit, the current will increase rapidly to a very high value limited only by an external resistance.

DC diode parameters. The most important parameters are the followings:

- ***Forward voltage, V_F*** is the voltage drop of a diode across A and K at a defined current level when it is forward biased.
- ***Breakdown voltage, V_B*** is the voltage drop across the diode at a defined current level when it is beyond reverse biased level. This is popularly known as avalanche.
- ***Reverse current I_R*** is the current at a particular voltage, which is below the breakdown voltage.

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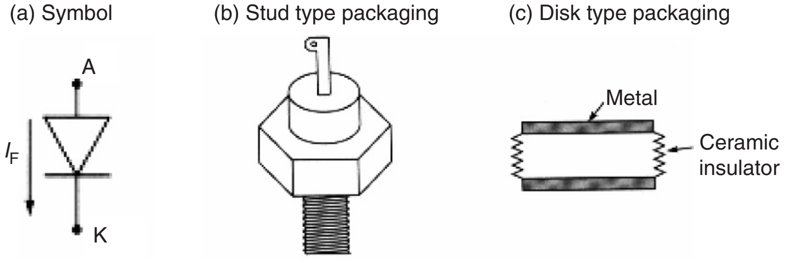


FIGURE 2.1 Power diode: (a) symbol; (b) and (c) types of packaging.

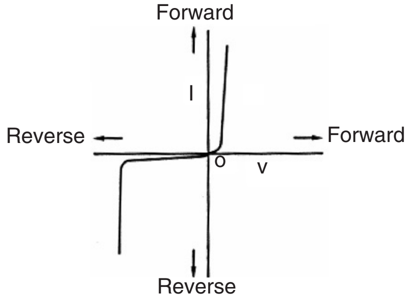


FIGURE 2.2a Typical static characteristic of a power diode (forward and reverse have different scale).

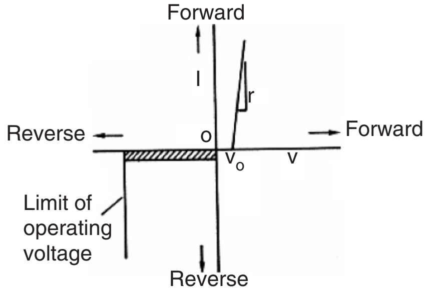


FIGURE 2.2b Practical representation of the static characteristic of a power diode.

AC diode parameters. The commonly used parameters are the followings:

- ***Forward recovery time, t_{FR}*** is the time required for the diode voltage to drop to a particular value after the forward current starts to flow.
- ***Reverse recovery time t_{rr}*** is the time interval between the application of reverse voltage and the reverse current dropped to a particular value as shown in Fig. 2.3. Parameter t_a is the interval between the zero crossing of the diode current to when it becomes I_{RR}. On the other hand, t_b is the time interval from the maximum reverse recovery current to approximately 0.25 of I_{RR}. The ratio of the two parameters t_a and t_b is known as the softness factor (SF). Diodes with abrupt recovery characteristics are used for high frequency switching.

In practice, a design engineer frequently needs to calculate the reverse recovery time. This is in order to evaluate the possibility of high frequency switching. As a thumb rule, the lower t_{RR} the faster the diode can be switched.

$$t_{rr} = t_a + t_b \tag{2.1}$$

If t_b is negligible compared to t_a which is a very common case, then the following expression is valid:

$$t_{RR} = \sqrt{\frac{2Q_{RR}}{(di/dt)}}$$

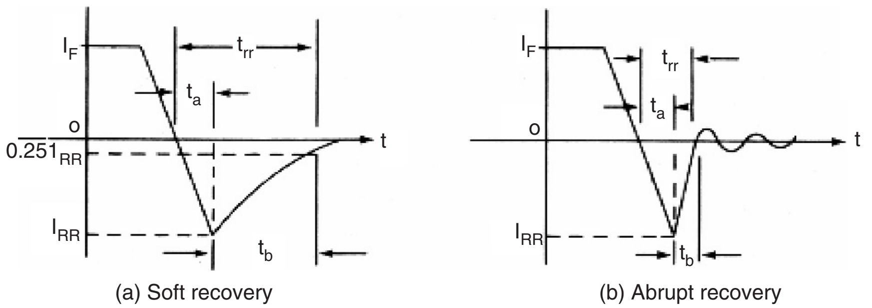


FIGURE 2.3 Diode reverse recovery with various softness factors.

from which the reverse recovery current

$$I_{RR} = \sqrt{\frac{di}{dt} 2Q_{RR}}$$

where Q_{RR} is the storage charge and can be calculated from the area enclosed by the path of the recovery current.

EXAMPLE 2.1 The manufacturer of a selected diode gives the rate of fall of the diode current $di/dt = 20\,\text{A}/\mu\text{s}$, and its reverse recovery time $t_{rr} = 5\,\mu\text{s}$. What value of peak reverse current do you expect?

SOLUTION. The peak reverse current is given as:

$$I_{RR} = \sqrt{\frac{di}{dt} 2Q_{RR}}$$

The storage charge Q_{RR} is calculated as:

$$Q_{RR} = \frac{1}{2}\frac{di}{dt} t_{rr}^2 = 1/2 \times 20\,\text{A}/\mu\text{s} \times (5 \times 10^{-6})^2 = 50\,\mu\text{C}$$

Hence,

$$I_{RR} = \sqrt{20\,\frac{\text{A}}{\mu\text{s}} \times 2 \times 50\,\mu\text{C}} = 44.72\,\text{A}$$

- ***Diode capacitance***, C_D is the net diode capacitance including the junction (C_J) plus package capacitance (C_P).

In high-frequency pulse switching, a parameter known as transient thermal resistance is of vital importance since it indicates the instantaneous junction temperature as a function of time under constant input power.

2.3 Common Diode Types

Depending on their applications, diodes can be segregated into the following major divisions:

Small signal diode: They are perhaps the most widely used semiconductor devices used in wide variety of applications. In general purpose applications, they are used as a switch in rectifiers, limiters, capacitors, and in wave-shaping. Some common diode parameters a designer needs to know are the forward voltage, reverse breakdown voltage, reverse leakage current, and the recovery time.

Silicon rectifier diode: These are the diodes, which have high forward current carrying capability, typically up to several hundred amperes. They usually have a forward resistance of only a fraction of an ohm while their reverse resistance is in the mega-ohm range. Their primary application is in power conversion, like in power supplies, UPS, rectifiers/inverters, etc. In case of current exceeding the rated value, their case temperature will rise. For stud-mounted diodes, their thermal resistance is between 0.1 and 1°C/W.

Zener diode: Its primary applications are in the voltage reference or regulation. However, its ability to maintain a certain voltage depends on its temperature coefficient and the impedance. The voltage reference or regulation applications of zener diodes are based on their avalanche properties. In the reverse biased mode, at a certain voltage the resistance of these devices may suddenly drop. This occurs at the zener voltage V_X, a parameter the designer knows beforehand.

Figure 2.4 shows a circuit using a zener diode to control a reference voltage of a linear power supply. Under normal operating condition, the transistor will transmit power to the load (output) circuit. The output power level will depend on the transistor base current. A very high base current will impose a large voltage across the zener and it may attain zener voltage V_X, when it will crush and limit the power supply to the load.

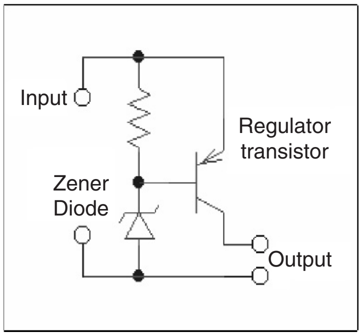


FIGURE 2.4 Voltage regulator with a zener diode for reference.

Photo diode: When a semiconductor junction is exposed to light, photons generate hole–electron pairs. When these charges diffuse across the junction, they produce photocurrent. Hence this device acts as a source of current, which increases with the intensity of light.

Light emitting diode (***LED***): Power diodes used in PE circuits are high power versions of the commonly used devices employed in analog and digital circuits. They are manufactured in wide varieties and ranges. The current rating can be from a few amperes to several hundreds while the voltage rating varies from tens of volts to several thousand volts.

2.4 Typical Diode Ratings

2.4.1 Voltage Ratings

For power diodes, a given datasheet has two voltage ratings. One is the repetitive peak inverse voltage (V_{RRM}), the other is the non-repetitive peak inverse voltage. The non-repetitive voltage (V_{RM}) is the diodes capability to block a reverse voltage that may occur occasionally due to a overvoltage surge.

Repetitive voltage on the other hand is applied on the diode in a sustained manner. To understand this, let us look at the circuit in Fig. 2.5.

EXAMPLE 2.2 Two equal source voltages of 220 V peak and phase shifted from each other by 180° are supplying a common load as shown. (a) Show the load voltage; (b) describe when diode D1 will experience V_{RRM}; and (c) determine the V_{RRM} magnitude considering a safety factor of 1.5.

SOLUTION. (a) The input voltage, load voltage, and the voltage across D1 when it is not conducting (V_{RRM}) are shown in Fig. 2.5b.

(b) Diode D1 will experience V_{RRM} when it is not conducting. This happens when the applied voltage $V1$ across it is in the negative region (from 70 to 80 ms as shown in the figure) and consequently the diode is reverse biased. The actual ideal voltage across it is the peak value of the two input voltages i.e. $220 \times 2 = 440$ V. This is because when D1 is not conducting, D2 conducts. Hence in addition V_{an}, V_{bn} is also applied across it since D2 is practically shorted.

(c) The $V_{RRM} = 440$ V is the value in ideal situation. In practice, higher voltages may occur due to stray circuit inductances and/or transients due to the reverse recovery of the diode. They are hard to estimate. Hence, a design engineer would always use a safety factor to cater to these overvoltages. Hence, one should use a diode with a $220 \times 2 \times 1.5 = 660$ V rating.

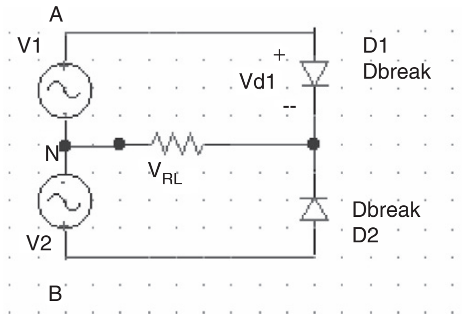


FIGURE 2.5a The circuit.

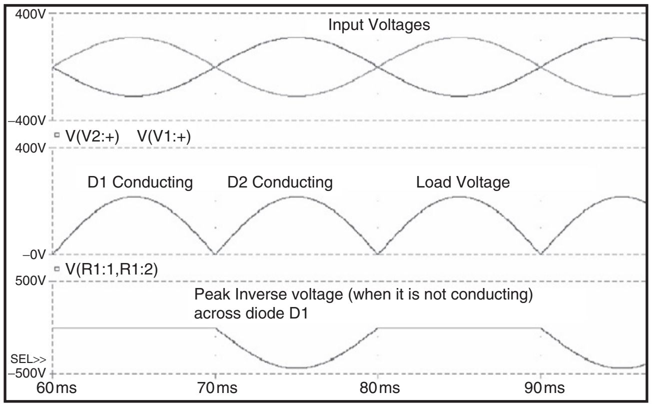


FIGURE 2.5b The waveforms.

2.4.2 Current Ratings

Power diodes are usually mounted on a heat sink. This effectively dissipates the heat arising due to continuous conduction. Hence, current ratings are estimated based on temperature rise considerations. The datasheet of a diode normally specifies three different current ratings. They are (1) the average current, (2) the rms current, and (3) the peak current. A design engineer must ensure that each of these values is not exceeded. To do that, the actual current (average, rms, and peak) in the circuit must be evaluated either by calculation, simulation, or measurement. These values must be checked against the ones given in the datasheet for that selected diode. The calculated values must be less than or equal to the datasheet values. The following example shows this technique.

EXAMPLE 2.3 The current waveform passing through a diode switch in a switch mode power supply application is shown in Fig. 2.6. Find the average, rms, and the peak current.

SOLUTION. The current pulse duration is shown to be 0.2 ms within a period of 1 ms and with a peak amplitude of 50 A. Hence the required currents are:

$$I_{average} = 50 \times \frac{0.2}{1} = 10\,\text{A}$$

$$I_{rms} = \sqrt{50^2 \times \frac{0.2}{1}} = 22.36\,\text{A}$$

$$I_{peak} = 50\,\text{A}$$

Sometimes, a surge current rating and its permissible duration is also given in a datasheet. For protection of diodes and other semiconductor devices, a fast acting fuse is required. These fuses are selected based on their I^2t rating which is normally specified in a datasheet for a selected diode.

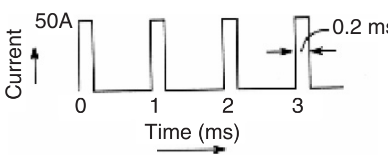


FIGURE 2.6 The current waveform.

2.5 Snubber Circuits for Diode

Snubber circuits are essential for diodes used in switching circuits. It can save a diode from overvoltage spikes, which may arise during the reverse recovery process. A very common snubber circuit for a power diode consists of a capacitor and a resistor connected in parallel with the diode as shown in Fig. 2.7.

When the reverse recovery current decreases, the capacitor by virtue of its property will try to hold the voltage across it, which, approximately, is the voltage across the diode. The resistor on the other hand will help to dissipate some of the energy stored in the inductor, which forms the I_{RR} loop. The dv/dt across a diode can be calculated as:

$$\frac{dv}{dt} = \frac{0.632 \times V_S}{\tau} = \frac{0.632 \times V_S}{R_S \times C_S} \tag{2.2}$$

where V_S is the voltage applied across the diode.

Usually the dv/dt rating of a diode is given in the manufacturers datasheet. Knowing dv/dt and the R_S, one can choose the value of the snubber capacitor C_S. The R_S can be calculated from the diode reverse recovery current:

$$R_S = \frac{V_S}{I_{RR}} \tag{2.3}$$

The designed dv/dt value must always be equal or lower than the dv/dt value found from the datasheet.

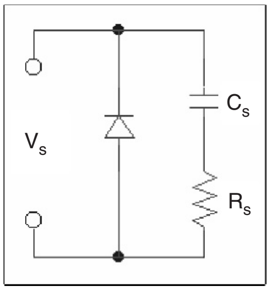


FIGURE 2.7 A typical snubber circuit.

2.6 Series and Parallel Connection of Power Diodes

For specific applications, when the voltage or current rating of a chosen diode is not enough to meet the designed rating, diodes can be connected in series or parallel. Connecting them in series will give the structure a high voltage rating that may be necessary for high-voltage applications. However, one must ensure that the diodes are properly matched especially in terms of their reverse recovery properties. Otherwise, during reverse recovery there may be a large voltage imbalances between the

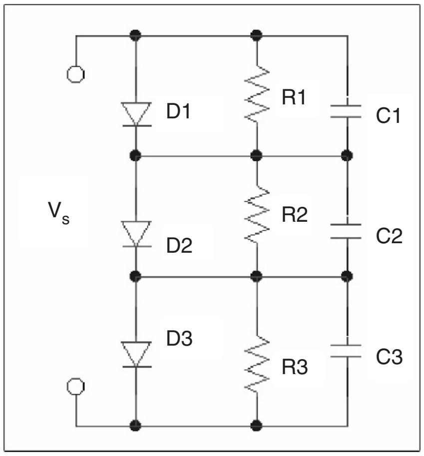


FIGURE 2.8 Series connected diodes with necessary protection.

series connected diodes. Additionally, due to the differences in the reverse recovery times, some diodes may recover from the phenomenon earlier than the other causing them to bear the full reverse voltage. All these problems can effectively be overcome by connecting a bank of a capacitor and a resistor in parallel with each diode as shown in Fig. 2.8.

If a selected diode cannot match the required current rating, one may connect several diodes in parallel. In order to ensure equal current sharing, the designer must choose diodes with the same forward voltage drop properties. It is also important to ensure that the diodes are mounted on similar heat sinks and are cooled (if necessary) equally. This will affect the temperatures of the individual diodes, which in turn may change the forward characteristics of diode.

Tutorial 2.1 Reverse Recovery and Overvoltages

Figure 2.9 shows a simple switch mode power supply. The switch (1-2) is closed at $t = 0$ s. When the switch is open, a freewheeling current $I_F = 20$ A flows through the load (RL), freewheeling diode (DF), and the large load circuit inductance (LL). The diode reverse recovery current is 20 A and it then decays to zero at the rate of 10 A/μs. The load is rated at 10 Ω and the forward on-state voltage drop is neglected.

(a) Draw the current waveform during the reverse recovery (I_{RR}) and find its time (t_{rr}).
(b) Calculate the maximum voltage across the diode during this process (I_{RR}).

Solution. (a) A typical current waveform during reverse recovery process is shown in Fig. 2.10 for an ideal diode.

When the switch is closed, the steady-state current is, $I_{SS} = 200\,\text{V}/10\,\Omega = 20\,\text{A}$, since under steady-state condition, the inductor is shorted. When the switch is open, the reverse recovery current flows in the right-hand side

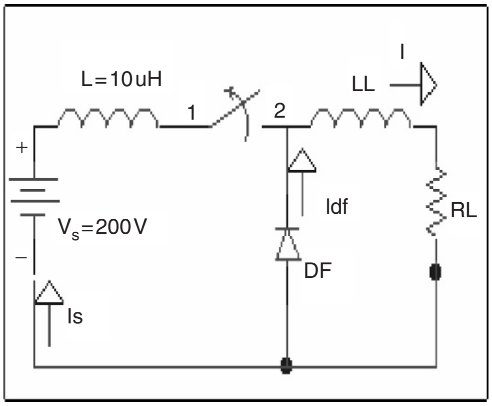


FIGURE 2.9 A simple switch mode power supply with freewheeling diode.

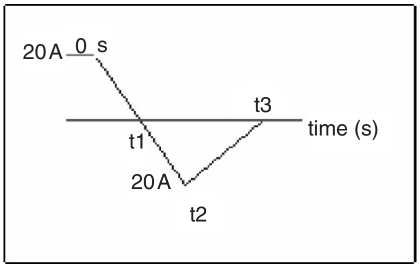


FIGURE 2.10 Current through the freewheeling diode during reverse recovery.

loop consisting of the LL, RL, and DF. The load inductance, LL is assumed to be shorted. Hence, when the switch is closed, the loop equation is:

$$V = L\frac{di_S}{dt}$$

from which

$$\frac{di_S}{dt} = \frac{V}{L} = \frac{200}{10} = 20\,\text{A}/\mu\text{s}$$

At the moment the switch is open, the same current keeps flowing in the right-hand side loop. Hence,

$$\frac{di_d}{dt} = -\frac{di_S}{dt} = -20\,\text{A}/\mu\text{s}$$

from time zero to time t_1 the current will decay at a rate of 20 A/s and will be zero at $t_1 = 20/20 = 1\,\mu\text{s}$. The reverse recovery current starts at this point and, according to the given condition, becomes 20 A at t_2. From this point on, the rate of change remains unchanged at 20 A/μs. Period $t_2 - t_1$ is found as:

$$t_2 - t_1 = \frac{20\,\text{A}}{20\,\text{A}/\mu\text{s}} = 1\,\mu\text{s}$$

From t_2 to t_3, the current decays to zero at the rate of 20 A/μs. The required time:

$$t_3 - t_2 = \frac{20\,\text{A}}{10\,\text{A}/\mu\text{s}} = 2\,\mu\text{s}$$

Hence the actual *reverse recovery time*: $t_{rr} = t_3 - t_1 = (1 + 1 + 2) - 1 = 3\,\mu\text{s}$.

(b) The diode experiences the maximum voltage just when the switch is open. This is because both the source voltage 200 V and the newly formed voltage due to the change in current through the inductor L. The voltage across the diode:

$$V_D = -V + L\frac{di_S}{dt} = -200 + (10\times10^{-6})(-20\times10^{6}) = -400\text{V}$$

Tutorial 2.2 Ideal Diode Operation, Mathematical Analysis, and PSPICE Simulation

This tutorial illustrates the operation of a diode circuit. Most of the PE applications operate at a relative high voltage, and in such cases, the voltage drop across the power diode usually is small. It is quite often justifiable to use the ideal diode model. An ideal diode has a zero conduction drop when it is forward biased and has zero current when it is reverse biased. The explanation and the analysis presented below is based on the ideal diode model.

Circuit Operation A circuit with a single diode and an RL load is shown in Fig. 2.11. The source V_S is an alternating sinusoidal source. If $V_S = E\sin(\omega t)$, then V_S is positive when $0 < \omega t < \pi$, and V_S is negative when $\pi < \omega t < 2\pi$. When V_S starts becoming positive, the diode starts conducting and the positive source keeps the diode in conduction till ωt reaches π radians. At that instant, defined by $\omega t = \pi$ radians, the current through the circuit is not zero and there is some energy stored in the inductor. The voltage across an inductor is positive when the current through it is increasing and becomes negative when the current through it tends to fall. When the

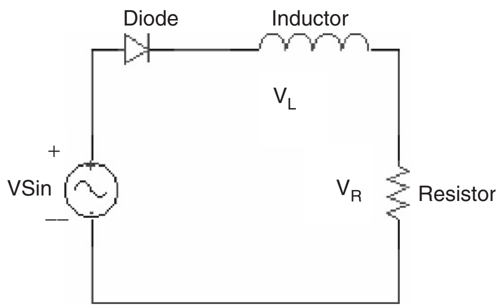


FIGURE 2.11 Circuit diagram.

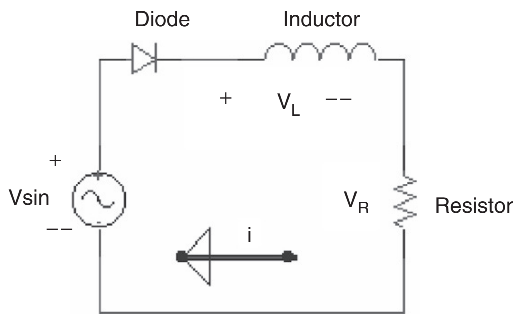


FIGURE 2.12 Current increasing, $0 < \omega t < \pi/2$.

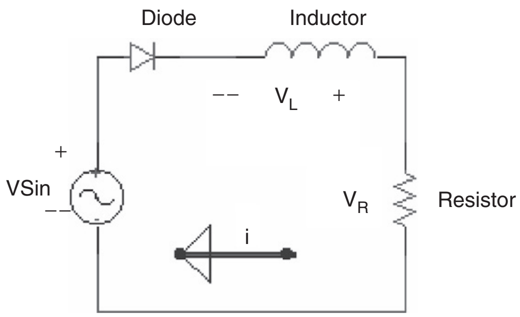


FIGURE 2.13 Current decreasing, $\pi/2 < \omega t < \pi$.

voltage across the inductor is negative, it is in such a direction as to forward bias the diode. The polarity of voltage across the inductor is as shown in Fig. 2.12 or 2.13.

When V_S changes from a positive to a negative value, there is current through the load at the instant $\omega t = \pi$ radians and the diode continues to conduct till the energy stored in the inductor becomes zero. After that the current tends to flow in the reverse direction and the diode blocks conduction. The entire applied voltage now appears across the diode.

Mathematical Analysis An expression for the current through the diode can be obtained as shown in the equations. It is assumed that the current flows for $0 < \omega t < \beta$, where $\beta > \pi$, when the diode conducts, the driving function for the differential equation is the sinusoidal function defining the source voltage. During the period defined by $\beta < \omega t < 2\pi$, the diode blocks current and acts as an open switch. For this period, there is no equation defining the behavior of the circuit. For $0 < \omega t < \beta$, Eq. (2.4) applies.

$$L\frac{di}{dt} + R \times i = E \times \sin(\theta), \textit{ where } -0 \leq \theta \leq \beta \qquad (2.4)$$

$$L\frac{di}{dt} + R \times i = 0 \qquad (2.5)$$

$$\omega L\frac{di}{d\theta} + R \times i = 0 \qquad (2.6)$$

$$i(\theta) = A \times e^{-R\theta/\omega L} \qquad (2.7)$$

Given a linear differential equation, the solution is found out in two parts. The homogeneous equation is defined by Eq. (2.5). It is preferable to express the equation in terms of the angle θ instead of "t." Since $\theta = \omega t$, we get that $d\theta = \omega \cdot dt$. Then Eq. (2.5) gets converted to Eq. (2.6). Equation (2.7) is the solution to this homogeneous equation and is called the complementary integral.

The value of constant A in the complimentary solution is to be evaluated later. The particular solution is the steady-state response and Eq. (2.8) expresses the particular solution. The steady-state response is the current that would flow in steady state in a circuit that contains only the source, resistor, and inductor shown in the circuit, the only element missing being the diode. This response can be obtained using the differential equation or the Laplace transform or the ac sinusoidal circuit analysis. The total solution is the sum of both the complimentary and the particular solution and it is shown in Eq. (2.9). The value of A is obtained using the initial condition. Since the diode starts conducting at $\omega t = 0$ and the current starts building up from zero, $i(0) = 0$. The value of A is expressed by Eq. (2.10).

Once the value of A is known, the expression for current is known. After evaluating A, current can be evaluated at different values of ωt, starting from $\omega t = \pi$. As ωt increases, the current would keep decreasing. For some values of ωt, say β, the current would be zero. If $\omega t > \beta$, the current would evaluate to a negative value. Since the diode blocks current in the reverse direction, the diode stops conducting when ωt reaches. Then an expression for the average output voltage can be obtained. Since the average voltage across the inductor has to be zero, the average voltage across the resistor and average voltage at the cathode of the diode are the same. This average value can be obtained as shown in Eq. (2.11).

$$i(\theta) = \left(\frac{E}{Z}\right)\sin(\omega t - \alpha) \qquad (2.8)$$

where

$$\alpha = a\tan\left(\frac{\omega l}{R}\right) \text{ and } Z^2 = R^2 + \omega l^2$$

$$i(\theta) = A \times e^{(-R\theta/\omega L)} + \frac{E}{Z}\sin(\theta - \alpha) \qquad (2.9)$$

$$A = \left(\frac{E}{Z}\right)\sin(\alpha) \qquad (2.10)$$

Hence, the average output voltage:

$$V_{OAVG} = \frac{E}{2\pi}\int_0^\beta \sin\theta \cdot d\theta = \frac{E}{2\pi} \times [1 - \cos(\beta)] \qquad (2.11)$$

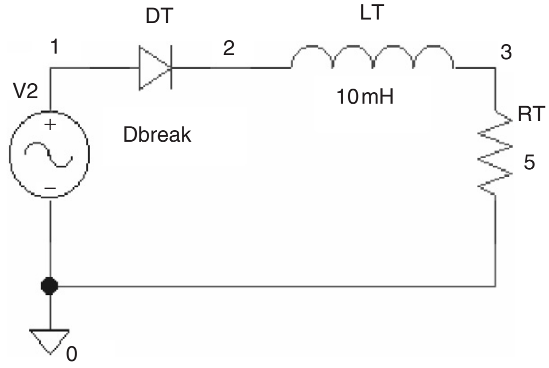


FIGURE 2.14 PSPICE model to study an R–L diode circuit.

PSPICE Simulation For simulation using PSPICE, the circuit used is shown in Fig. 2.14. Here the nodes are numbered. The ac source is connected between the nodes 1 and 0. The diode is connected between the nodes 1 and 2 and the inductor links the nodes 2 and 3. The resistor is connected from the node 3 to the reference node, that is, node 0. The circuit diagram is shown in Fig. 2.14.

The PSPICE program in textform is presented below.

```
*Half-wave Rectifier with RL Load
*An exercise to find the diode current
VIN 1 0 SIN(0 100 V 50 Hz)
D1 1 2 Dbreak
L1 2 3 10 mH
R1 3 0 5 Ohms
.MODEL Dbreak D(IS=10N N=1 BV=1200
   IBV=10E-3 VJ=0.6)
.TRAN 10 uS 100 mS 60 mS 100 uS
.PROBE
.OPTIONS (ABSTOL=1N RELTOL=.01 VNTOL=1MV)
.END
```

The diode is described using the MODEL statement. The TRAN statement simulates the transient operation for a period of 100 ms at an interval of 10 ms. The OPTIONS statement sets limits for tolerances. The output can be viewed on the screen because of the PROBE statement. A snapshot of various voltages/currents is shown in Fig. 2.15.

From Fig. 2.15, it is evident that the current lags the source voltage. This is a typical phenomenon in any inductive circuit and is associated with the energy storage property of the inductor. This property of the inductor causes the current to change slowly, governed by the time constant $\tau = \tan^{-1}(\omega l/R)$. Analytically, this is calculated by the expression in Eq. (2.8).

2.7 Typical Applications of Diodes

A. In rectification

Four diodes can be used to fully rectify an ac signal as shown in Fig. 2.16. Apart from other rectifier circuits, this topology does not require an input transformer. However, they are used for isolation and protection. The direction of the current is decided by two diodes conducting at any given time. The direction of the current through the load is always the same. This rectifier topology is known as the full bridge rectifier.

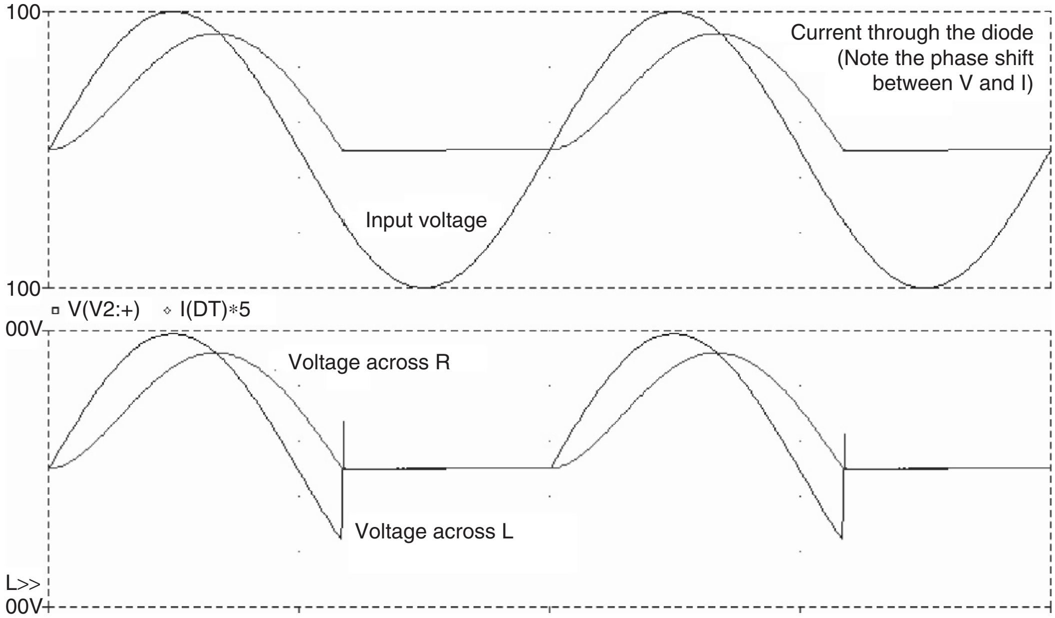


FIGURE 2.15 Voltage/current waveforms at various points in the circuit.

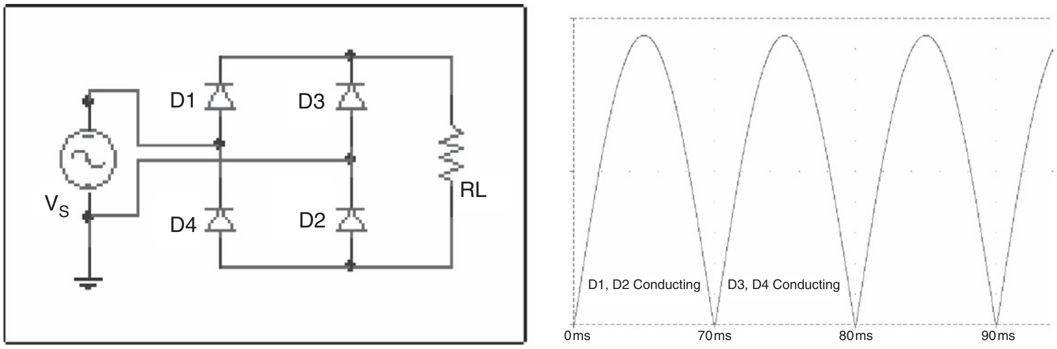


FIGURE 2.16 Full bridge rectifier and its output dc voltage.

The average rectifier output voltage:

$$V_{dc} = \frac{2V_m}{\pi}, \text{ where } V_m \text{ is the peak input voltage}$$

The rms rectifier output voltage:

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

This rectifier is twice as efficient as compared to a single phase one.

B. For voltage clamping

Figure 2.17 shows a voltage clamper. The negative pulse of the sinusoidal input voltage charges the capacitor to its maximum value in the direction shown. After charging, the capacitor cannot discharge, since it is open circuited by the diode. Hence the output voltage:

$$V_o = V_c + V_i = V_m(1 + \sin(\omega t))$$

The output voltage is clamped between zero and $2V_m$.

C. As voltage multiplier

Connecting diode in a predetermined manner, an ac signal can be doubled, tripled, and even quadrupled. This is shown in Fig. 2.18. As evident, the circuit will yield a dc voltage equal to $2V_m$. The capacitors are alternately charged to the maximum value of the input voltage.

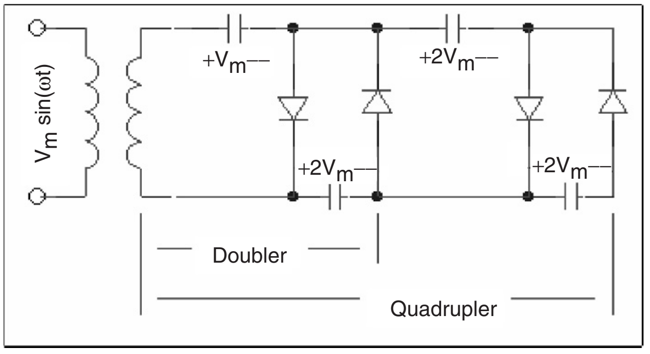


FIGURE 2.18 Voltage doubler and quadrupler circuit.

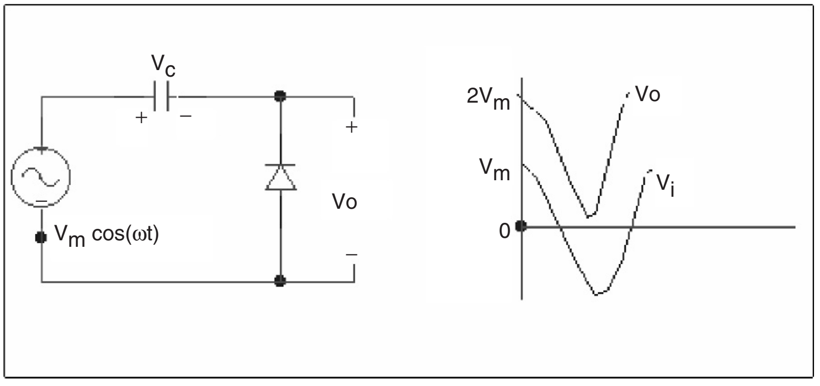


FIGURE 2.17 Voltage clamping with diode.

2.8 Standard Datasheet for Diode Selection

In order for a designer to select a diode switch for specific applications, the following tables and standard test results can be used. A power diode is primarily chosen based on forward current (I_F) and the peak inverse (V_{RRM}) voltage. For example, the designer chooses the diode type V30 from the table in Fig. 2.19 because it closely matches their calculated values of I_F and V_{RRM} without going over. However, if for some reason only the V_{RRM} matches but the calculated value of I_F comes higher, one should go for diode H14, and so on. Similar concept is used for V_{RRM}.

General-Use Rectifier Diodes

Glass Molded Diodes

$I_{F(AV)}$ (A)	V_{RRM}(V) / Type	50	100	200	300	400	500	600	800	1000	1300	1500
0.4	V30	-	-	-	-	-	-	-	yes	yes	yes	yes
1.0	H14	-	yes	yes	yes	yes	yes	yes	yes	yes	-	-
1.1	V06	-	-	yes	-	yes	-	yes	yes	-	-	-
1.3		-	-	yes	-	yes	-	yes	yes	-	-	-
2.5	U05	-	yes	yes	-	yes	-	yes	yes	-	-	-
3.0	U15	-	yes	yes	-	yes	-	yes	yes	-	-	-

FIGURE 2.19 Table of diode selection based on average forward current, $I_{F(AV)}$ and peak inverse voltage, V_{RRM} (courtesy of Hitachi semiconductors).

ABSOLUTE MAXIMUM RATINGS

Item	Type		V30J	V30L	V30M	V30N
Repetitive Peak Reverse Voltage	V_{RRM}	V	800	1000	1300	1500
Non-Repetitive Peak Reverse Voltage	V_{RSM}	V	1000	1300	1600	1800
Average Forward Current	$I_{F(AV)}$	A	0.4 (Single-phase half sine wave 180° conduction TL = 100°C, Lead length = 10 mm)			
Surge(Non-Repetitive) Forward Current	I_{FSM}	A	30 (Without PIV, 10 ms conduction, Tj = 150°C start)			
I^2t Limit Value	I^2t	A^2s	3.6 (Time = 2 ~ 10 ms, I = RMS value)			
Operating Junction Temperature	T_j	°C	–50 ~ +150			
Storage Temperature	T_{s1g}	°C	–50 ~ +150			

Notes (1) Lead Mounting: Lead temperature 300°C max. to 3.2 mm from body for 5 sec. max.
(2) Mechanical strength: Bending 90° × 2 cycles or 180° × 1 cycle, Tensile 2kg, Twist 90° × l cycle.

CHARACTERISTICS (T_L=25°c)

Item	Symbols	Units	Min.	Typ.	Max.	Test Conditions
Peak Reverse Current	I_{RRM}	μA	–	0.6	10	All class Rated V_{RRM}
Peak Forward Voltage	V_{FM}	V	–	–	1.3	I_{FM}=0.4 Ap, Single-phase half sine wave 1 cycle
Reverse Recovery Time	t_{rr}	μs	–	3.0	–	I_F=2 mA, V_R=–15 V
Steady State Thermal Impedance	$R_{th(j-a)}$	°C/W	–	–	80	Lead length = 10 mm
	$R_{th(j-1)}$				50	

FIGURE 2.20 Details of diode characteristics for diode *V30* selected from Fig. 2.19.

In addition to the above mentioned diode parameters, one should also calculate parameters like the peak forward voltage, reverse recovery time, case and junction temperatures, etc. and check them against the datasheet values. Some of these datasheet values are provided in Fig. 2.20 for the selected diode V30. Figures 2.21–2.23 give the standard experimental relationships between voltages, currents, power, and case temperatures for our selected V30 diode. These characteristics help a designer to understand the safe operating area for the diode, and to make a decision whether or not to use a snubber or a heat sink. If one is particularly interested in the actual reverse recovery time measurement, the circuit given in Fig. 2.24 can be constructed and experimented upon.

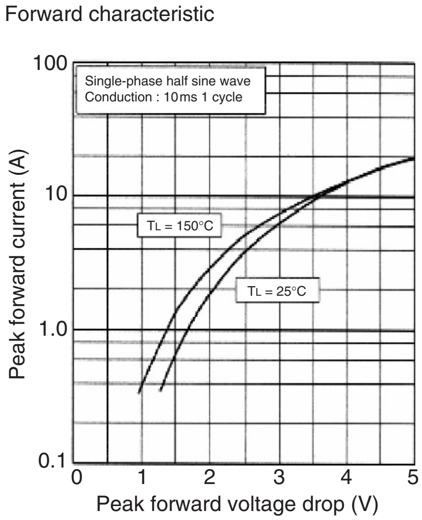


FIGURE 2.21 Variation of peak forward voltage drop with peak forward current.

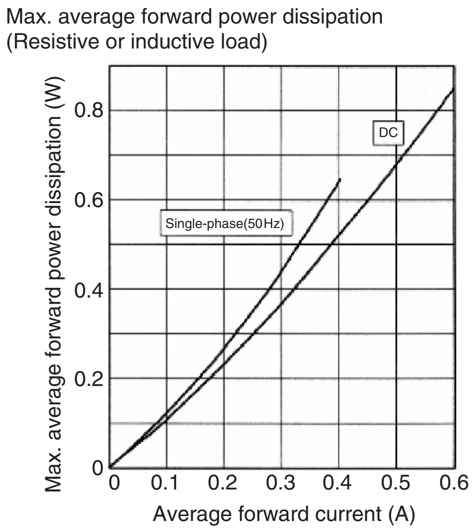


FIGURE 2.22 Variation of maximum forward power dissipation with average forward current.

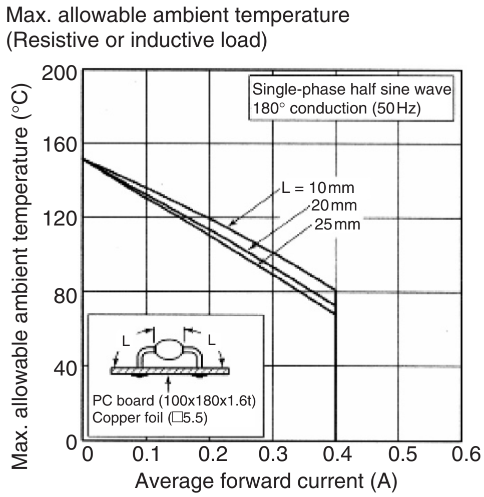


FIGURE 2.23 Maximum allowable case temperature with variation of average forward current.

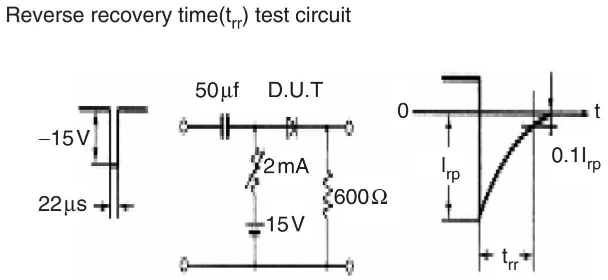


FIGURE 2.24 Reverse recovery time (t_{rr}) measurement.

References

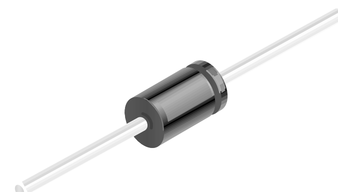
1. N. Lurch, *Fundamentals of Electronics*, 3rd ed., John Wiley & Sons Ltd., New York, 1981.
2. R. Tartar, *Solid-State Power Conversion Handbook*, John Wiley & Sons Ltd., New York, 1993.
3. R.M. Marston, *Power Control Circuits Manual*, Newnes circuits manual series. Butterworth Heinemann Ltd., New York, 1995.
4. Internet information on "Hitachi Semiconductor Devices," http://semiconductor.hitachi.com.
5. International rectifier, *Power Semiconductors Product Digest*, 1992/93.
6. Internet information on, "Electronic Devices & SMPS Books," http://www.smpstech.com/books/booklist.htm.

FAIRCHILD
SEMICONDUCTOR®

1N4001 - 1N4007

Features

- Low forward voltage drop.
- High surge current capability.



DO-41
COLOR BAND DENOTES CATHODE

General Purpose Rectifiers

Absolute Maximum Ratings*

T_A = 25°C unless otherwise noted

Symbol	Parameter	Value							Units
		4001	4002	4003	4004	4005	4006	4007	
V_{RRM}	Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
$I_{F(AV)}$	Average Rectified Forward Current, .375 " lead length @ T_A = 75°C	1.0							A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	30							A
T_{stg}	Storage Temperature Range	-55 to +175							°C
T_J	Operating Junction Temperature	-55 to +175							°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.0	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	50	°C/W

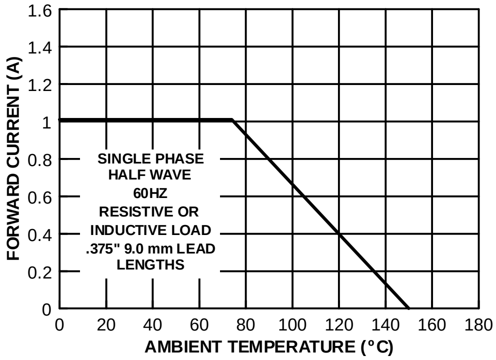
Electrical Characteristics

T_A = 25°C unless otherwise noted

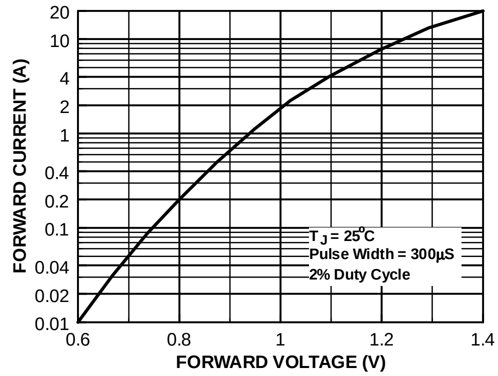
Symbol	Parameter	Device							Units
		4001	4002	4003	4004	4005	4006	4007	
V_F	Forward Voltage @ 1.0 A	1.1							V
I_{rr}	Maximum Full Load Reverse Current, Full Cycle T_A = 75°C	30							µA
I_R	Reverse Current @ rated V_R T_A = 25°C T_A = 100°C	5.0 500							µA µA
C_T	Total Capacitance V_R = 4.0 V, f = 1.0 MHz	15							pF

Typical Characteristics

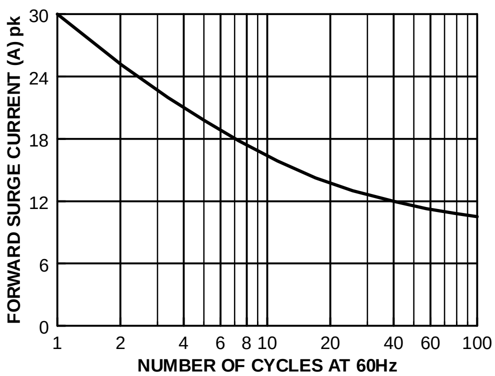
Forward Current Derating Curve



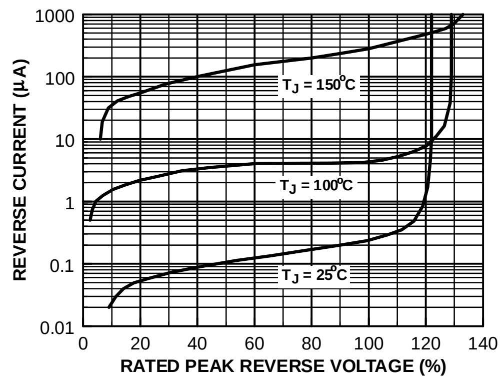
Forward Characteristics



Non-Repetitive Surge Current



Reverse Characteristics



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ImpliedDisconnect™
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MicroPak™
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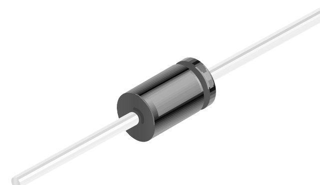
Rev. I2

FAIRCHILD SEMICONDUCTOR®

1N5400 - 1N5408

Features

- 3.0 ampere operation at $T_A = 75°C$ with no thermal runaway.
- High current capability.
- Low leakage.



DO-201AD
COLOR BAND DENOTES CATHODE

General Purpose Rectifiers

Absolute Maximum Ratings* $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Value									Units
		5400	5401	5402	5403	5404	5405	5406	5407	5408	
V_{RRM}	Maximum Repetitive Reverse Voltage	50	100	200	300	400	500	600	800	1000	V
$I_{F(AV)}$	Average Rectified Forward Current, .375 " lead length @ $T_A = 75°C$	3.0									A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	200									A
T_{stg}	Storage Temperature Range	-55 to +150									°C
T_J	Operating Junction Temperature	-55 to +150									°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	6.25	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	20	°C/W

Electrical Characteristics $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Device									Units
		5400	5401	5402	5403	5404	5405	5406	5407	5408	
V_F	Forward Voltage @ 3.0 A	1.2									V
I_{rr}	Maximum Full Load Reverse Current, Full Cycle $T_A = 105°C$	0.5									mA
I_R	Reverse Current @ rated V_R $T_A = 25°C$ $T_A = 100°C$	5.0 500									µA µA
C_T	Toatal Capacitance $V_R = 4.0$ V, f = 1.0 MHz	30									pF

Typical Characteristics

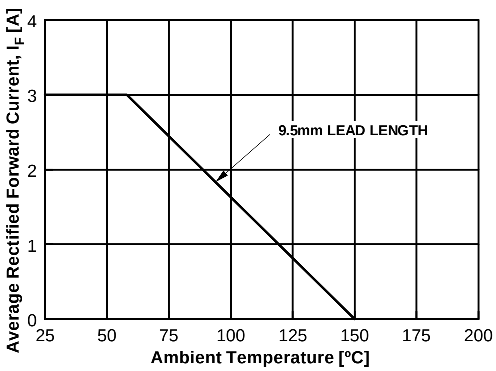


Figure 1. Forward Current Derating Curve

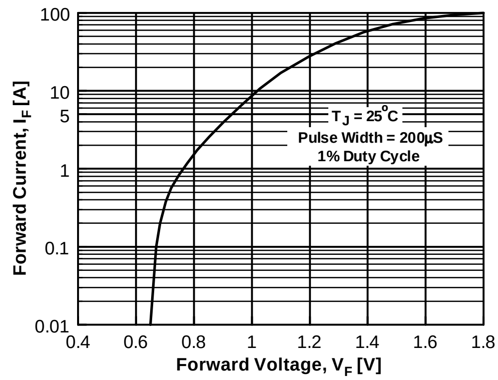


Figure 2. Forward Voltage Characteristics

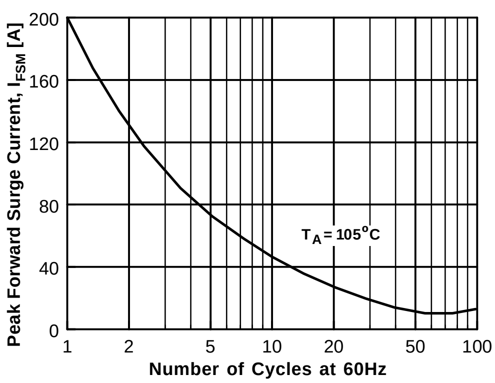


Figure 3. Non-Repetitive Surge Current

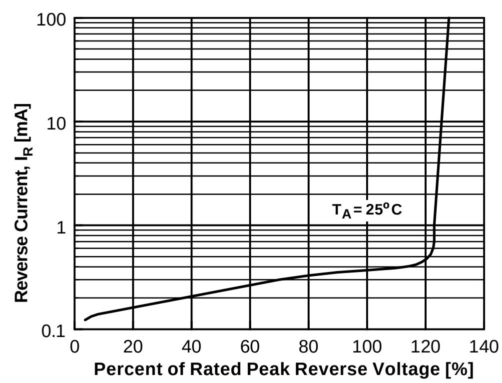


Figure 4. Reverse Current vs Reverse Voltage

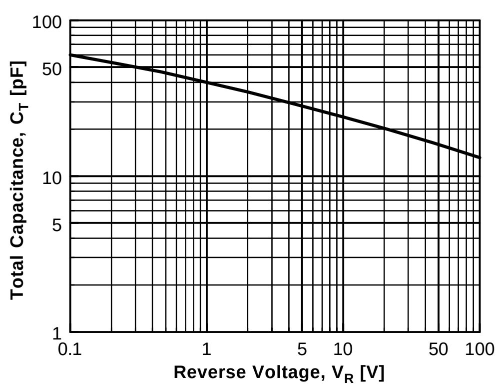


Figure 5. Total Capacitance

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DenseTrench™	GTO™	Power247™	SuperSOT™-6	
DOME™	HiSeC™	PowerTrench ®	SuperSOT™-8	
EcoSPARK™	ISOPLANAR™	QFET™	SyncFET™	
E^2CMOS™	LittleFET™	QS™	TinyLogic™	
EnSigna™	MicroFET™	QT Optoelectronics™	TruTranslation™	
FACT™	MicroPak™	Quiet Series™	UHC™	
FACT Quiet Series™	MICROWIRE™	SILENT SWITCHER ®	UltraFET ®	

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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Rev. H4

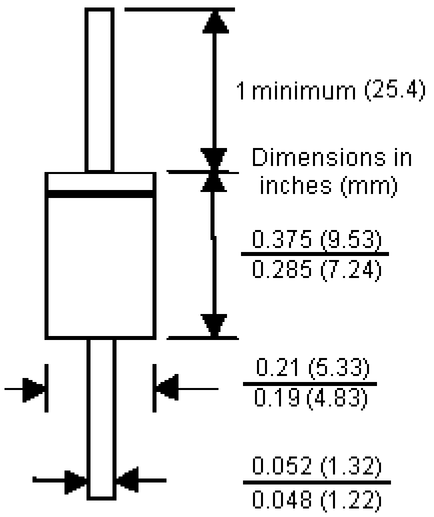
General Purpose Rectifiers

multicomp

DO-201AD

Features:

- 3 amperes operation at T_A = 75°C with no thermal runaway
- High current capability
- Low leakage



Colour Band Denotes Cathode

Dimensions : Inches (Millimetres)

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Parameter	Symbol	Value	Units
Average Rectified Current 0.375 Inches Lead Length at T_A = 75°C	I_O	3	A
Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave Superimposed on Rated Load (JEDEC Method)	i_f (surge)	200	
Total Device Dissipation Derate above 25°C	P_D	6.25 50	W mW/°C
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	20	°C/W
Storage Temperature Range	T_{stg}	-55 to +150	°C
Operating Junction Temperature	T_J		

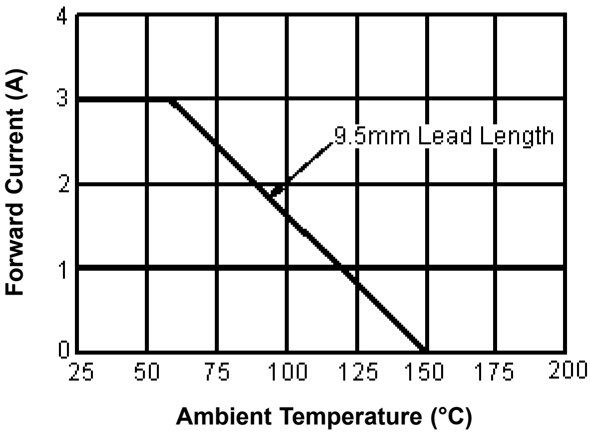
*These Ratings are Limiting Values above Which the Serviceability of Any Semiconductor Device may be Impaired.

Electrical Characteristics T_A = 25°C unless otherwise noted

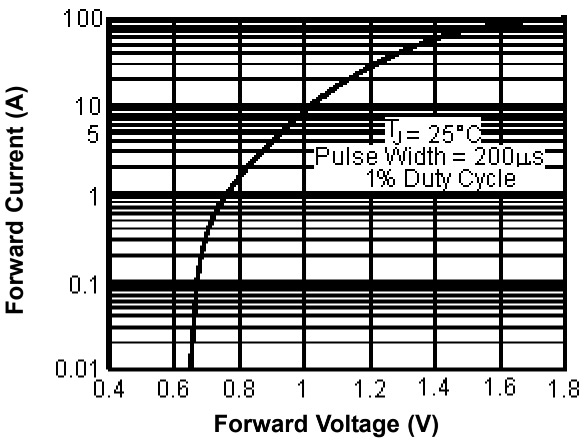
Parameter	Device					Unit
	5401	5402	5404	5406	5408	
Peak Repetitive Reverse Voltage	100	200	400	600	1000	
Maximum RMS Voltage	70	140	280	420	700	V
DC Reverse Voltage (Rated V_R)	100	200	400	600	1000	
Maximum Reverse Current at Rated V_R T_A = 25°C T_A = 100°C	5 500					µA
Maximum Forward Voltage at 3 A	1.2					V
Maximum Full Load Reverse Current, Full Cycle T_A = 105°C	0.5					mA
Typical Junction Capacitance V_R = 4 V, f = 1 MHz	30					pF

Typical Characteristics

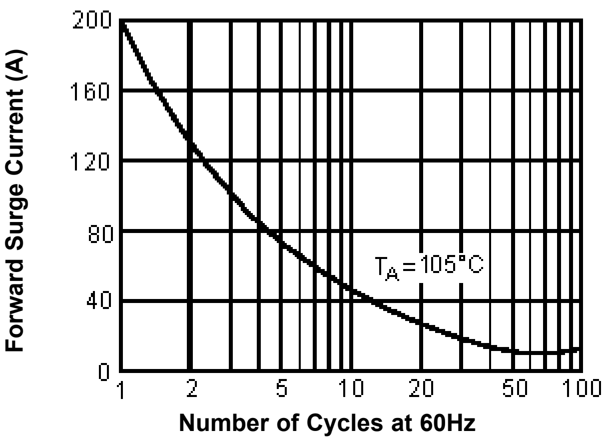
Forward Current Derating Curve



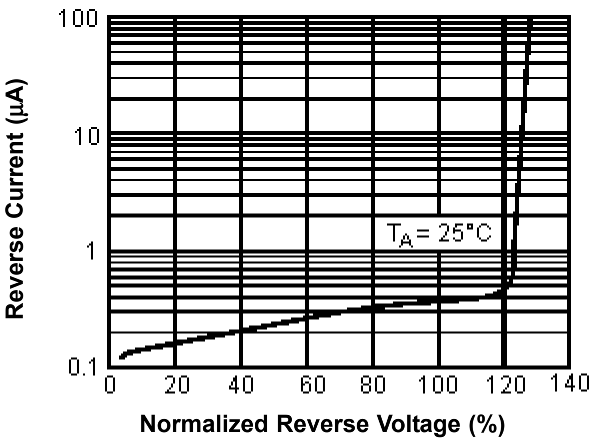
Forward Characteristics



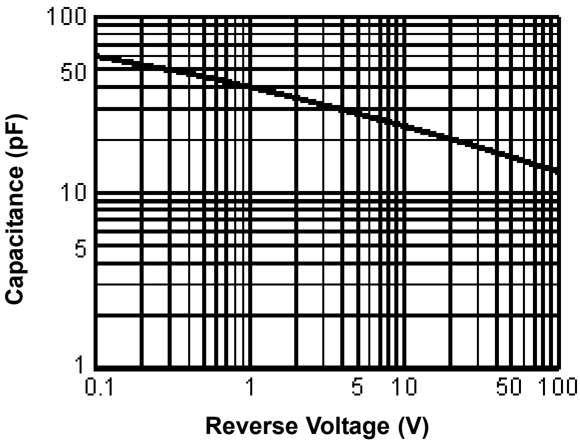
Overload Surge Current



Reverse Characteristics



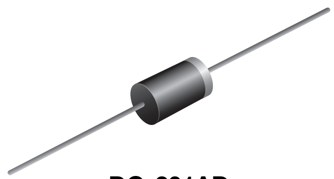
Junction Capacitance



Part Number Table

Description	Part Number
Diode, 3 A, 100 V Reel 1250	1N5401 R0
Diode, 3 A, 400 V Reel 1250	1N5404 R0
Diode, 3 A, 600 V Reel 1250	1N5406 R0
Diode, 3 A, 1,000 V Reel 1250	1N5408 R0
Diode, Standard, 3 A, 100 V	1N5401
Diode, Standard, 3 A, 200 V	1N5402
Diode, Standard, 3 A, 400 V	1N5404
Diode, Standard, 3 A, 600 V	1N5406
Diode, Standard, 3 A, 1,000 V	1N5408

General Purpose Plastic Rectifier



DO-201AD

FEATURES

- Low forward voltage drop
- Low leakage current
- High forward surge capability
- Solder dip 275 °C max. 10 s, per JESD 22-B106
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

RoHS COMPLIANT

TYPICAL APPLICATIONS

For use in general purpose rectification of power supplies, inverters, converters and freewheeling diodes application.

Note

- These devices are not AEC-Q101 qualified.

MECHANICAL DATA

Case: DO-201AD, molded epoxy body
Molding compound meets UL 94 V-0 flammability rating
Base P/N-E3 - RoHS-compliant, commercial grade

Terminals: Matte tin plated leads, solderable per J-STD-002 and JESD 22-B102
E3 suffix meets JESD 201 class 1A whisker test

Polarity: Color band denotes cathode end

PRIMARY CHARACTERISTICS	
$I_{F(AV)}$	3.0 A
V_{RRM}	50 V, 100 V, 200 V, 300 V, 500 V, 600 V, 800 V, 1000 V
I_{FSM}	200 A
I_R	5.0 μA
V_F	1.2 V
T_J max.	150 °C
Package	DO-201AD
Diode variations	Single die

MAXIMUM RATINGS (T_A = 25 °C unless otherwise noted)

PARAMETER	SYMBOL	1N5400	1N5401	1N5402	1N5403	1N5404	1N5405	1N5406	1N5407	1N5408	UNIT
Maximum repetitive peak reverse voltage	V_{RRM}	50	100	200	300	400	500	600	800	1000	V
Maximum RMS voltage	V_{RMS}	35	70	140	210	280	350	420	560	700	V
Maximum DC blocking voltage	V_{DC}	50	100	200	300	400	500	600	800	1000	V
Maximum average forward rectified current 0.5" (12.5 mm) lead length at T_L = 105 °C	$I_{F(AV)}$	3.0									A
Peak forward surge current 8.3 ms single half sine-wave superimposed on rated load	I_{FSM}	200									A
Maximum full load reverse current, full cycle average 0.5" (12.5 mm) lead length at T_L = 105 °C	$I_{R(AV)}$	500									μA
Operating junction and storage temperature range	T_J, T_{STG}	- 50 to + 150									°C

ELECTRICAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)												
PARAMETER	**TEST CONDITIONS**	**SYMBOL**	**1N5400**	**1N5401**	**1N5402**	**1N5403**	**1N5404**	**1N5405**	**1N5406**	**1N5407**	**1N5408**	**UNIT**
Maximum instantaneous forward voltage	3.0 A	V_F					1.2					V
Maximum DC reverse current at rated DC blocking voltage	T_A = 25 °C	I_R					5.0					μA
	T_A = 150 °C						500					
Typical junction capacitance	4.0 V, 1 MHz	C_J					30					pF

THERMAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)											
PARAMETER	**SYMBOL**	**1N5400**	**1N5401**	**1N5402**	**1N5403**	**1N5404**	**1N5405**	**1N5406**	**1N5407**	**1N5408**	**UNIT**
Typical thermal resistance	$R_{\theta JA}$ (1)					20					°C/W

Note

(1) Thermal resistance from junction to ambient at 0.375" (9.5 mm) lead length, PCB mounted with 0.8" x 0.8" (20 mm x 20 mm) copper heatsinks

ORDERING INFORMATION (Example)				
PREFERRED P/N	**UNIT WEIGHT (g)**	**PREFERRED PACKAGE CODE**	**BASE QUANTITY**	**DELIVERY MODE**
1N5404-E3/54	1.1	54	1400	13" diameter paper tape and reel
1N5404-E3/73	1.1	73	1000	Ammo pack packaging

RATINGS AND CHARACTERISTICS CURVES (T_A = 25 °C unless otherwise noted)

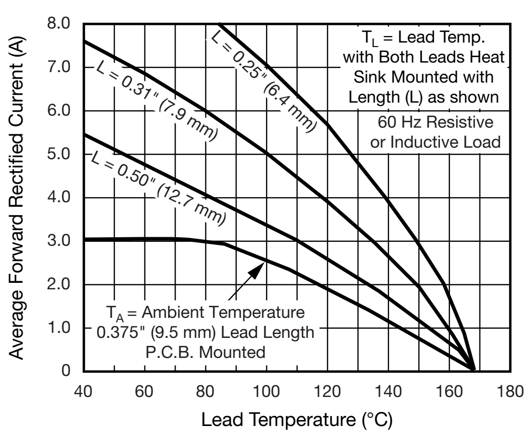


Fig. 1 - Forward Current Derating Curve

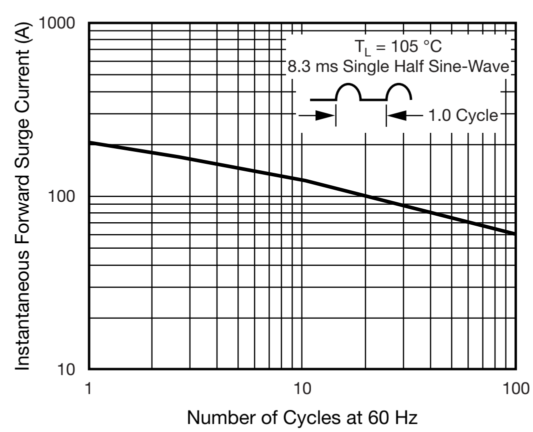


Fig. 2 - Maximum Non-Repetitive Peak Forward Surge Current

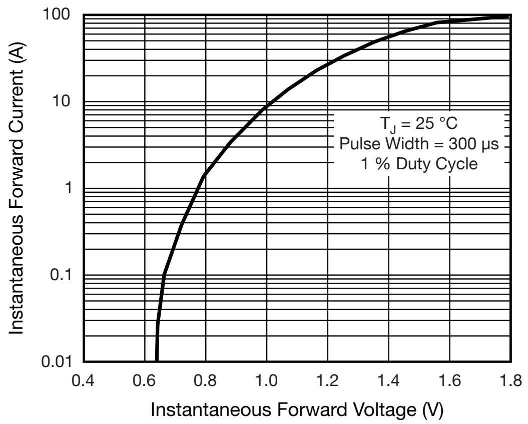


Fig. 3 - Typical Instantaneous Forward Characteristics

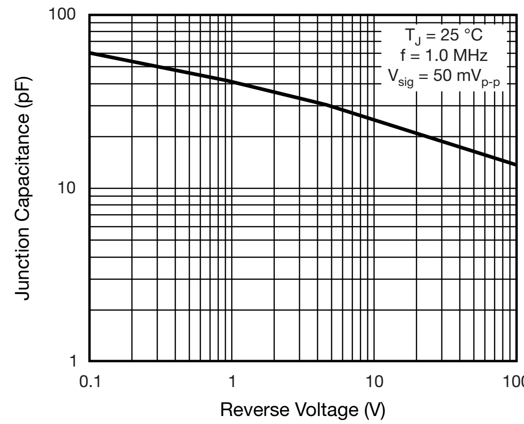


Fig. 5 - Typical Junction Capacitance

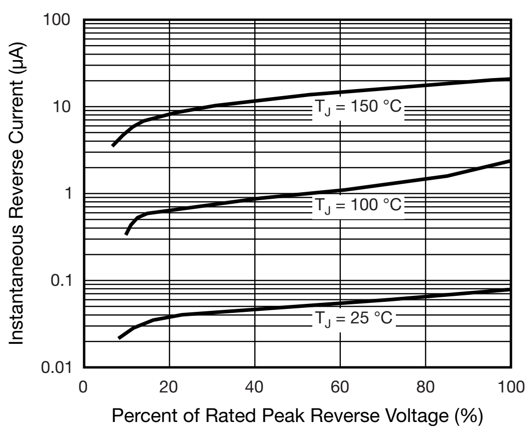


Fig. 4 - Typical Reverse Characteristics

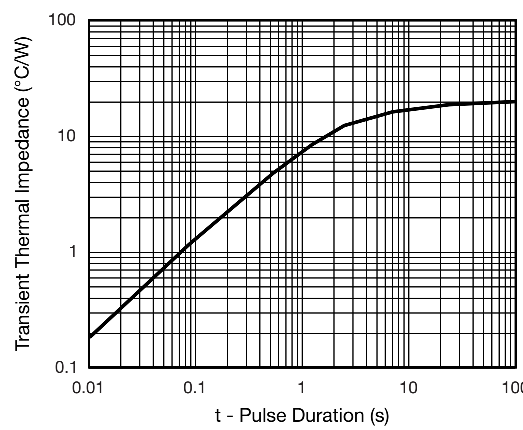
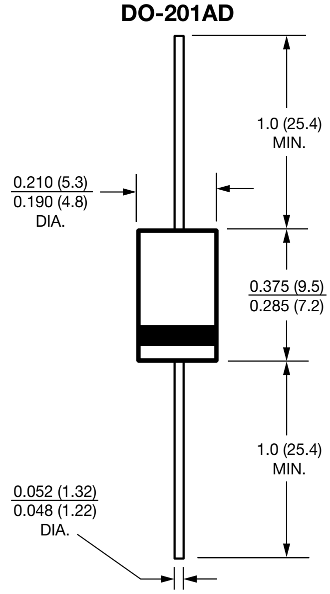


Fig. 6 - Typical Transient Thermal Impedance

PACKAGE OUTLINE DIMENSIONS in inches (millimeters)

DO-201AD



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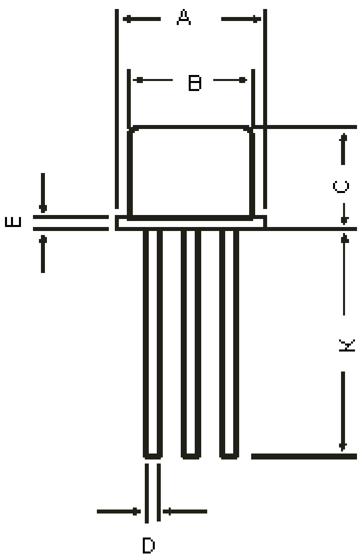
General Purpose Amplifier/Switches

Feature:

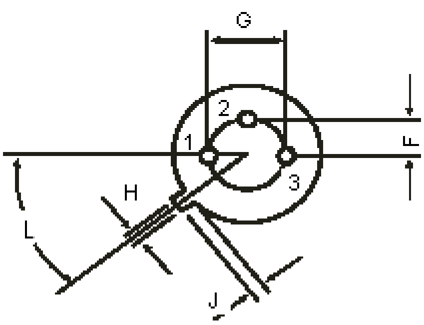
- NPN Silicon Planar Epitaxial Transistors.

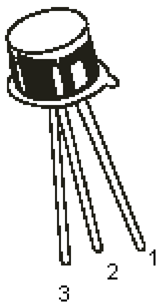
TO-18 Metal Can Package



Dimensions	Minimum	Maximum
A	5.24	5.84
B	4.52	4.97
C	4.31	5.33
D	0.40	0.53
E	-	0.76
F	-	1.27
G	-	2.97
H	0.91	1.17
J	0.71	1.21
K	12.70	-
L	45°	

Dimensions : Millimetres





Pin Configuration:
1. Emitter
2. Base
3. Collector

Absolute Maximum Ratings

Description	Symbol	BC107	BC108	Unit
Collector-Emitter Voltage	V_{CEO}	45	25	V
Collector-Base Voltage	V_{CBO}	50	30	
Emitter-Base Voltage	V_{EBO}	6.0	5.0	
Collector Current Continuous	I_C	0.2		A
Power Dissipation at T_a = 25°C Derate above 25°C	P_D	0.6 2.28		W mW/°C
Power Dissipation at T_C = 25°C Derate above 25°C		1.0 6.67		
Operating and Storage Junction Temperature Range	T_J, Tstg	-65 to +200		°C
Thermal Resistance				
Junction to Case	$R_{th\ (j-c)}$	175		°C/W

Electrical Characteristics (T_a = 25°C unless otherwise specified)

Description	Symbol	Test Condition	Minimum	Maximum	Unit
Collector-Emitter Voltage	V_{CEO}	I_C = 2mA, I_B = 0 BC107 BC108	45 25	-	V
Emitter-Base Voltage	V_{EBO}	I_E = 10µA, I_C = 0 BC107 BC108	6.0 5.0	-	
Collector-Cut off Current	I_{CBO}	V_{CB} = 45V, I_E = 0 BC107 V_{CB} = 25V, I_E = 0 BC108 T_{amb} = 125°C V_{CB} = 45V, I_E = 0 BC107 V_{CB} = 25V, I_E = 0 BC108	-	15 15 4.0 4.0	nA µA
DC Current	h_{FE}	I_C = 10µA, V_{CE} = 5V **B Group** **C Group** I_C = 2mA, V_{CE} = 5V **BC 107** **BC 108** **A Group** **B Group** **C Group**	 40 100 110 110 110 200 420	 - - 450 800 220 450 800	-
Base Emitter Saturation Voltage	$V_{BE\ (Sat)}$	I_C = 10mA, I_B = 0.5mA I_C = 100mA, I_B = 5mA	-	0.83 1.05	V
Collector Emitter Saturation Voltage	$V_{CE\ (Sat)}$		-	0.25 0.60	
Base Emitter On Voltage	$V_{BE\ (on)}$	I_C = 2mA, V_{CE} = 5V I_C = 10mA, V_{CE} = 5V	0.55 -	0.70 0.77	

Electrical Characteristics (T_a = 25°C unless otherwise specified)

Description	Symbol	Test Condition	Minimum	Maximum	Unit
Collector Knee Voltage	$V_{CE\ (K)}$	I_C = 10mA, I_B = The value for which I_C = 11mA at V_{CE} = 1V	-	0.60	V
Transition Frequency	f_t	V_{CE} = 5V, I_C = 10mA, f = 100MHz	150	-	MHz
Noise Figure	NF	V_{CE} = 5V, I_C = 0.2mA R_g = 2kΩ F = 1kHz,B = 200Hz		10	dB
Output Capacitance	C_{obo}	V_{CB} = 10V, f = 1MHz	-	4.5	pF
Small Signal Current Gain	h_{fe}	ALL f = 1kHz I_C = 2mA, V_{CE} = 5V **BC 107** **BC 108** **A Group** **B Group** **C Group**	125 125 125 240 450	500 900 260 500 900	-
Input Impedance	h_{ie}	I_C = 2mA, V_{CE} = 5V **A Group** **B Group** **C Group**	1.6 3.2 6.0	4.5 8.5 15	KΩ KΩ
Output Admittance	h_{oe}	I_C = 2mA, V_{CE} = 5V **A Group** **B Group** **C Group**	-	30 60 110	umhos

Specifications

V_{CEO} (V)	V_{CBO} maximum (V)	I_C (A)	h_{FE} minimum at I_C = 2mA	f_T minimum (*Typical) (V)	P_{tot} (mW)	Type	Package	Part Number
45	50	0.1	110	150	600	NPN	TO-18	BC107
								BC107A
			200					BC107B
20	30		110		300			BC108
					600			BC108B
			200					BC108C

Notes:

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ELECTRONICS, INC.
44 FARRAND STREET
BLOOMFIELD, NJ 07003
(973) 748–5089

NTE312 / 2N5248
N–Channel Silicon Junction Field Effect Transistor

Description:
The NTE312 is a field effect transistor designed for VHF amplifier and mixer applications. The NTE312 comes in a TO–92 package.

Features:
- High Power Gain: 10dB Min at 400MHz
- High Transconductance: 4000 μmho Min at 400MHz
- Low C_{rss}: 1pF Max
- High (Y_{fs}) / C_{iss} Ratio (High–Frequency Figure–of–Merit)
- Drain and Gate Leads Separated for High Maximum Stable Gain
- Cross–Modulation Minimized by Square–Law Transfer Characteristic
- For Use in VHF Amplifiers in FM, TV, and Mobile Communications Equipment

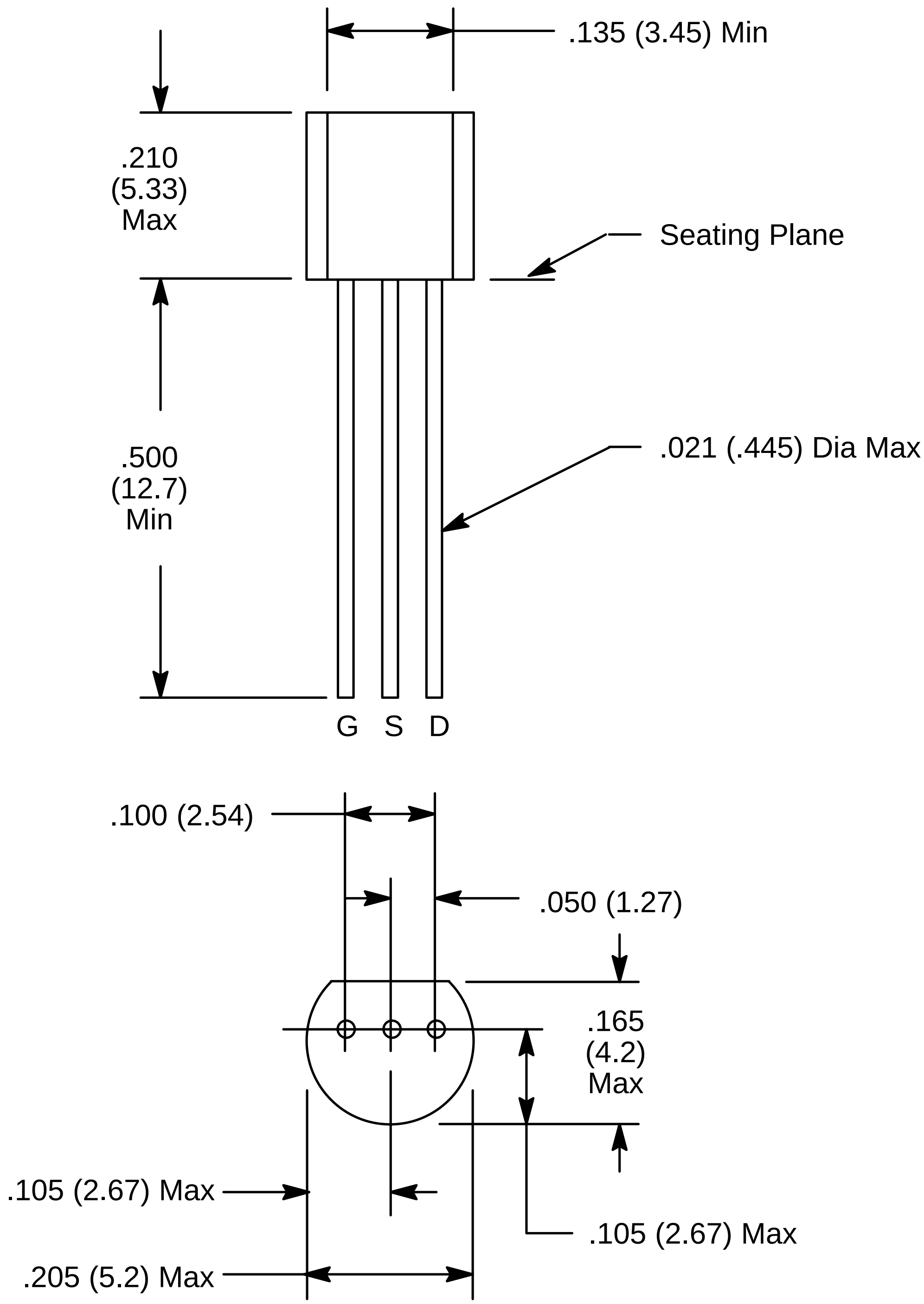
Absolute Maximum Ratings: (T_A = +25°C unless otherwise specified)

Drain–Gate Voltage, V_{DG} 30V
Gate–Source Voltage, V_{GS} . . . . –30V
Gate Current, I_G 50mA
Total Device Dissipation (T_A = +25°C), P_D 360mW
  Derate Above +25°C . . . . 2.88mW/°C
Total Device Dissipation (T_C = +25°C), P_D 500mW
  Derate Above +25°C . . . . 4.0mW/°C
Storage Temperature Range, T_{stg} . . . . –65° to +150°C
Lead Temperature, During Soldering (1/16 Inch from Case for 10sec), T_L . . . . +260°C

Electrical Characteristics: (T_A = +25°C unless otherwise specified)

Parameter	Symbol	Test Conditions		Min	Typ	Max	Unit
OFF Characteristics							
Gate–Source Breakdown Voltage	$V_{(BR)GSS}$	I_G = –1.0μA, V_{DS} = 0		–30	–	–	V
Gate Reverse Current	I_{GSS}	V_{GS} = –20V, V_{DS} = 0		–	–	–1.0	nA
Gate 1 Leakage Current	I_{G1SS}	V_{G1S} = –20V, V_{DS} = 0, T_A = +100°C		–	–	–0.5	μA
Gate–Source Cutoff Voltage	$V_{GS(off)}$	V_{DS} = 15V, I_D = 10mA		–1.0	–	–6.0	V
ON Characteristics							
Zero–Gate Voltage Drain Current	I_{DSS}	V_{DS} = 15V, V_{GS} = 0, Note 1		5.0	–	15	mA
Small–Signal Characteristics							
Forward Transfer Admittance	$\|y_{fs}\|$	V_{DS} = 15V, V_{GS} = 0, f = 1kHz		4500	–	7500	μmhos
Input Admittance	$Re(y_{is})$	100MHz	V_{DS} = 15V, V_{GS} = 0	–	–	100	μmhos
		400MHz		–	–	1000	μmhos
Output Admittance	$\|y_{os}\|$	V_{DS} = 15V, V_{GS} = 0, f = 1kHz		–	–	50	μmhos
Output Conductance	$Re(y_{os})$	100MHz	V_{DS} = 15V, V_{GS} = 0	–	–	75	μmhos
		400MHz		–	–	100	μmhos
Forward Transconductance	$Re(y_{fs})$	V_{DS} = 15V, V_{GS} = 0, f = 400MHz		4000	–	–	μmhos
Input Capacitance	C_{iss}	V_{DS} = 15V, V_{GS} = 0, f = 1.0MHz		–	–	4.5	pF
Reverse Transfer Capacitance	C_{rss}	V_{DS} = 15V, V_{GS} = 0, f = 1.0MHz		–	–	1.0	pF
Input Susceptance	$I_M(Yis)$	100MHz	V_{DS} = 15V, V_{GS} = 0	–	–	3.0	mmho
		400MHz		–	–	12.0	mmho
Functional Characteristics							
Noise Figure	NF	100MHz	V_{DS} = 15V, I_D = 5mA, R'_G = 1kΩ	–	–	2.0	dB
		400MHz		–	–	4.0	dB
Common Source Power Gain	G_{ps}	100MHz	V_{DS} = 15V, I_D = 5mA, R'_G = 1kΩ	18	–	–	dB
		400MHz		10	–	–	dB
Output Susceptance	$I_M(Yos)$	100MHz	V_{DS} = 15V, V_{GS} = 0	–	–	1000	μmhos
		400MHz		–	–	4000	μmhos

Note 1. tp = 100ms, Duty Cycle = 10%.



NOTE: Drain and Source are interchangeable.

NTE ELECTRONICS, INC.
44 FARRAND STREET
BLOOMFIELD, NJ 07003
(973) 748–5089

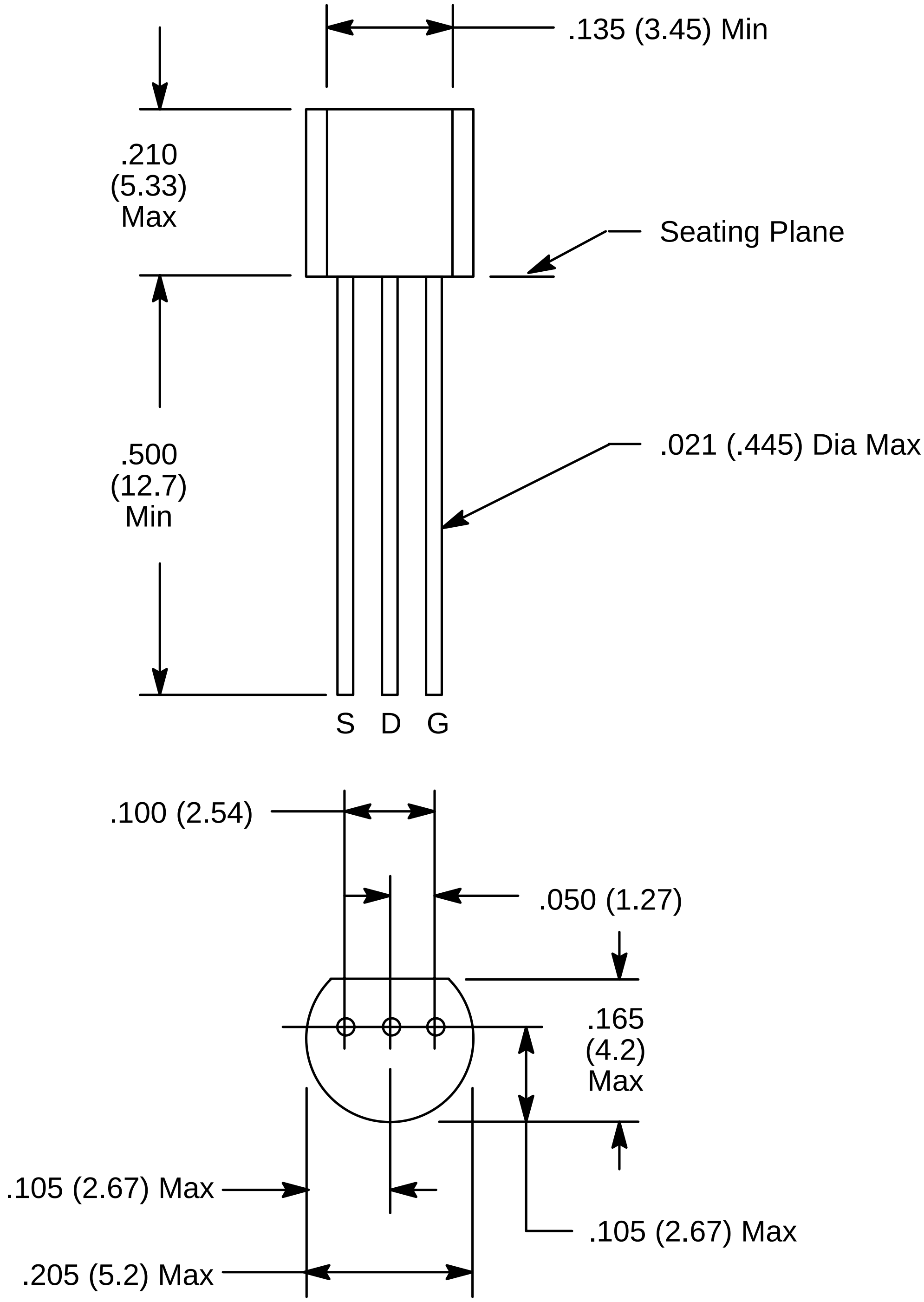
NTE326 / 2N5460
Silicon P–Channel JFET Transistor
General Purpose AF Amplifier

Absolute Maximum Ratings: (T_A = +25°C unless otherwise specified)

Drain–Gate Voltage, V_{DG} 40V
Reverse Gate–Source Voltage, V_{GSR} 40V
Forward Gate Current, $I_{G(f)}$ 10mA
Total Device Dissipation (T_A = +25°C), P_D 310mW
Derate Above 25°C . . . . 2.82mW/°C
Operating Junction Temperature Range, T_J . . . . –65° to +135°C
Storage Temperature Range, T_{stg} . . . . –55° to +150°C

Electrical Characteristics: (T_A = +25°C unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
OFF Characteristics						
Gate–Source Breakdown Voltage	$V_{(BR)GSS}$	I_G = 10μA, V_{DS} = 0	40	–	–	V
Gate Reverse Current	I_{GSS}	V_{GS} = 20V, V_{DS} = 0	–	–	5	nA
		V_{GS} = 20V, V_{DS} = 0, T_A = +100°C	–	–	1	μA
Gate–Source Cutoff Voltage	$V_{GS(off)}$	I_D = 1μA, V_{DS} = 15V	1.0	–	7.5	V
Gate–Source Voltage	V_{GS}	I_D = 0.2mA, V_{DS} = 15V	0.8	–	4.5	V
ON Characteristics						
Zero–Gate–Voltage Drain Current	I_{DSS}	V_{DS} = 15V, V_{GS} = 0, f = 1kHz	2	–	9	mA
Small–Signal Characteristics						
Forward Transfer Admittance	$\|y_{fs}\|$	V_{DS} = 15V, V_{GS} = 0, f = 1kHz	1500	–	5000	μmho
Output Admittance	$\|y_{os}\|$	V_{DS} = 15V, V_{GS} = 0, f = 1kHz	–	–	75	μmho
Input Capacitance	C_{iss}	V_{DS} = 15V, V_{GS} = 0, f = 1MHz	–	5	7	pF
Reverse Transfer Capacitance	C_{rss}	V_{DS} = 15V, V_{GS} = 0, f = 1MHz	–	1	2	pF
Functional Characteristics						
Noise Figure	NF	V_{DS} = 15V, V_{GS} = 0, R_G = 1MΩ, f = 100Hz, BW = 1Hz	–	1.0	2.5	dB
Equivalent Short–Circuit Input Noise Voltage	e_n	V_{DS} = 15V, V_{GS} = 0, f = 100Hz, BW = 1Hz	–	60	115	$nV/\sqrt{Hz}$


.135 (3.45) Min
.210
(5.33)
Max
Seating Plane
.500
(12.7)
Min
.021 (.445) Dia Max
S D G
.100 (2.54)
.050 (1.27)
.165
(4.2)
Max
.105 (2.67) Max
.105 (2.67) Max
.205 (5.2) Max

DATA SHEET

J210; J211; J212
N-channel field-effect transistors

Product specification
1997 Dec 01
File under Discrete Semiconductors, SC07

Philips
Semiconductors

PHILIPS

N-channel field-effect transistors J210; J211; J212

FEATURES

- High speed switching
- Interchangeability of drain and source connections
- High impedance.

APPLICATIONS

- Analog switches
- Choppers, multiplexers and commutators
- Audio amplifiers.

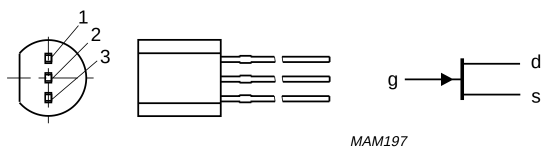
DESCRIPTION

N-channel symmetrical junction field-effect transistor in a TO-92 (SOT54) package.

CAUTION
This product is supplied in anti-static packing to prevent damage caused by electrostatic discharge during transport and handling. For further information, refer to Philips specs.: SNW-EQ-608, SNW-FQ-302A and SNW-FQ-302B.

PINNING - TO-92 (SOT54)

PIN	SYMBOL	DESCRIPTION
1	g	gate
2	s	source
3	d	drain



Marking codes:
J210: J210.
J211: J211.
J212: J212.

Fig.1 Simplified outline and symbol.

QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{DS}	drain-source voltage		–	±25	V
V_{GSoff}	gate-source cut-off voltage	I_D = 1 nA; V_{DS} = 15 V			
	J210		–1	–3	V
	J211		–2.5	–4.5	V
	J212		–4	–6	V
I_{DSS}	drain current	V_{GS} = 0; V_{DS} = 15 V			
	J210		2	15	mA
	J211		7	20	mA
	J212		15	40	mA
P_{tot}	total power dissipation	$T_{amb} \leq 50$ °C	–	400	mW
$\lvert y_{fs} \rvert$	common-source transfer admittance	V_{GS} = 0; V_{DS} = 15 V			
	J210		4	12	mS
	J211		6	12	mS
	J212		7	12	mS

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{DS}	drain-source voltage		–	±25	V
V_{GSO}	gate-source voltage	open drain	–	–25	V
V_{DGO}	drain-gate voltage	open source	–	–25	V
I_G	forward gate current (DC)		–	10	mA
P_{tot}	total power dissipation	$T_{amb} \leq 50$ °C; note 1; see Fig.13	–	400	mW
T_{stg}	storage temperature		–65	150	°C
T_j	operating junction temperature		–	150	°C

Note

1. Device mounted on a printed-circuit board, maximum lead length 4 mm; mounting pad for the drain lead 10 mm^2.

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	VALUE	UNIT
$R_{th\ j-a}$	thermal resistance from junction to ambient; note 1	250	K/W

Note

1. Device mounted on a printed-circuit board, maximum lead length 4 mm; mounting pad for the drain lead 10 mm^2.

STATIC CHARACTERISTICS

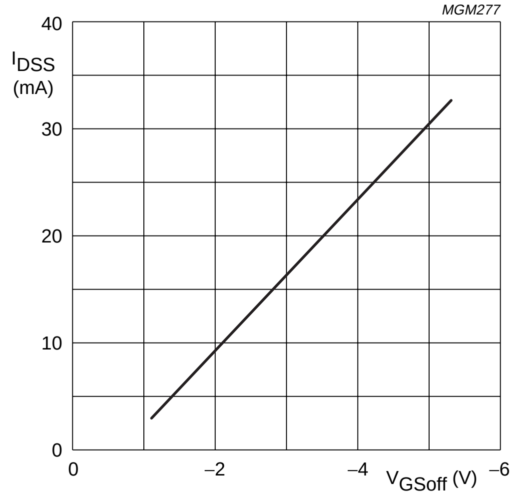
T_j = 25 °C.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
$V_{(BR)GSS}$	gate-source breakdown voltage	I_G = –1 μA; V_{DS} = 0	–	–25	V
V_{GSoff}	gate-source cut-off voltage	I_D = 1 nA; V_{DS} = 15 V			
	J210		–1	–3	V
	J211		–2.5	–4.5	V
	J212		–4	–6	V
V_{GSS}	gate-source forward voltage	I_G = 0; V_{DS} = 0	–	1	V
I_{DSS}	drain current	V_{GS} = 0; V_{DS} = 15 V			
	J10		2	15	mA
	J11		7	20	mA
	J12		15	40	mA
I_{GSS}	reverse gate leakage current	V_{GS} = –15 V; V_{DS} = 0	–	–100	pA
$\|y_{fs}\|$	common-source transfer admittance	V_{GS} = 0; V_{DS} = 15 V			
	J210		4	12	mS
	J211		6	12	mS
	J212		7	12	mS
$\|y_{os}\|$	common source output admittance	V_{GS} = 0; V_{DS} = 15 V			
	J210		–	150	μS
	J211		–	200	μS
	J212		–	200	μS

DYNAMIC CHARACTERISTICS

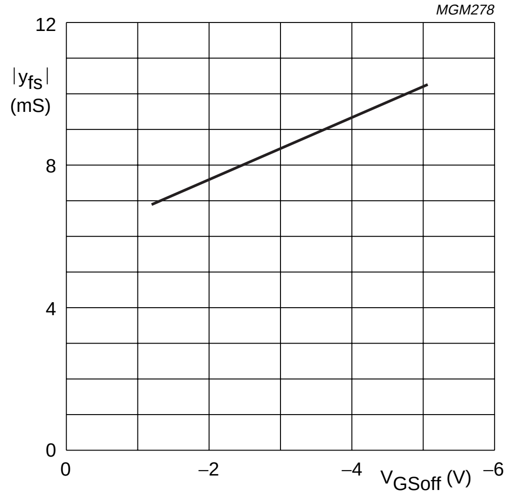
T_{amb} = 25 °C.

SYMBOL	PARAMETER	CONDITIONS	TYP.	UNIT
C_{is}	input capacitance	V_{DS} = 15 V; V_{GS} = –10 V; f = 1 MHz	2	pF
		V_{DS} = 15 V; V_{GS} = 0; f = 1 MHz	4	pF
C_{os}	output capacitance	V_{DS} = 15 V; V_{GS} = –10 V; f = 1 MHz	0.8	pF
		V_{DS} = 15 V; V_{GS} = 0; f = 1 MHz	2	pF
C_{rs}	feedback capacitance	V_{DS} = 15 V; V_{GS} = –10 V; f = 1 MHz	0.8	pF
		V_{DS} = 15 V; V_{GS} = 0; f = 1 MHz	0.9	pF
g_{is}	common source input conductance	V_{DS} = 15 V; V_{GS} = 0; f = 100 MHz	70	μS
		V_{DS} = 15 V; V_{GS} = 0; f = 450 MHz	1.1	mS
g_{fs}	common source transfer conductance	V_{DS} = 15 V; V_{GS} = 0; f = 100 MHz	7.5	mS
		V_{DS} = 15 V; V_{GS} = 0; f = 450 MHz	7.5	mS
g_{rs}	common source feedback conductance	V_{DS} = 15 V; V_{GS} = 0; f = 100 MHz	–8	μS
		V_{DS} = 15 V; V_{GS} = 0; f = 450 MHz	–90	μS
g_{os}	common source output conductance	V_{DS} = 15 V; V_{GS} = 0; f = 100 MHz	95	μS
		V_{DS} = 15 V; V_{GS} = 0; f = 450 MHz	200	μS
V_n	equivalent input noise voltage	V_{DS} = 15 V; V_{GS} = 0; f = 1 kHz	5	nV/√Hz



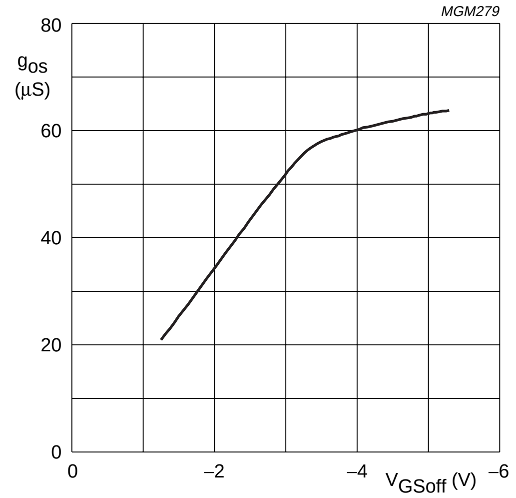
V_{DS} = 15 V; T_j = 25 °C.

Fig.2 Drain current as a function of gate-source cut-off voltage; typical values.



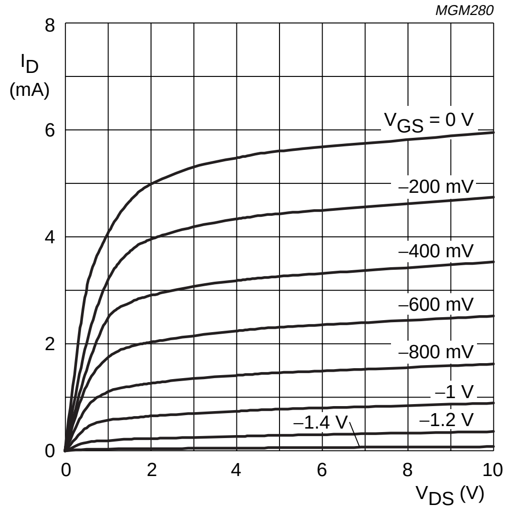
V_{DS} = 15 V; T_j = 25 °C.

Fig.3 Common-source transfer admittance as a function of gate-source cut-off voltage; typical values.



V_{DS} = 15 V; T_{amb} = 25 °C.

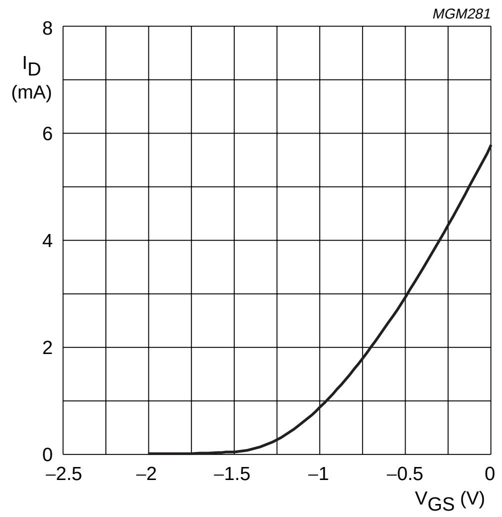
Fig.4 Common-source output conductance as a function of gate-source cut-off voltage; typical values.



J210.

T_j = 25 °C.

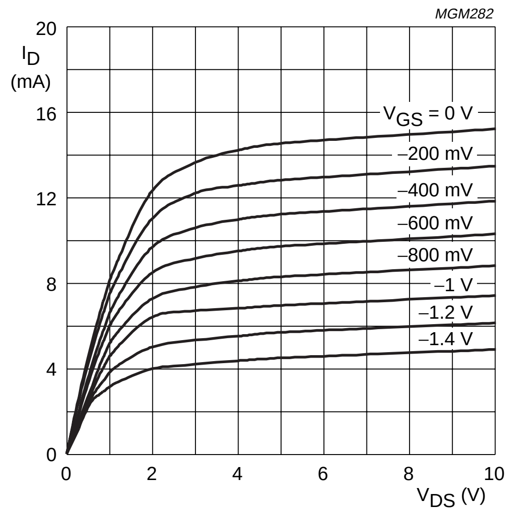
Fig.5 Output characteristics; typical values.



J210.

V_{DS} = 10 V; T_j = 25 °C.

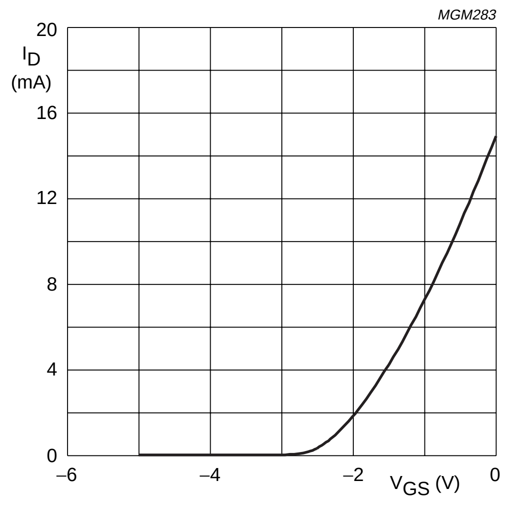
Fig.6 Input characteristics; typical values.



J211.

T_j = 25 °C.

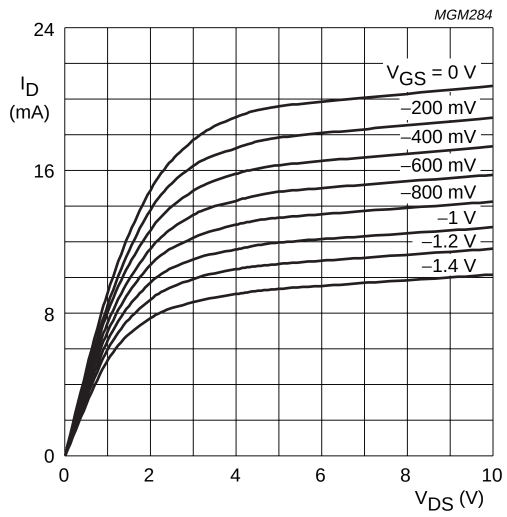
Fig.7 Output characteristics; typical values.



J211.

V_{DS} = 10 V; T_j = 25 °C.

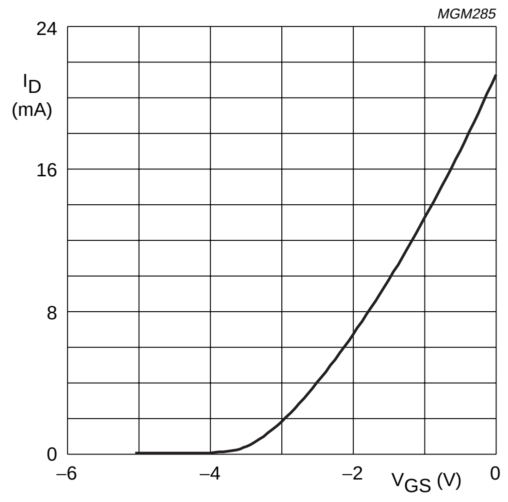
Fig.8 Input characteristics; typical values.



J212.

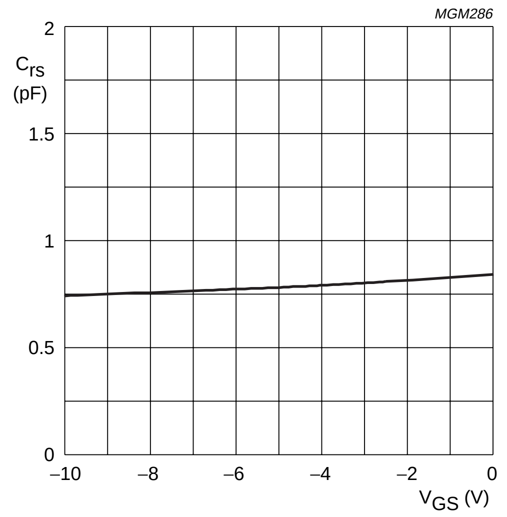
T_j = 25 °C.

Fig.9 Output characteristics; typical values.



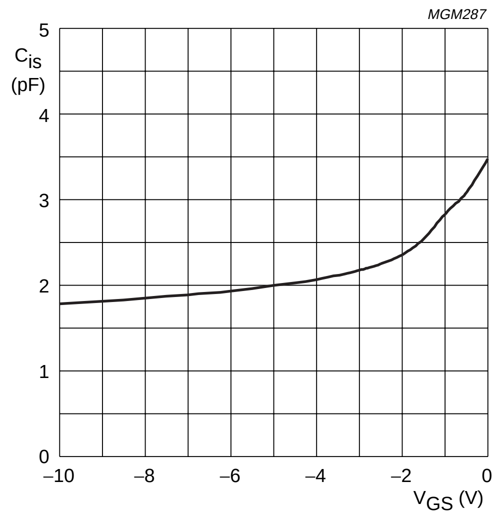
J212.
V_{DS} = 10 V; T_j = 25 °C.

Fig.10 Input characteristics; typical values.



V_{DS} = 15 V; f = 1 Mhz; T_{amb} = 25 °C.

Fig.11 Feedback capacitance as a function of gate-source voltage; typical values.



V_{DS} = 15 V; f = 1 Mhz; T_{amb} = 25 °C.

Fig.12 Input capacitance as a function of gate-source voltage; typical values.

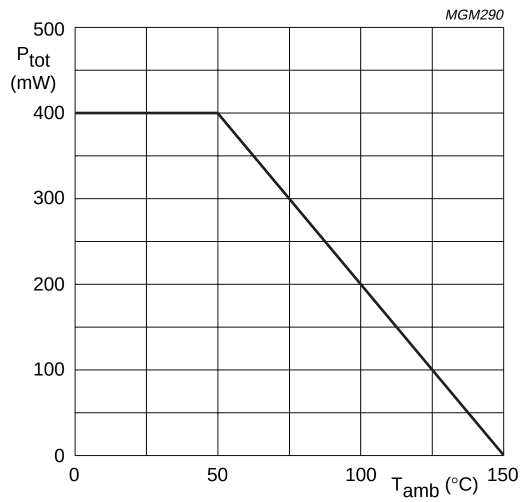
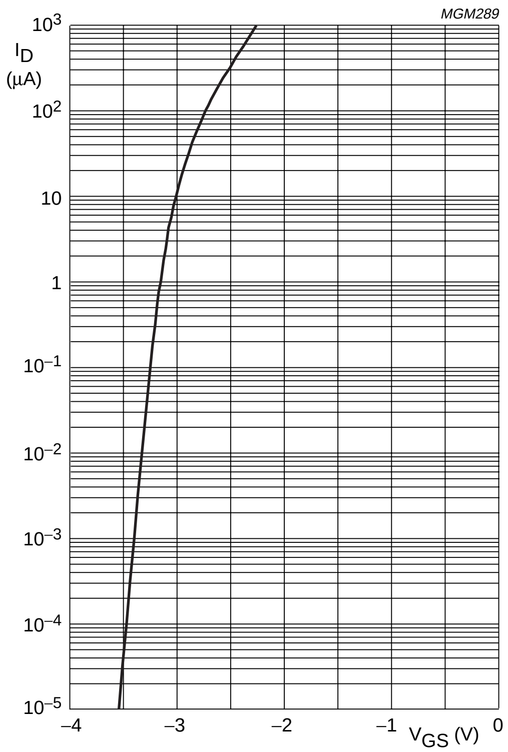
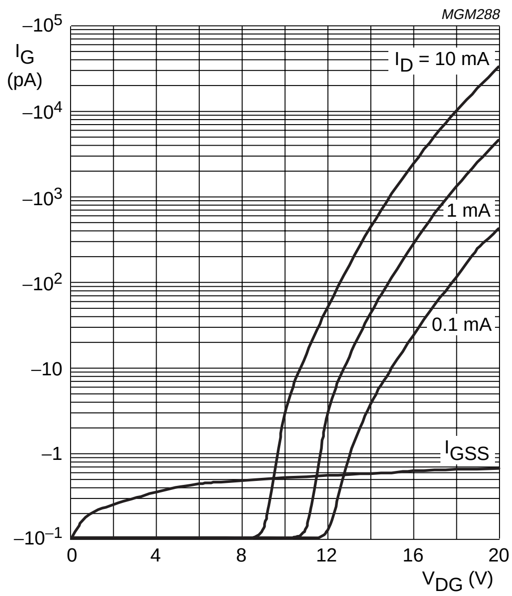


Fig.13 Power derating curve.



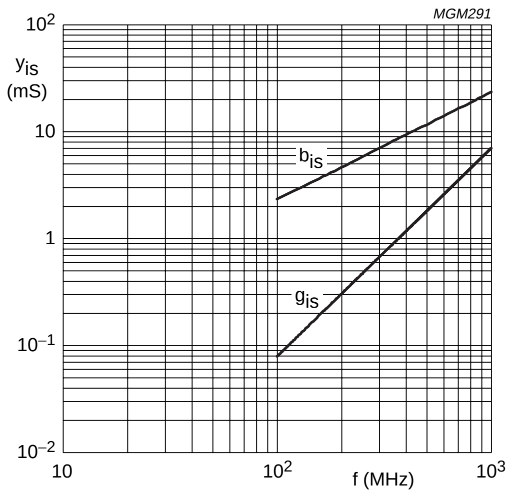
V_{DS} = 15 V; T_j = 25 °C.

Fig.14 Drain current as a function of gate-source voltage; typical values.



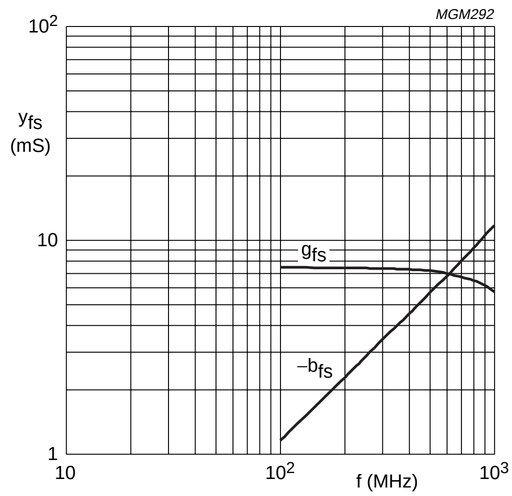
T_j = 25 °C.

Fig.15 Gate current as a function of drain-gate voltage; typical values.



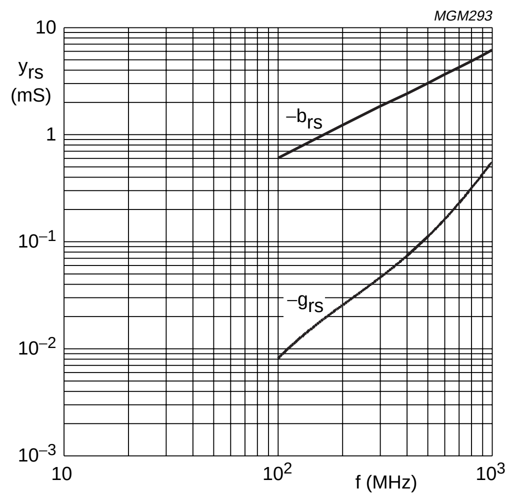
V_{DS} = 15 V; V_{GS} = 0; T_{amb} = 25 °C.

Fig.16 Common source input admittance as a function of frequency; typical values.



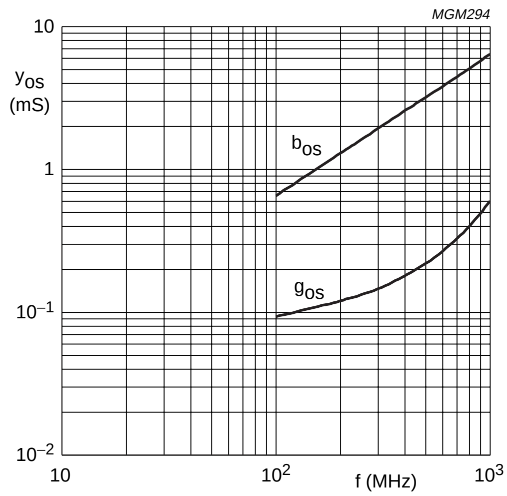
V_{DS} = 15 V; V_{GS} = 0; T_{amb} = 25 °C.

Fig.17 Common source transfer admittance as a function of frequency; typical values.



V_{DS} = 15 V; V_{GS} = 0; T_{amb} = 25 °C.

Fig.18 Common source reverse admittance as a function of frequency; typical values.

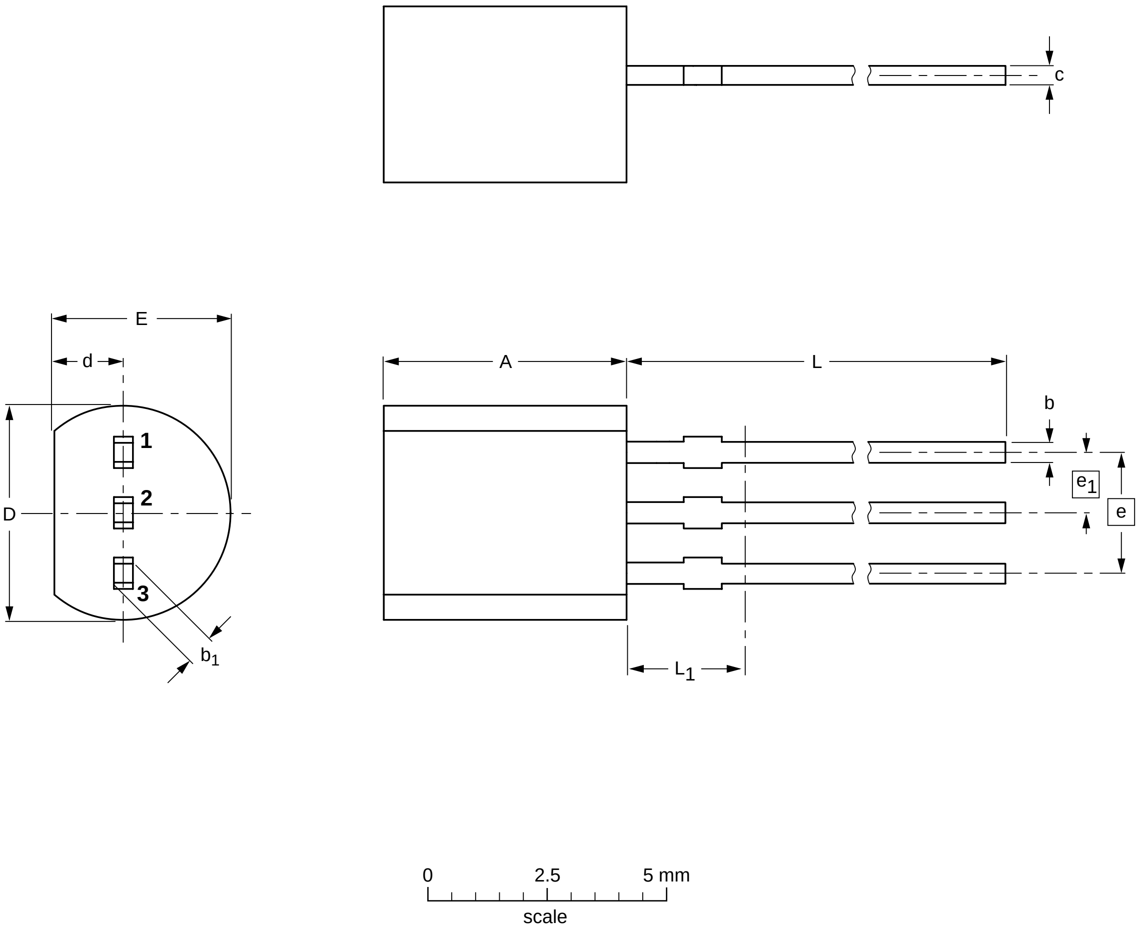


V_{DS} = 15 V; V_{GS} = 0; T_{amb} = 25 °C.

Fig.19 Common source output admittance as a function of frequency; typical values.

PACKAGE OUTLINE

Plastic single-ended leaded (through hole) package; 3 leads **SOT54**



DIMENSIONS (mm are the original dimensions)

UNIT	A	b	b_1	c	D	d	E	e	e_1	L	$L_1^{(1)}$
mm	5.2 5.0	0.48 0.40	0.66 0.56	0.45 0.40	4.8 4.4	1.7 1.4	4.2 3.6	2.54	1.27	14.5 12.7	2.5

Note

1. Terminal dimensions within this zone are uncontrolled to allow for flow of plastic and terminal irregularities.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	EIAJ			
SOT54		TO-92	SC-43			97-02-28

DEFINITIONS

Data Sheet Status	
Objective specification	This data sheet contains target or goal specifications for product development.
Preliminary specification	This data sheet contains preliminary data; supplementary data may be published later.
Product specification	This data sheet contains final product specifications.
Limiting values	
Limiting values given are in accordance with the Absolute Maximum Rating System (IEC 134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.	
Application information	
Where application information is given, it is advisory and does not form part of the specification.	

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