

*Designer's™ Data Sheet*  
**SWITCHMODE Series**  
**NPN Silicon Power Transistors**

These devices are designed for high-voltage, high-speed power switching inductive circuits where fall time is critical. They are particularly suited for 115 and 220 V SWITCHMODE applications such as Switching Regulators, Inverters, Motor Controls, Solenoid/Relay drivers and Deflection circuits.

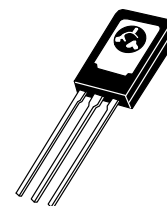
**SPECIFICATION FEATURES:**

- Reverse Biased SOA with Inductive Loads @  $T_C = 100^\circ\text{C}$
- Inductive Switching Matrix 0.5 to 1.5 Amp, 25 and  $100^\circ\text{C}$   
...  $t_c$  @ 1 A,  $100^\circ\text{C}$  is 290 ns (Typ).
- 700 V Blocking Capability
- SOA and Switching Applications Information.

**MJE13002\***  
**MJE13003\***

\*Motorola Preferred Device

**1.5 AMPERE  
NPN SILICON  
POWER TRANSISTORS  
300 AND 400 VOLTS  
40 WATTS**



**CASE 77-08  
TO-225AA TYPE**

**MAXIMUM RATINGS**

Rating	Symbol	MJE13002	MJE13003	Unit
Collector-Emitter Voltage	$V_{CEO(sus)}$	300	400	Vdc
Collector-Emitter Voltage	$V_{CEV}$	600	700	Vdc
Emitter Base Voltage	$V_{EBO}$	9		Vdc
Collector Current — Continuous — Peak (1)	$I_C$ $I_{CM}$	1.5 3		Adc
Base Current — Continuous — Peak (1)	$I_B$ $I_{BM}$	0.75 1.5		Adc
Emitter Current — Continuous — Peak (1)	$I_E$ $I_{EM}$	2.25 4.5		Adc
Total Power Dissipation @ $T_A = 25^\circ\text{C}$ Derate above $25^\circ\text{C}$	$P_D$	1.4 11.2		Watts mW/ $^\circ\text{C}$
Total Power Dissipation @ $T_C = 25^\circ\text{C}$ Derate above $25^\circ\text{C}$	$P_D$	40 320		Watts mW/ $^\circ\text{C}$
Operating and Storage Junction Temperature Range	$T_J, T_{stg}$	-65 to +150		$^\circ\text{C}$

**THERMAL CHARACTERISTICS**

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	3.12	$^\circ\text{C/W}$
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	89	$^\circ\text{C/W}$
Maximum Load Temperature for Soldering Purposes: 1/8" from Case for 5 Seconds	$T_L$	275	$^\circ\text{C}$

(1) Pulse Test: Pulse Width = 5 ms, Duty Cycle  $\leq$  10%.

**Designer's Data for "Worst Case" Conditions** — The Designer's Data Sheet permits the design of most circuits entirely from the information presented. SOA Limit curves — representing boundaries on device characteristics — are given to facilitate "worst case" design.

**Preferred** devices are Motorola recommended choices for future use and best overall value.

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# MJE13002 MJE13003

## ELECTRICAL CHARACTERISTICS (T<sub>C</sub> = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
<b>OFF CHARACTERISTICS (1)</b>					
Collector–Emitter Sustaining Voltage (I <sub>C</sub> = 10 mA, I <sub>B</sub> = 0)	V <sub>CEO(sus)</sub>	300 400	— —	— —	Vdc
Collector Cutoff Current (V <sub>CEV</sub> = Rated Value, V <sub>BE(off)</sub> = 1.5 Vdc) (V <sub>CEV</sub> = Rated Value, V <sub>BE(off)</sub> = 1.5 Vdc, T <sub>C</sub> = 100°C)	I <sub>CEV</sub>	— —	— —	1 5	mAdc
Emitter Cutoff Current (V <sub>EB</sub> = 9 Vdc, I <sub>C</sub> = 0)	I <sub>EBO</sub>	—	—	1	mAdc

## SECOND BREAKDOWN

Second Breakdown Collector Current with base forward biased	I <sub>S/b</sub>	See Figure 11		
Clamped Inductive SOA with base reverse biased	RBSOA	See Figure 12		

## ON CHARACTERISTICS (1)

DC Current Gain (I <sub>C</sub> = 0.5 Adc, V <sub>CE</sub> = 2 Vdc) (I <sub>C</sub> = 1 Adc, V <sub>CE</sub> = 2 Vdc)	h <sub>FE</sub>	8 5	— —	40 25	—
Collector–Emitter Saturation Voltage (I <sub>C</sub> = 0.5 Adc, I <sub>B</sub> = 0.1 Adc) (I <sub>C</sub> = 1 Adc, I <sub>B</sub> = 0.25 Adc) (I <sub>C</sub> = 1.5 Adc, I <sub>B</sub> = 0.5 Adc) (I <sub>C</sub> = 1 Adc, I <sub>B</sub> = 0.25 Adc, T <sub>C</sub> = 100°C)	V <sub>CE(sat)</sub>	— — — —	— — — —	0.5 1 3 1	Vdc
Base–Emitter Saturation Voltage (I <sub>C</sub> = 0.5 Adc, I <sub>B</sub> = 0.1 Adc) (I <sub>C</sub> = 1 Adc, I <sub>B</sub> = 0.25 Adc) (I <sub>C</sub> = 1 Adc, I <sub>B</sub> = 0.25 Adc, T <sub>C</sub> = 100°C)	V <sub>BE(sat)</sub>	— — —	— — —	1 1.2 1.1	Vdc

## DYNAMIC CHARACTERISTICS

Current–Gain — Bandwidth Product (I <sub>C</sub> = 100 mAdc, V <sub>CE</sub> = 10 Vdc, f = 1 MHz)	f <sub>T</sub>	4	10	—	MHz
Output Capacitance (V <sub>CB</sub> = 10 Vdc, I <sub>E</sub> = 0, f = 0.1 MHz)	C <sub>ob</sub>	—	21	—	pF

## SWITCHING CHARACTERISTICS

Resistive Load (Table 1)						
Delay Time	(V <sub>CC</sub> = 125 Vdc, I <sub>C</sub> = 1 A, I <sub>B1</sub> = I <sub>B2</sub> = 0.2 A, t <sub>p</sub> = 25 μs, Duty Cycle ≤ 1%)	t <sub>d</sub>	—	0.05	0.1	μs
Rise Time		t <sub>r</sub>	—	0.5	1	μs
Storage Time		t <sub>s</sub>	—	2	4	μs
Fall Time		t <sub>f</sub>	—	0.4	0.7	μs
Inductive Load, Clamped (Table 1, Figure 13)						
Storage Time	(I <sub>C</sub> = 1 A, V <sub>clamp</sub> = 300 Vdc, I <sub>B1</sub> = 0.2 A, V <sub>BE(off)</sub> = 5 Vdc, T <sub>C</sub> = 100°C)	t <sub>sv</sub>	—	1.7	4	μs
Crossover Time		t <sub>c</sub>	—	0.29	0.75	μs
Fall Time		t <sub>fj</sub>	—	0.15	—	μs

(1) Pulse Test: PW = 300 μs, Duty Cycle ≤ 2%.

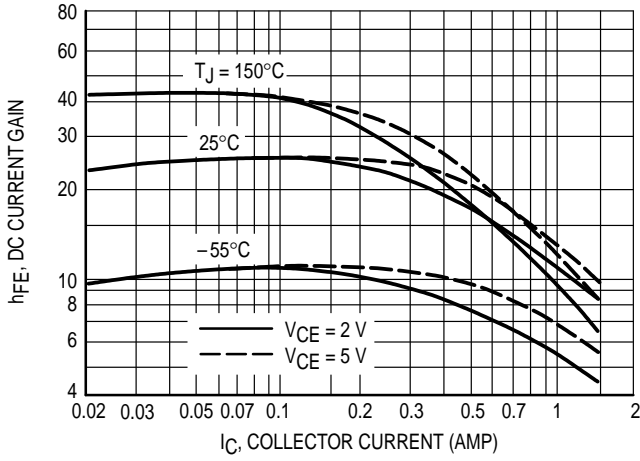


Figure 1. DC Current Gain

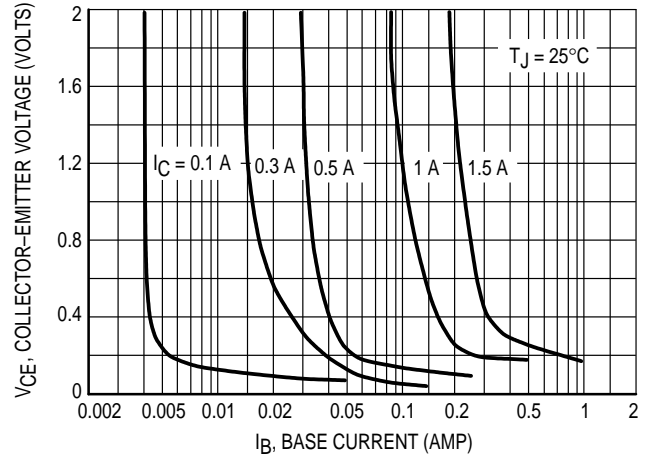


Figure 2. Collector Saturation Region

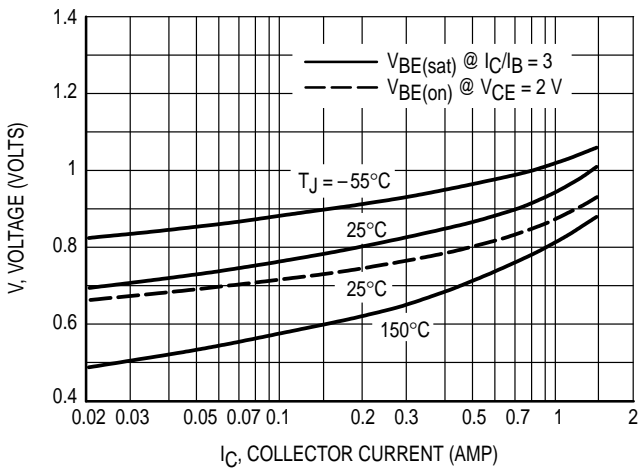


Figure 3. Base-Emitter Voltage

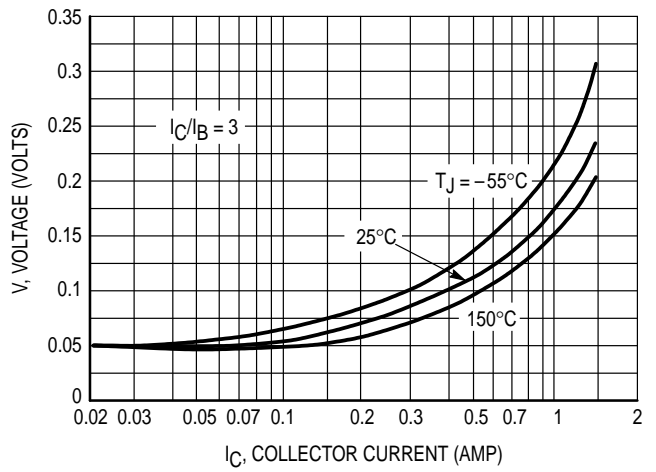


Figure 4. Collector-Emitter Saturation Region

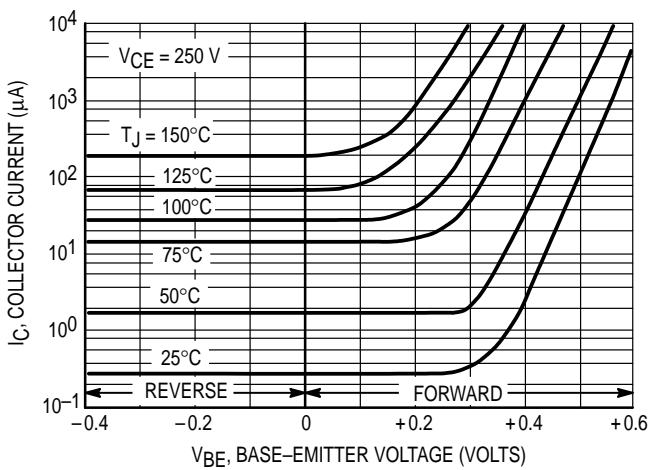


Figure 5. Collector Cutoff Region

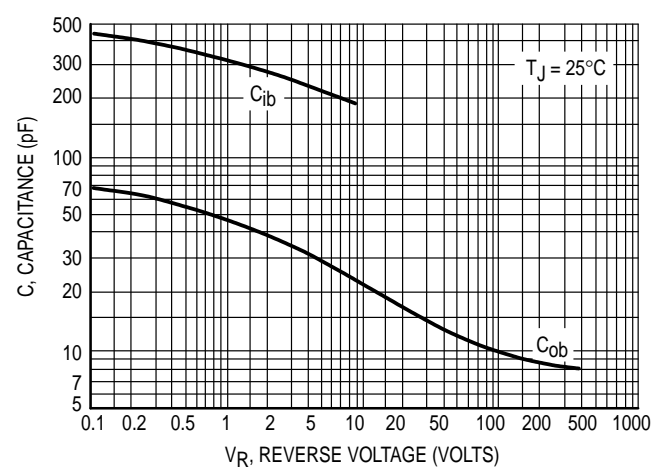


Figure 6. Capacitance

Table 1. Test Conditions for Dynamic Performance

REVERSE BIAS SAFE OPERATING AREA AND INDUCTIVE SWITCHING		RESISTIVE SWITCHING
TEST CIRCUITS	<p>DUTY CYCLE <math>\leq 10\%</math>  <math>t_r, t_f \leq 10\text{ ns}</math></p> <p>NOTE  PW and <math>V_{CC}</math> Adjusted for Desired <math>I_C</math>  <math>R_B</math> Adjusted for Desired <math>I_{B1}</math></p>	
CIRCUIT VALUES	<p>Coil Data:  Ferroxcube Core #6656  Full Bobbin (~200 Turns) #20</p> <p>GAP for 30 mH/2 A  <math>L_{\text{coil}} = 50\text{ mH}</math></p> <p><math>V_{CC} = 20\text{ V}</math>  <math>V_{\text{clamp}} = 300\text{ Vdc}</math></p>	<p><math>V_{CC} = 125\text{ V}</math>  <math>R_C = 125\ \Omega</math>  <math>D1 = 1N5820\text{ or Equiv.}</math>  <math>R_B = 47\ \Omega</math></p>
TEST WAVEFORMS	<p>OUTPUT WAVEFORMS</p> <p><math>t_1</math> Adjusted to Obtain <math>I_C</math></p> $t_1 \approx \frac{L_{\text{coil}} (I_{Cpk})}{V_{CC}}$ <p>Test Equipment  Scope—Tektronics 475 or Equivalent</p> $t_2 \approx \frac{L_{\text{coil}} (I_{Cpk})}{V_{\text{clamp}}}$	<p><math>t_r, t_f &lt; 10\text{ ns}</math>  Duty Cycle = 1.0%  <math>R_B</math> and <math>R_C</math> adjusted for desired <math>I_B</math> and <math>I_C</math></p>

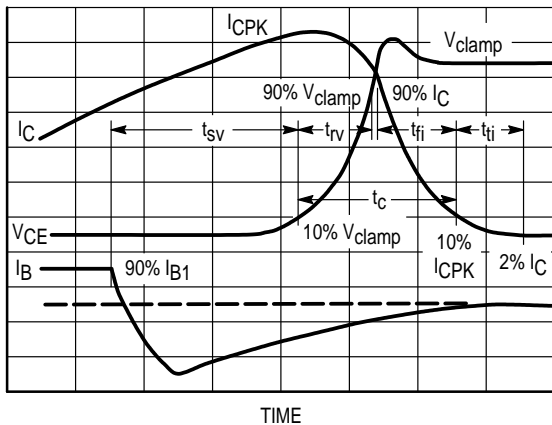


Figure 7. Inductive Switching Measurements

Table 2. Typical Inductive Switching Performance

$I_C$ AMP	$T_C$ °C	$t_{sv}$ μs	$t_{rv}$ μs	$t_{fi}$ μs	$t_{ti}$ μs	$t_c$ μs
0.5	25	1.3	0.23	0.30	0.35	0.30
	100	1.6	0.26	0.30	0.40	0.36
1	25	1.5	0.10	0.14	0.05	0.16
	100	1.7	0.13	0.26	0.06	0.29
1.5	25	1.8	0.07	0.10	0.05	0.16
	100	3	0.08	0.22	0.08	0.28

NOTE: All Data Recorded in the Inductive Switching Circuit in Table 1

SWITCHING TIMES NOTE

In resistive switching circuits, rise, fall, and storage times have been defined and apply to both current and voltage waveforms since they are in phase. However, for inductive loads which are common to SWITCHMODE power supplies and hammer drivers, current and voltage waveforms are not in phase. Therefore, separate measurements must be made on each waveform to determine the total switching time. For this reason, the following new terms have been defined.

- $t_{SV}$  = Voltage Storage Time, 90%  $I_{B1}$  to 10%  $V_{clamp}$
- $t_{rV}$  = Voltage Rise Time, 10–90%  $V_{clamp}$
- $t_{fi}$  = Current Fall Time, 90–10%  $I_C$
- $t_{ti}$  = Current Tail, 10–2%  $I_C$
- $t_C$  = Crossover Time, 10%  $V_{clamp}$  to 10%  $I_C$

An enlarged portion of the inductive switching waveforms is

shown in Figure 7 to aid in the visual identity of these terms.

For the designer, there is minimal switching loss during storage time and the predominant switching power losses occur during the crossover interval and can be obtained using the standard equation from AN-222:

$$P_{SWT} = 1/2 V_{CC} I_C (t_C) f$$

In general,  $t_{rV} + t_{fi} \approx t_C$ . However, at lower test currents this relationship may not be valid.

As is common with most switching transistors, resistive switching is specified at 25°C and has become a benchmark for designers. However, for designers of high frequency converter circuits, the user oriented specifications which make this a "SWITCHMODE" transistor are the inductive switching speeds ( $t_C$  and  $t_{SV}$ ) which are guaranteed at 100°C.

RESISTIVE SWITCHING PERFORMANCE

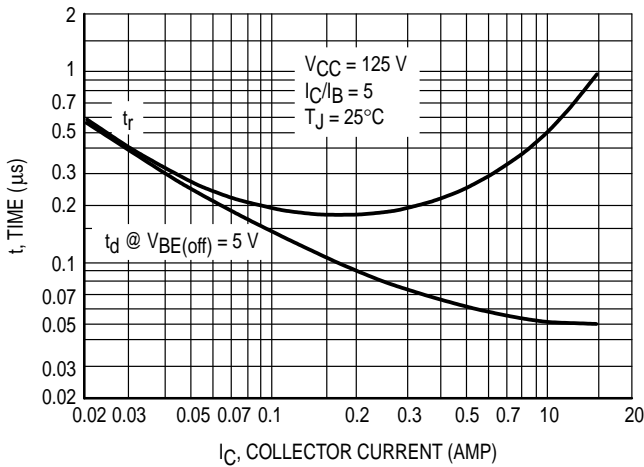


Figure 8. Turn-On Time

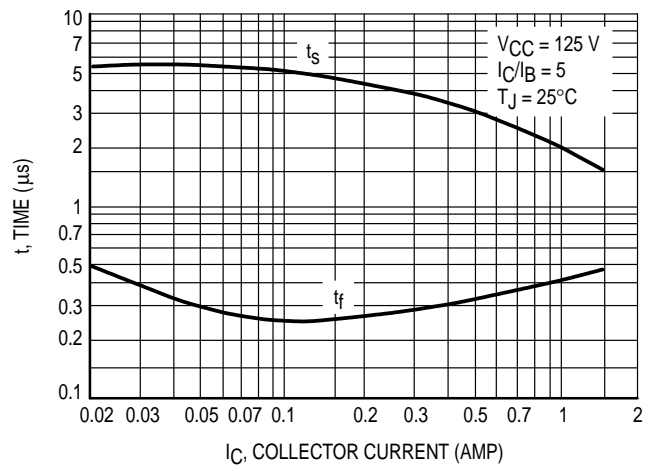


Figure 9. Turn-Off Time

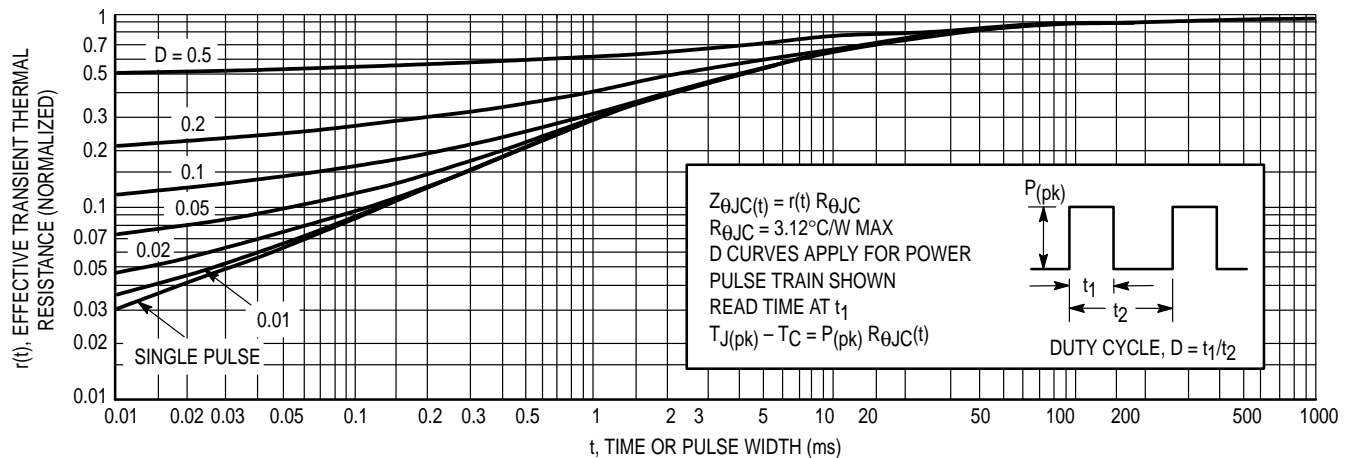


Figure 10. Thermal Response

## MJE13002 MJE13003

The Safe Operating Area figures shown in Figures 11 and 12 are specified ratings for these devices under the test conditions shown.

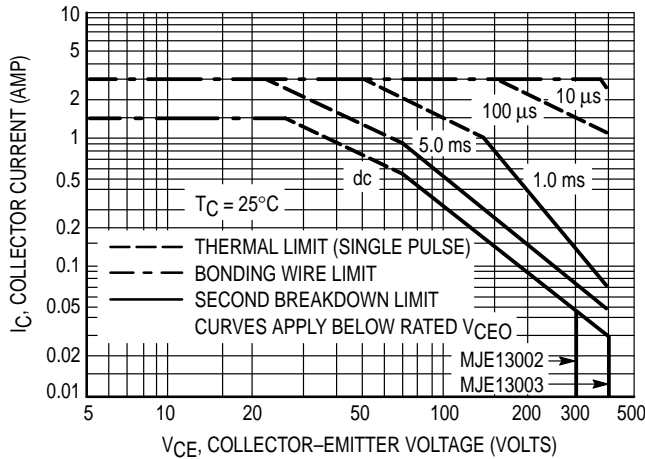


Figure 11. Active Region Safe Operating Area

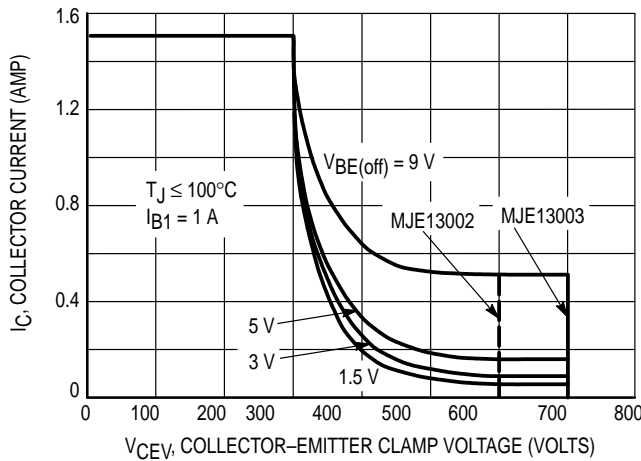


Figure 12. Reverse Bias Safe Operating Area

## SAFE OPERATING AREA INFORMATION

### FORWARD BIAS

There are two limitations on the power handling ability of a transistor: average junction temperature and second breakdown. Safe operating area curves indicate  $I_C - V_{CE}$  limits of the transistor that must be observed for reliable operation; i.e., the transistor must not be subjected to greater dissipation than the curves indicate.

The data of Figure 11 is based on  $T_C = 25^\circ\text{C}$ ;  $T_{J(pk)}$  is variable depending on power level. Second breakdown pulse limits are valid for duty cycles to 10% but must be derated when  $T_C \geq 25^\circ\text{C}$ . Second breakdown limitations do not derate the same as thermal limitations. Allowable current at the voltages shown on Figure 11 may be found at any case temperature by using the appropriate curve on Figure 13.

$T_{J(pk)}$  may be calculated from the data in Figure 10. At high case temperatures, thermal limitations will reduce the power that can be handled to values less than the limitations imposed by second breakdown.

### REVERSE BIAS

For inductive loads, high voltage and high current must be sustained simultaneously during turn-off, in most cases, with the base to emitter junction reverse biased. Under these conditions the collector voltage must be held to a safe level at or below a specific value of collector current. This can be accomplished by several means such as active clamping, RC snubbing, load line shaping, etc. The safe level for these devices is specified as Reverse Bias Safe Operating Area and represents the voltage-current conditions during reverse biased turn-off. This rating is verified under clamped conditions so that the device is never subjected to an avalanche mode. Figure 12 gives RBSOA characteristics.

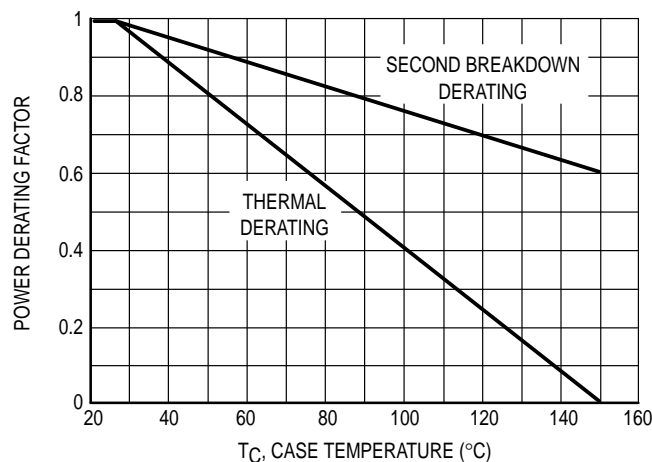
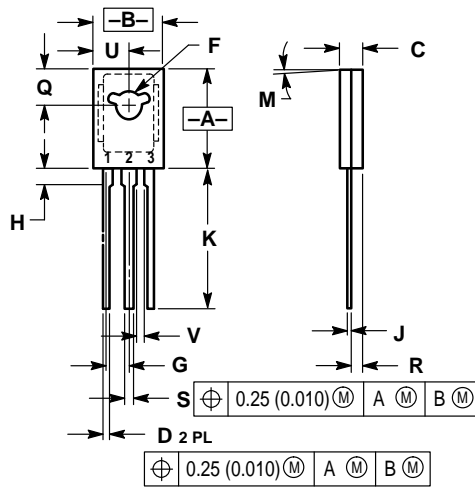


Figure 13. Forward Bias Power Derating

PACKAGE DIMENSIONS




- NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
  2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.425	0.435	10.80	11.04
B	0.295	0.305	7.50	7.74
C	0.095	0.105	2.42	2.66
D	0.020	0.026	0.51	0.66
F	0.115	0.130	2.93	3.30
G	0.094 BSC		2.39 BSC	
H	0.050	0.095	1.27	2.41
J	0.015	0.025	0.39	0.63
K	0.575	0.655	14.61	16.63
M	5° TYP		5° TYP	
Q	0.148	0.158	3.76	4.01
R	0.045	0.055	1.15	1.39
S	0.025	0.035	0.64	0.88
U	0.145	0.155	3.69	3.93
V	0.040	—	1.02	—

- STYLE 3:
1. BASE
  2. COLLECTOR
  3. EMITTER

CASE 77-08  
TO-225AA TYPE  
ISSUE V

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