

*Designer's™ Data Sheet*  
**NPN Silicon Power Transistor**  
**High Voltage SWITCHMODE™ Series**

Designed for use in electronic ballast (light ballast) and in Switchmode Power supplies up to 50 Watts. Main features include:

- Improved Efficiency Due to:
  - Low Base Drive Requirements (High and Flat DC Current Gain  $h_{FE}$ )
  - Low Power Losses (On-State and Switching Operations)
  - Fast Switching:  $t_{fi} = 100$  ns (typ) and  $t_{sj} = 3.2$   $\mu$ s (typ)  
@  $I_C = 2.0$  A,  $I_{B1} = I_{B2} = 0.4$  A
- Full Characterization at 125°C
- Tight Parametric Distributions Consistent Lot-to-Lot
- BUL45F, Case 221D, is UL Recognized at 3500 V<sub>RMS</sub>: File #E69369

**MAXIMUM RATINGS**

| Rating   | Symbol            | BUL45       | BUL45F               | Unit          |
|--|-------------------|-------------|----------------------|---------------|
| Collector-Emitter Sustaining Voltage   | $V_{CEO}$         | 400         |                      | Vdc           |
| Collector-Emitter Breakdown Voltage  | $V_{CES}$         | 700         |                      | Vdc           |
| Emitter-Base Voltage   | $V_{EBO}$         | 9.0         |                      | Vdc           |
| Collector Current — Continuous<br>— Peak(1)                                      | $I_C$<br>$I_{CM}$ | 5.0<br>10   |                      | Adc           |
| Base Current   | $I_B$             | 2.0         |                      | Adc           |
| RMS Isolated Voltage(2)<br>(for 1 sec, R.H. < 30%,<br>$T_C = 25^\circ\text{C}$ ) | $V_{ISOL}$        | —<br>—<br>— | 4500<br>3500<br>1500 | Volts         |
| Total Device Dissipation<br>Derate above 25°C                                    | $P_D$             | 75<br>0.6   | 35<br>0.28           | Watts<br>W/°C |
| Operating and Storage Temperature  | $T_J, T_{stg}$    | - 65 to 150 |                      | °C            |

**THERMAL CHARACTERISTICS**

| Rating   | Symbol                             | MJE18006     | MJF18006     | Unit |
|--|------------------------------------|--------------|--------------|------|
| Thermal Resistance — Junction to Case<br>— Junction to Ambient | $R_{\theta JC}$<br>$R_{\theta JA}$ | 1.65<br>62.5 | 3.55<br>62.5 | °C/W |

**ELECTRICAL CHARACTERISTICS** ( $T_C = 25^\circ\text{C}$  unless otherwise noted)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|----------------|--------|-----|-----|-----|------|
|----------------|--------|-----|-----|-----|------|

**OFF CHARACTERISTICS**

|  |                |     |   |           |           |
|--|----------------|-----|---|-----------|-----------|
| Collector-Emitter Sustaining Voltage ( $I_C = 100$ mA, $L = 25$ mH)  | $V_{CEO(sus)}$ | 400 | — | —         | Vdc       |
| Collector Cutoff Current ( $V_{CE} = \text{Rated } V_{CEO}, I_B = 0$ )                                     | $I_{CEO}$      | —   | — | 100       | $\mu$ Adc |
| Collector Cutoff Current ( $V_{CE} = \text{Rated } V_{CES}, V_{EB} = 0$ )<br>( $T_C = 125^\circ\text{C}$ ) | $I_{CES}$      | —   | — | 10<br>100 | $\mu$ Adc |
| Emitter Cutoff Current ( $V_{EB} = 9.0$ Vdc, $I_C = 0$ )   | $I_{EBO}$      | —   | — | 100       | $\mu$ Adc |

(1) Pulse Test: Pulse Width = 5.0 ms, Duty Cycle  $\leq$  10%.

(2) Proper strike and creepage distance must be provided.

(continued)

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**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.

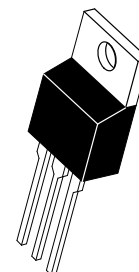
**Preferred** devices are Motorola recommended choices for future use and best overall value.

REV 2

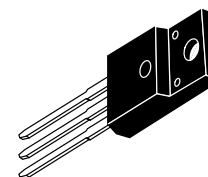
**BUL45\***  
**BUL45F\***

\*Motorola Preferred Device

**POWER TRANSISTOR**  
**5.0 AMPERES**  
**700 VOLTS**  
**35 and 75 WATTS**



**BUL45**  
**CASE 221A-06**  
**TO-220AB**



**BUL45F**  
**CASE 221D-02**  
**ISOLATED TO-220 TYPE**  
**UL RECOGNIZED**

# BUL45 BUL45F

## ELECTRICAL CHARACTERISTICS — continued ( $T_C = 25^\circ\text{C}$ unless otherwise noted)

| Characteristic  | Symbol        | Min                         | Typ                       | Max                    | Unit |
|---|---------------|-----------------------------|---------------------------|------------------------|------|
| <b>ON CHARACTERISTICS</b>   |               |                             |                           |                        |      |
| Base-Emitter Saturation Voltage ( $I_C = 1.0 \text{ Adc}$ , $I_B = 0.2 \text{ Adc}$ )<br>( $I_C = 2.0 \text{ Adc}$ , $I_B = 0.4 \text{ Adc}$ )  | $V_{BE(sat)}$ | —<br>—                      | 0.84<br>0.89              | 1.2<br>1.25            | Vdc  |
| Collector-Emitter Saturation Voltage<br>( $I_C = 1.0 \text{ Adc}$ , $I_B = 0.2 \text{ Adc}$ )<br><br>( $T_C = 125^\circ\text{C}$ )  | $V_{CE(sat)}$ | —<br>—                      | 0.175<br>0.150            | 0.25<br>—              | Vdc  |
| Collector-Emitter Saturation Voltage<br>( $I_C = 2.0 \text{ Adc}$ , $I_B = 0.4 \text{ Adc}$ )<br><br>( $T_C = 125^\circ\text{C}$ )  | $V_{CE(sat)}$ | —<br>—                      | 0.25<br>0.275             | 0.4<br>—               | Vdc  |
| DC Current Gain ( $I_C = 0.3 \text{ Adc}$ , $V_{CE} = 5.0 \text{ Vdc}$ )<br><br>( $I_C = 2.0 \text{ Adc}$ , $V_{CE} = 1.0 \text{ Vdc}$ )<br><br>( $I_C = 10 \text{ mAdc}$ , $V_{CE} = 5.0 \text{ Vdc}$ )<br><br>( $T_C = 125^\circ\text{C}$ ) | $h_{FE}$      | 14<br>—<br>7.0<br>5.0<br>10 | —<br>32<br>14<br>12<br>22 | 34<br>—<br>—<br>—<br>— | —    |

## DYNAMIC CHARACTERISTICS

|  |                            |  |  |  |                                      |  |                                      |     |
|--|----------------------------|--|--|--|--------------------------------------|--|--------------------------------------|-----|
| Current Gain Bandwidth ( $I_C = 0.5 \text{ Adc}$ , $V_{CE} = 10 \text{ Vdc}$ , $f = 1.0 \text{ MHz}$ )   | $f_T$                      | —  | 12                                     | —  | MHz                                  |  |                                      |     |
| Output Capacitance ( $V_{CB} = 10 \text{ Vdc}$ , $I_E = 0$ , $f = 1.0 \text{ MHz}$ )   | $C_{ob}$                   | —  | 50                                     | 75   | pF                                   |  |                                      |     |
| Input Capacitance ( $V_{EB} = 8.0 \text{ Vdc}$ )   | $C_{ib}$                   | —  | 920                                    | 1200   | pF                                   |  |                                      |     |
| Dynamic Saturation Voltage:<br><br>Determined 1.0 $\mu\text{s}$ and 3.0 $\mu\text{s}$ respectively after rising $I_{B1}$ reaches 90% of final $I_{B1}$ (see Figure 18) | $V_{CE} \text{ (Dyn sat)}$ | $I_C = 1.0 \text{ Adc}$<br>$I_{B1} = 100 \text{ mAdc}$<br>$V_{CC} = 300 \text{ V}$ | 1.0 $\mu\text{s}$<br>3.0 $\mu\text{s}$ | ( $T_C = 125^\circ\text{C}$ )<br>( $T_C = 125^\circ\text{C}$ ) | —<br>—<br>—<br>—<br>—<br>—<br>—<br>— | 1.75<br>4.4<br>0.5<br>1.0<br>1.85<br>6.0<br>0.5<br>1.0 | —<br>—<br>—<br>—<br>—<br>—<br>—<br>— | Vdc |

## SWITCHING CHARACTERISTICS: Resistive Load

|               |  |           |        |            |          |               |
|---------------|--|-----------|--------|------------|----------|---------------|
| Turn-On Time  | ( $I_C = 2.0 \text{ Adc}$ , $I_{B1} = I_{B2} = 0.4 \text{ Adc}$<br>Pulse Width = 20 $\mu\text{s}$ ,<br>Duty Cycle < 20%<br>$V_{CC} = 300 \text{ V}$ )<br><br>( $T_C = 125^\circ\text{C}$ ) | $t_{on}$  | —<br>— | 75<br>120  | 110<br>— | ns            |
| Turn-Off Time |  | $t_{off}$ | —<br>— | 2.8<br>3.5 | 3.5<br>— | $\mu\text{s}$ |

## SWITCHING CHARACTERISTICS: Inductive Load ( $V_{CC} = 15 \text{ Vdc}$ , $L_C = 200 \mu\text{H}$ , $V_{clamp} = 300 \text{ Vdc}$ )

|                |  |          |          |            |          |               |
|----------------|--|----------|----------|------------|----------|---------------|
| Fall Time      | ( $I_C = 2.0 \text{ Adc}$ , $I_{B1} = 0.4 \text{ Adc}$<br>$I_{B2} = 0.4 \text{ Adc}$ )<br><br>( $T_C = 125^\circ\text{C}$ )  | $t_{fi}$ | 70<br>—  | —<br>200   | 170<br>— | ns            |
| Storage Time   |  | $t_{si}$ | 2.6<br>— | —<br>4.2   | 3.8<br>— | $\mu\text{s}$ |
| Crossover Time |  | $t_c$    | —<br>—   | 230<br>400 | 350<br>— | ns            |
| Fall Time      | ( $I_C = 1.0 \text{ Adc}$ , $I_{B1} = 100 \text{ mAdc}$<br>$I_{B2} = 0.5 \text{ Adc}$ )<br><br>( $T_C = 125^\circ\text{C}$ ) | $t_{fi}$ | —<br>—   | 110<br>100 | 150<br>— | ns            |
| Storage Time   |  | $t_{si}$ | —<br>—   | 1.1<br>1.5 | 1.7<br>— | $\mu\text{s}$ |
| Crossover Time |  | $t_c$    | —<br>—   | 170<br>170 | 250<br>— | ns            |
| Fall Time      | ( $I_C = 2.0 \text{ Adc}$ , $I_{B1} = 250 \text{ mAdc}$<br>$I_{B2} = 2.0 \text{ Adc}$ )<br><br>( $T_C = 125^\circ\text{C}$ ) | $t_{fi}$ | —        | 80         | 120      | ns            |
| Storage Time   |  | $t_{si}$ | —        | 0.6        | 0.9      | $\mu\text{s}$ |
| Crossover Time |  | $t_c$    | —        | 175        | 300      | ns            |

TYPICAL STATIC CHARACTERISTICS

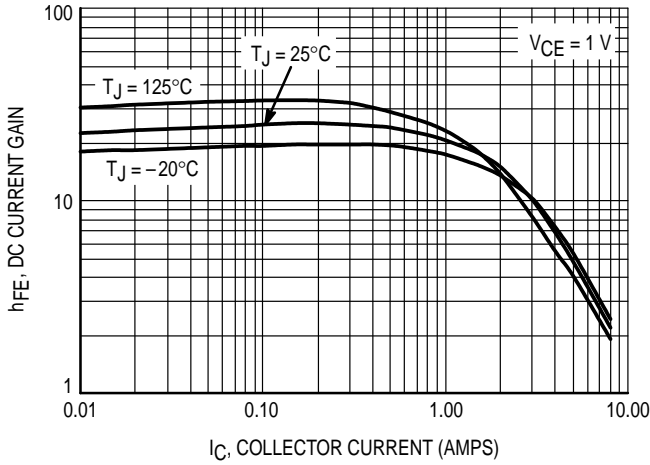


Figure 1. DC Current Gain @ 1 Volt

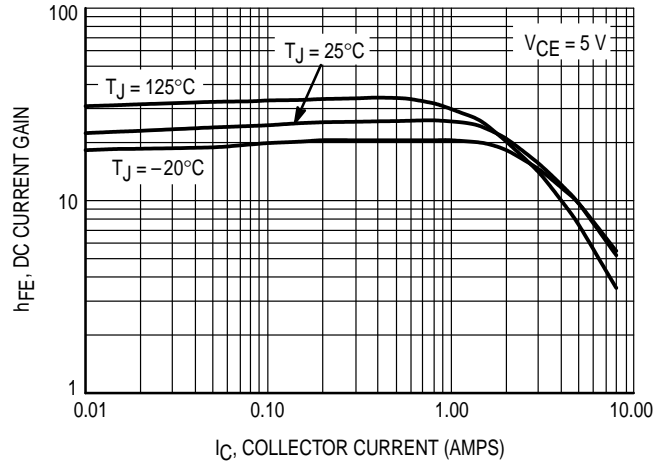


Figure 2. DC Current Gain at @ 5 Volts

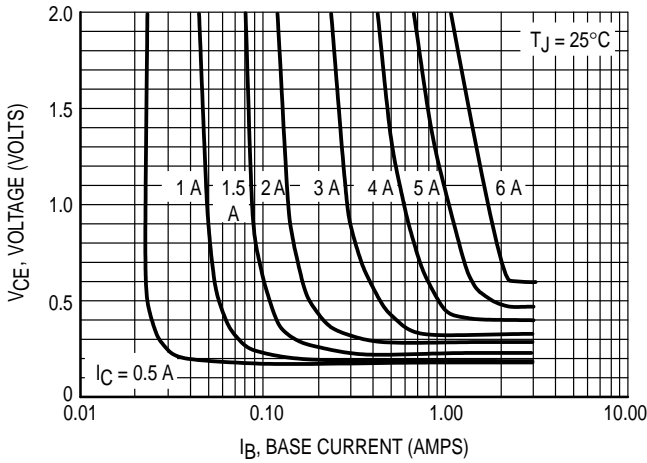


Figure 3. Collector-Emitter Saturation Region

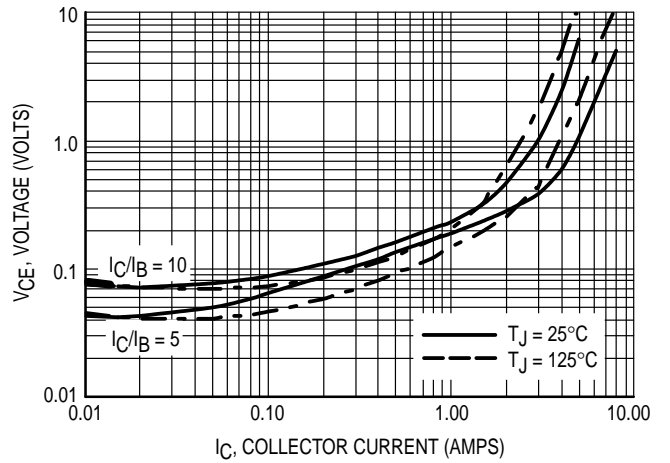


Figure 4. Collector-Emitter Saturation Voltage

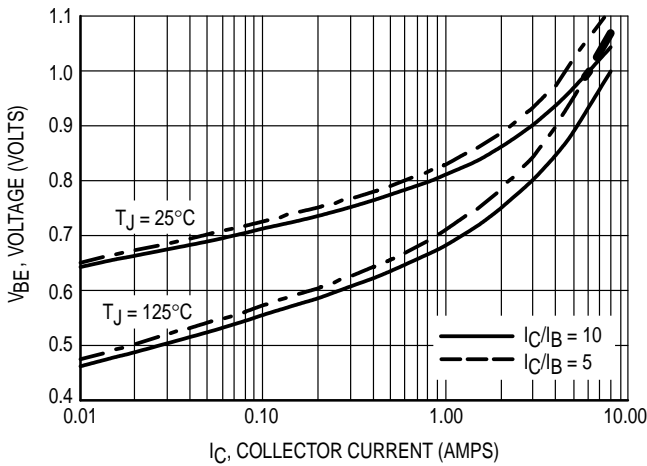


Figure 5. Base-Emitter Saturation Region

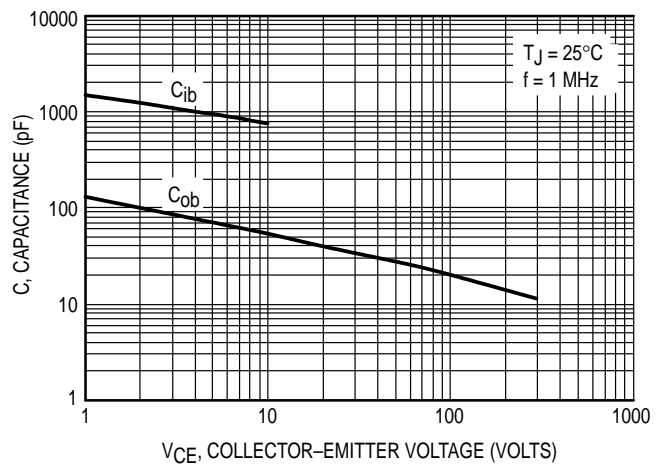


Figure 6. Capacitance

TYPICAL SWITCHING CHARACTERISTICS  
( $I_{B2} = I_C/2$  for all switching)

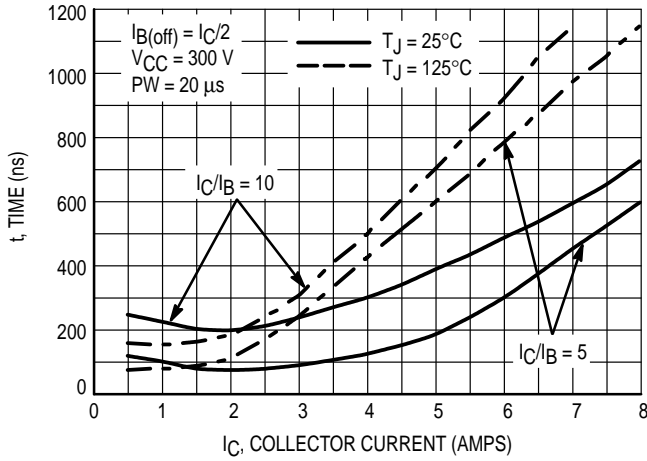


Figure 7. Resistive Switching,  $t_{on}$

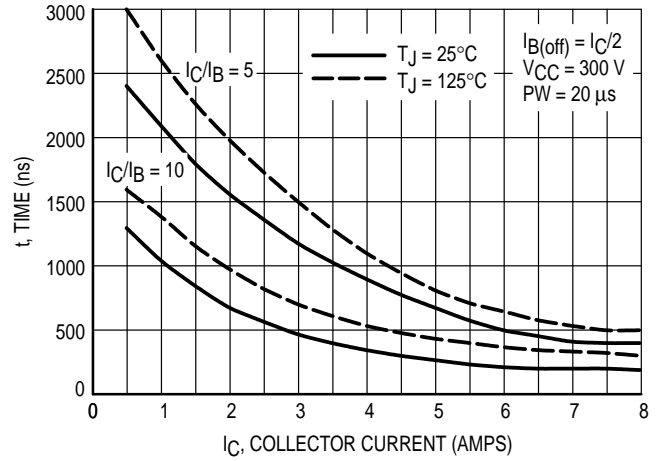


Figure 8. Resistive Switching,  $t_{off}$

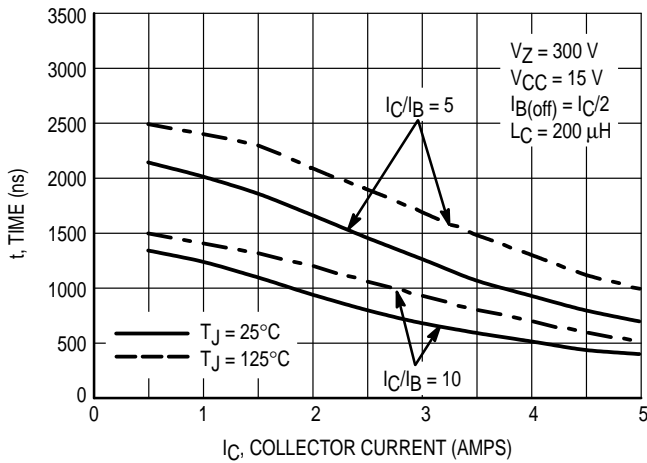


Figure 9. Inductive Storage Time,  $t_{si}$

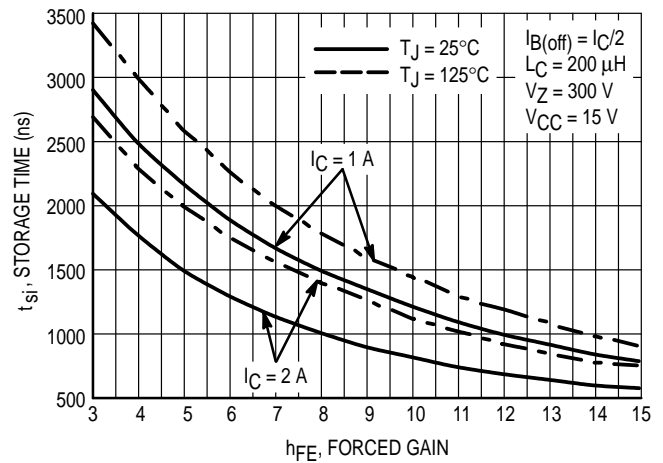


Figure 10. Inductive Storage Time,  $t_{si}(h_{FE})$

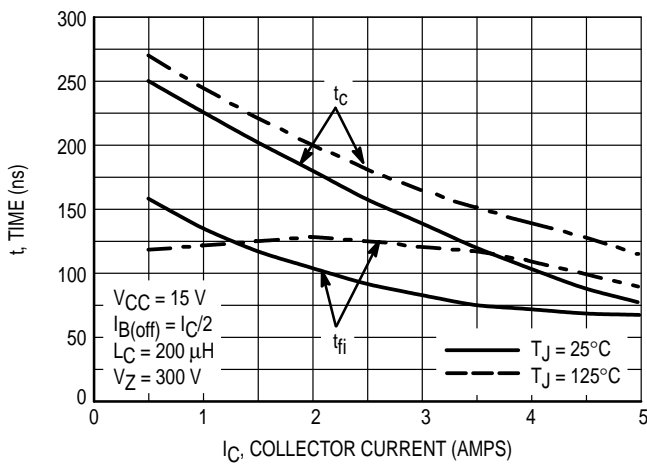


Figure 11. Inductive Switching,  $t_c$  &  $t_{fi}$ ,  $I_C/I_B = 5$

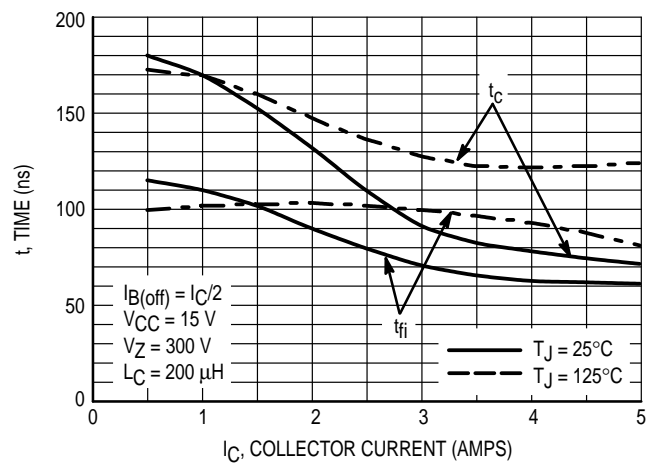
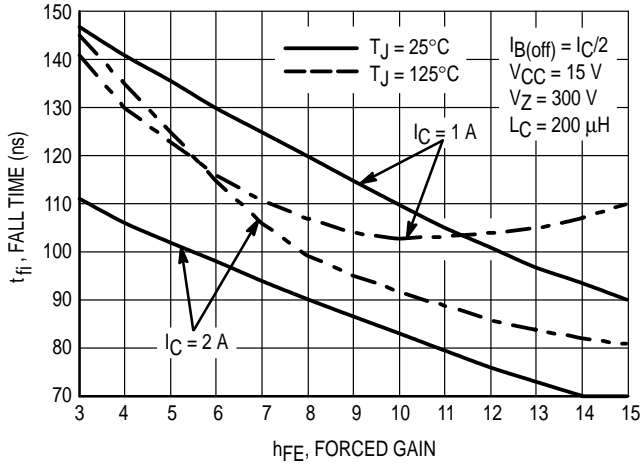
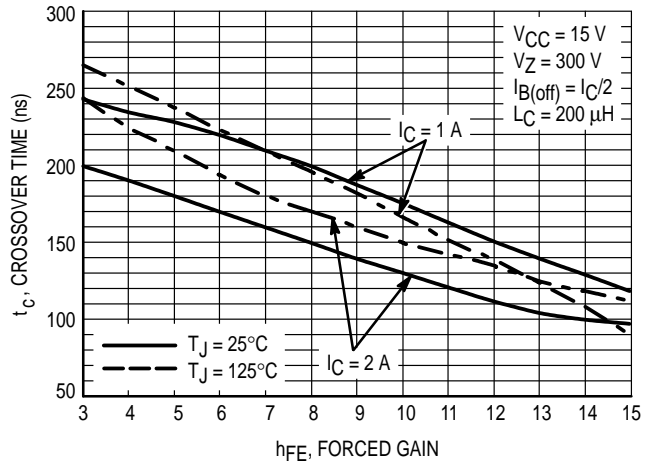


Figure 12. Inductive Switching,  $t_c$  &  $t_{fi}$ ,  $I_C/I_B = 10$

**TYPICAL SWITCHING CHARACTERISTICS**  
( $I_{B2} = I_C/2$  for all switching)

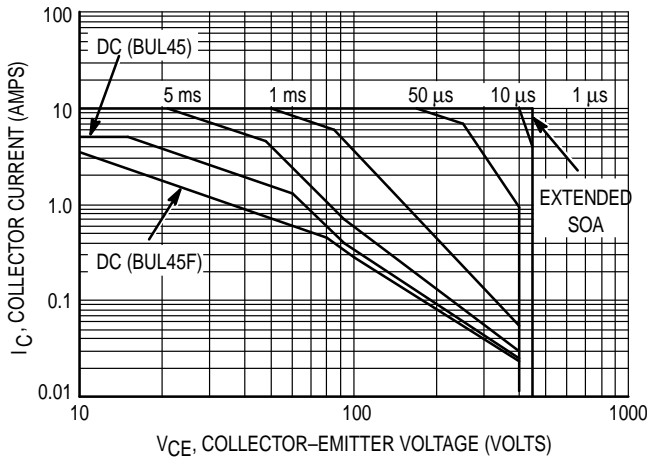


**Figure 13. Inductive Fall Time,  $t_{fi}(h_{FE})$**

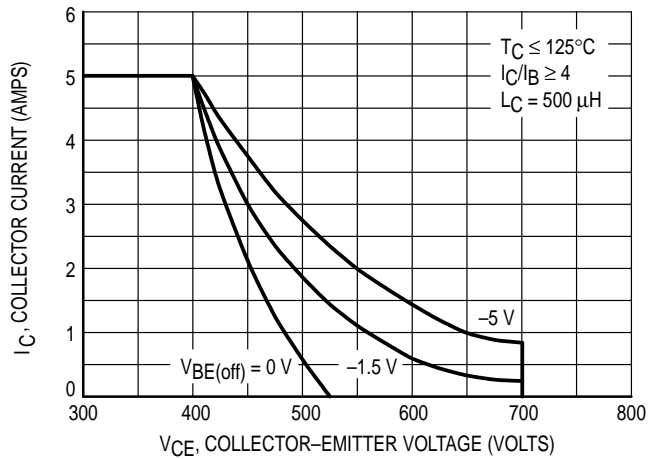


**Figure 14. Crossover Time**

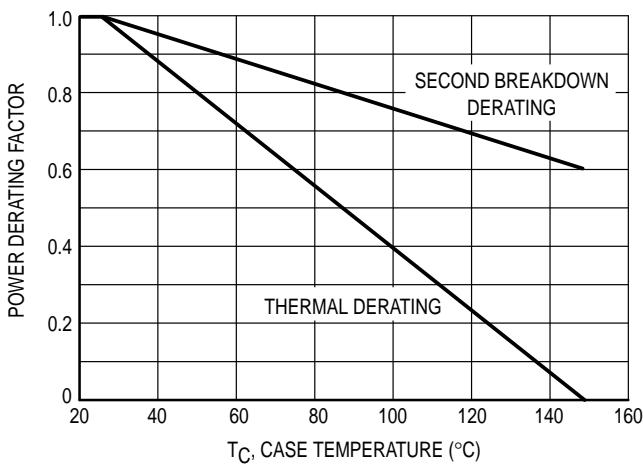
**GUARANTEED SAFE OPERATING AREA INFORMATION**



**Figure 15. Forward Bias Safe Operating Area**

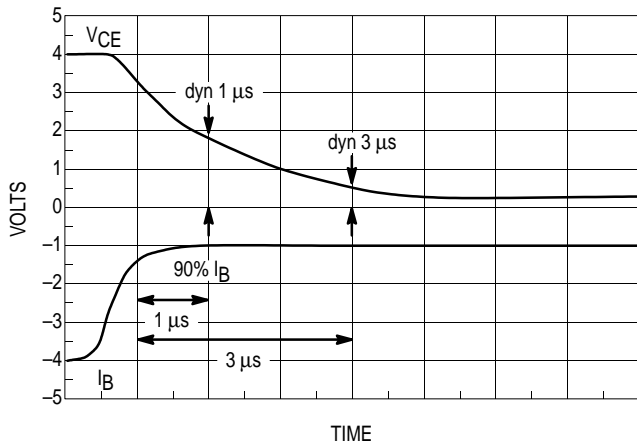


**Figure 16. Reverse Bias Switching Safe Operating Area**

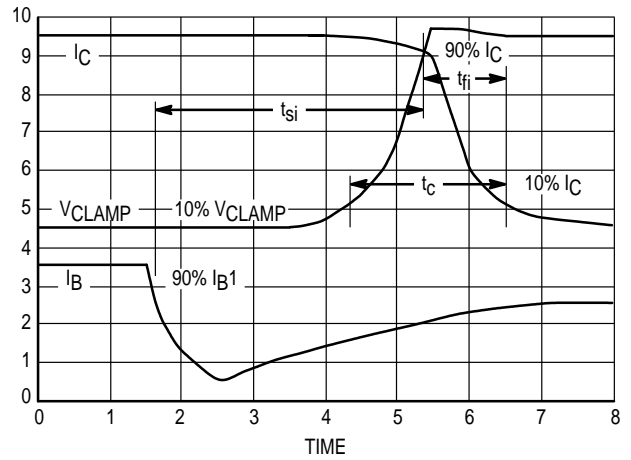


**Figure 17. Forward Bias Power Derating**

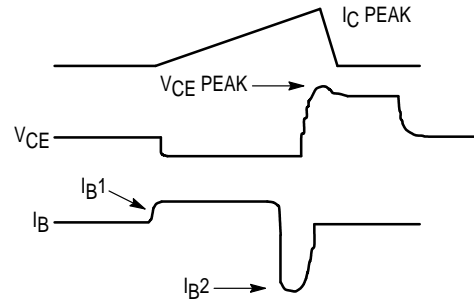
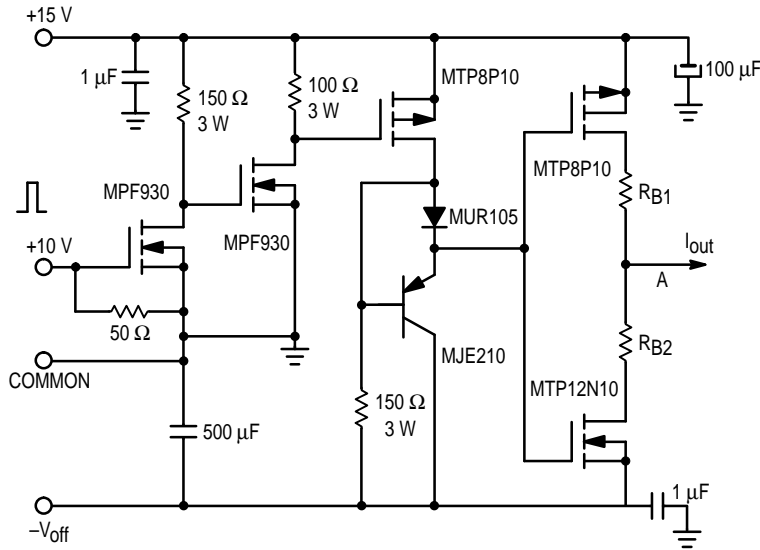
There are two limitations on the power handling ability of a transistor: average junction temperature and second breakdown. Safe operating area curves indicate  $I_C - V_{CE}$  limits of the transistor that must be observed for reliable operation; i.e., the transistor must not be subjected to greater dissipation than the curves indicate. The data of Figure 15 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 in Figure 15 may be found at any case temperature by using the appropriate curve on Figure 17.  $T_{J(pk)}$  may be calculated from the data in Figures 20 and 21. At any case temperatures, thermal limitations will reduce the power that can be handled to values less than the limitations imposed by second breakdown. For inductive loads, high voltage and current must be sustained simultaneously during turn-off with the base-to-emitter junction reverse-biased. The safe level is specified as a reverse-biased safe operating area (Figure 16). This rating is verified under clamped conditions so that the device is never subjected to an avalanche mode.



**Figure 18. Dynamic Saturation Voltage Measurements**



**Figure 19. Inductive Switching Measurements**



| V(BR)CEO(sus)   | INDUCTIVE SWITCHING          | RBSOA                        |
|-----------------|------------------------------|------------------------------|
| L = 10 mH       | L = 200 μH                   | L = 500 μH                   |
| RB2 = ∞         | RB2 = 0                      | RB2 = 0                      |
| VCC = 20 VOLTS  | VCC = 15 VOLTS               | VCC = 15 VOLTS               |
| IC(pk) = 100 mA | RB1 SELECTED FOR DESIRED IB1 | RB1 SELECTED FOR DESIRED IB1 |

**Table 1. Inductive Load Switching Drive Circuit**

TYPICAL THERMAL RESPONSE

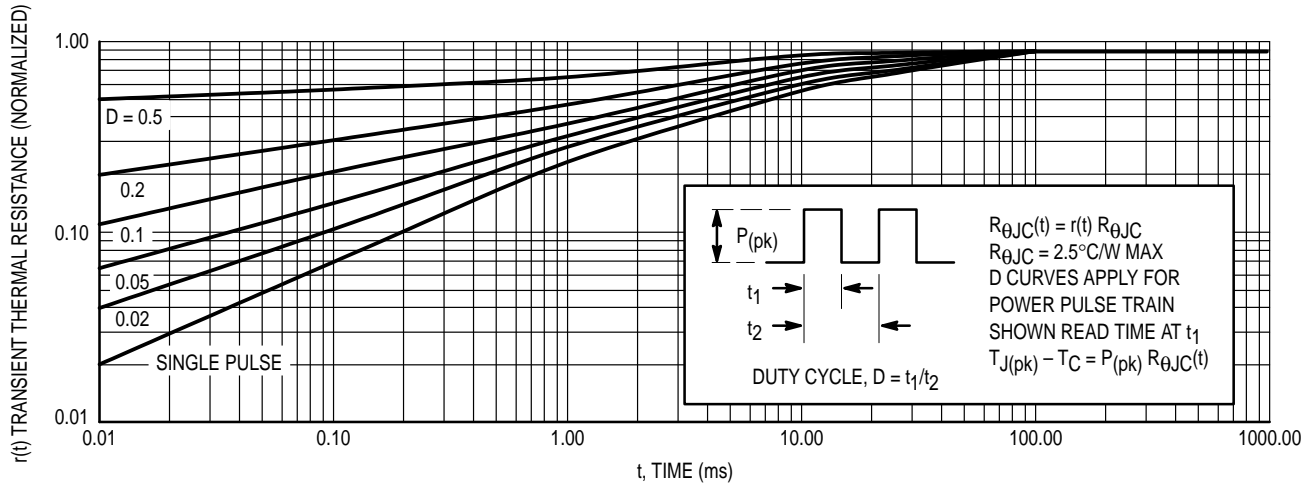


Figure 20. Typical Thermal Response ( $Z_{\theta JC}(t)$ ) for BUL45

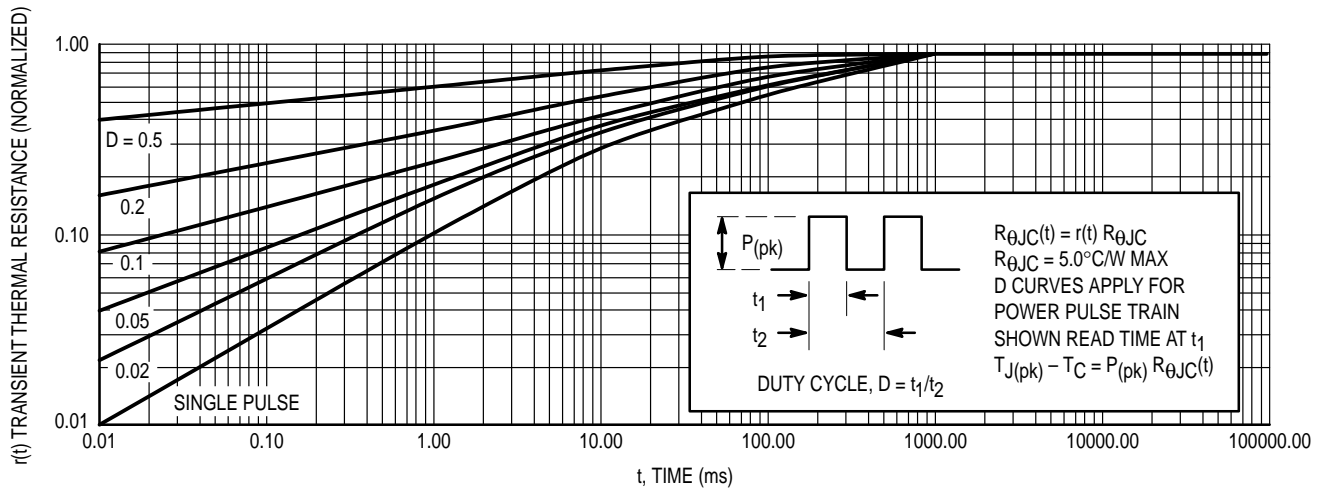
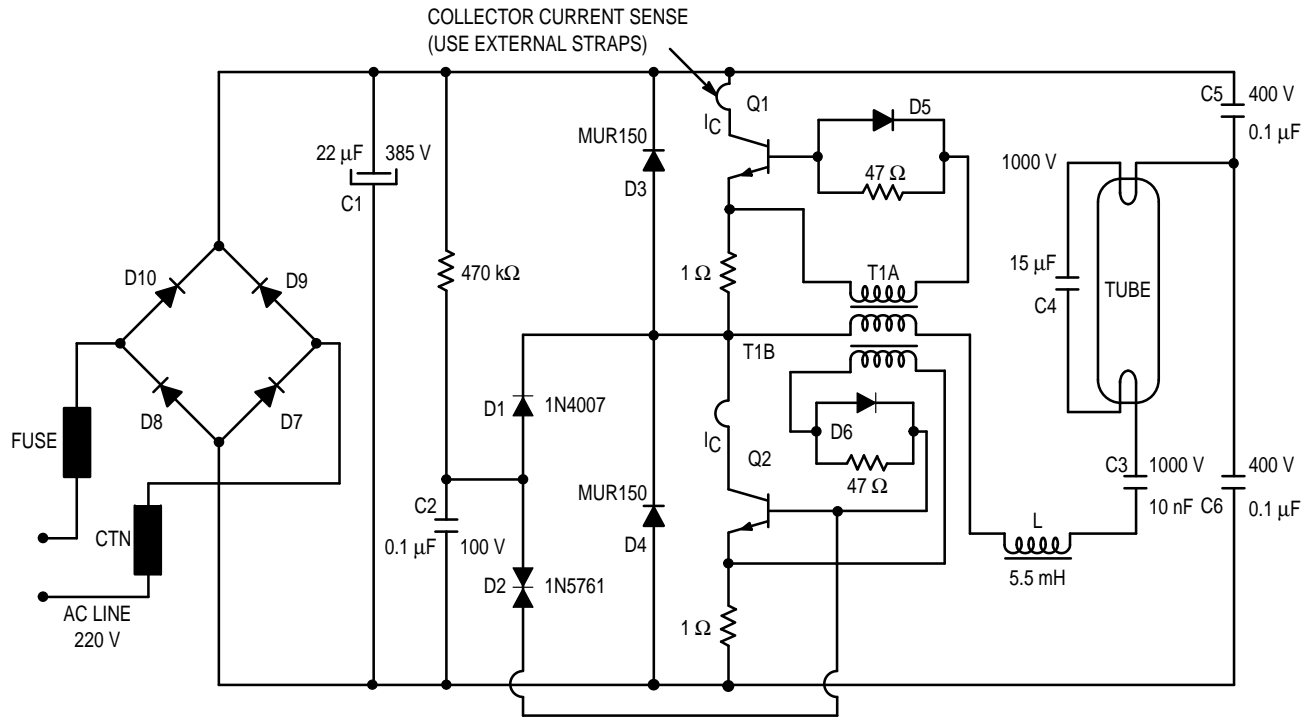


Figure 21. Typical Thermal Response ( $Z_{\theta JC}(t)$ ) for BUL45F

## BUL45 BUL45F

The BUL45/BUL45F Bipolar Power Transistors were specially designed for use in electronic lamp ballasts. A circuit designed by Motorola applications was built to

demonstrate how well these devices operate. The circuit and detailed component list are provided below.



### Components Lists

Q1 = Q2 = BUL45 Transistor  
 D1 = 1N4007 Rectifier  
 D2 = 1N5761 Rectifier  
 D3 = D4 = MUR150  
 D5 = D6 = MUR105  
 D7 = D8 = D9 = D10 = 1N400  
 CTN = 47  $\Omega$  @ 25°C  
 L = RM10 core, A1 = 400, B51 (LCC) 75 turns,  
 wire  $\varnothing$  = 0.6 mm  
 T1 = FT10 toroid, T4A (LCC)  
 Primary: 4 turns  
 Secondaries: T1A: 4 turns  
 T1B: 4 turns

All resistors are 1/4 Watt,  $\pm$ 5%  
 R1 = 470 k $\Omega$   
 R2 = R3 = 47  $\Omega$   
 R4 = R5 = 1  $\Omega$  (these resistors are optional, and  
 might be replaced by a short circuit)  
 C1 = 22  $\mu$ F/385 V  
 C2 = 0.1  $\mu$ F  
 C3 = 10 nF/1000 V  
 C4 = 15  $\mu$ F/1000 V  
 C5 = C6 = 0.1  $\mu$ F/400 V

### NOTES:

1. Since this design does not include the line input filter, it cannot be used "as-is" in a practical industrial circuit.
2. The windings are given for a 55 Watt load. For proper operation they must be re-calculated with any other loads.

Figure 22. Application Example



TEST CONDITIONS FOR ISOLATION TESTS\*

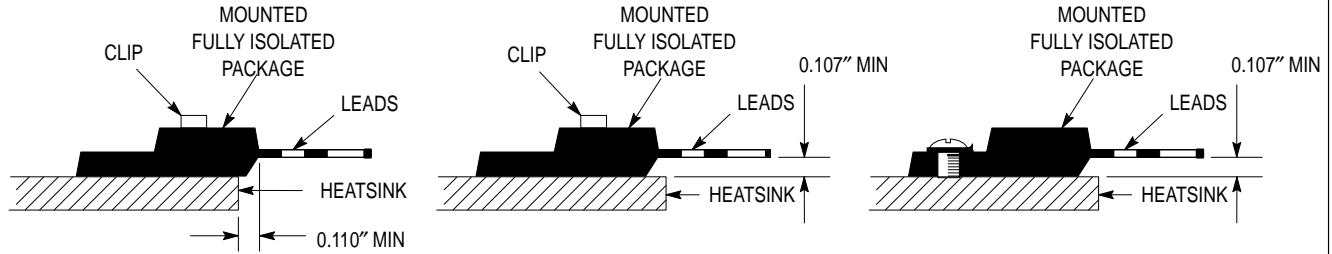


Figure 22a. Screw or Clip Mounting Position for Isolation Test Number 1

Figure 22b. Clip Mounting Position for Isolation Test Number 2

Figure 22c. Screw Mounting Position for Isolation Test Number 3

\* Measurement made between leads and heatsink with all leads shorted together.

MOUNTING INFORMATION\*\*

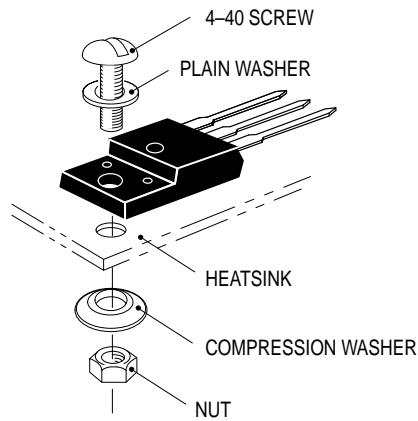


Figure 23a. Screw-Mounted

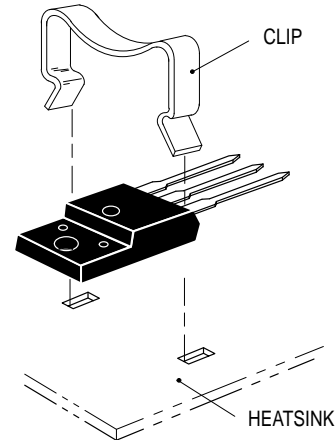


Figure 23b. Clip-Mounted

Figure 23. Typical Mounting Techniques for Isolated Package

Laboratory tests on a limited number of samples indicate, when using the screw and compression washer mounting technique, a screw torque of 6 to 8 in · lbs is sufficient to provide maximum power dissipation capability. The compression washer helps to maintain a constant pressure on the package over time and during large temperature excursions.

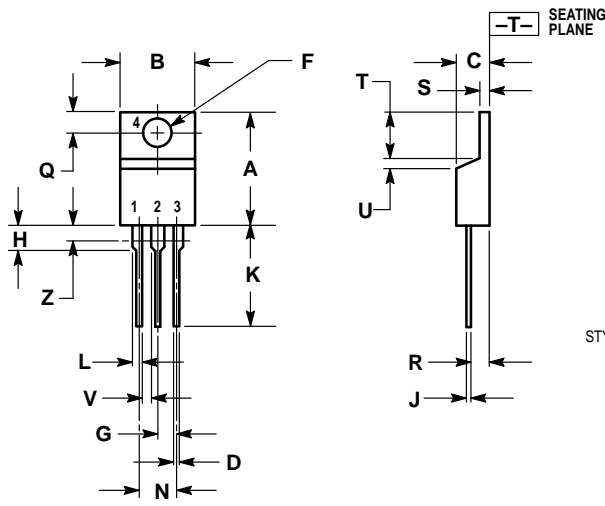
Destructive laboratory tests show that using a hex head 4-40 screw, without washers, and applying a torque in excess of 20 in · lbs will cause the plastic to crack around the mounting hole, resulting in a loss of isolation capability.

Additional tests on slotted 4-40 screws indicate that the screw slot fails between 15 to 20 in · lbs without adversely affecting the package. However, in order to positively ensure the package integrity of the fully isolated device, Motorola does not recommend exceeding 10 in · lbs of mounting torque under any mounting conditions.

\*\* For more information about mounting power semiconductors see Application Note AN1040.

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PACKAGE DIMENSIONS

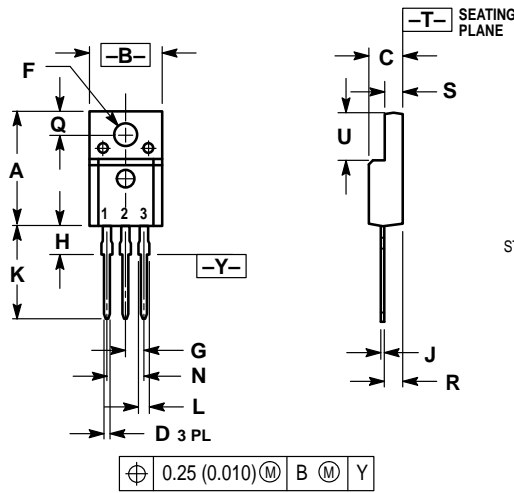


- NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
  2. CONTROLLING DIMENSION: INCH.
  3. DIMENSION Z DEFINES A ZONE WHERE ALL BODY AND LEAD IRREGULARITIES ARE ALLOWED.

| DIM | INCHES |       | MILLIMETERS |       |
|-----|--------|-------|-------------|-------|
|     | MIN    | MAX   | MIN         | MAX   |
| A   | 0.570  | 0.620 | 14.48       | 15.75 |
| B   | 0.380  | 0.405 | 9.66        | 10.28 |
| C   | 0.160  | 0.190 | 4.07        | 4.82  |
| D   | 0.025  | 0.035 | 0.64        | 0.88  |
| F   | 0.142  | 0.147 | 3.61        | 3.73  |
| G   | 0.095  | 0.105 | 2.42        | 2.66  |
| H   | 0.110  | 0.155 | 2.80        | 3.93  |
| J   | 0.018  | 0.025 | 0.46        | 0.64  |
| K   | 0.500  | 0.562 | 12.70       | 14.27 |
| L   | 0.045  | 0.060 | 1.15        | 1.52  |
| N   | 0.190  | 0.210 | 4.83        | 5.33  |
| Q   | 0.100  | 0.120 | 2.54        | 3.04  |
| R   | 0.080  | 0.110 | 2.04        | 2.79  |
| S   | 0.045  | 0.055 | 1.15        | 1.39  |
| T   | 0.235  | 0.255 | 5.97        | 6.47  |
| U   | 0.000  | 0.050 | 0.00        | 1.27  |
| V   | 0.045  | —     | 1.15        | —     |
| Z   | —      | 0.080 | —           | 2.04  |

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

**BUL45**  
**CASE 221A-06**  
**TO-220AB**  
**ISSUE Y**



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

| DIM | INCHES    |       | MILLIMETERS |       |
|-----|-----------|-------|-------------|-------|
|     | MIN       | MAX   | MIN         | MAX   |
| A   | 0.621     | 0.629 | 15.78       | 15.97 |
| B   | 0.394     | 0.402 | 10.01       | 10.21 |
| C   | 0.181     | 0.189 | 4.60        | 4.80  |
| D   | 0.026     | 0.034 | 0.67        | 0.86  |
| F   | 0.121     | 0.129 | 3.08        | 3.27  |
| G   | 0.100 BSC | —     | 2.54 BSC    | —     |
| H   | 0.123     | 0.129 | 3.13        | 3.27  |
| J   | 0.018     | 0.025 | 0.46        | 0.64  |
| K   | 0.500     | 0.562 | 12.70       | 14.27 |
| L   | 0.045     | 0.060 | 1.14        | 1.52  |
| N   | 0.200 BSC | —     | 5.08 BSC    | —     |
| Q   | 0.126     | 0.134 | 3.21        | 3.40  |
| R   | 0.107     | 0.111 | 2.72        | 2.81  |
| S   | 0.096     | 0.104 | 2.44        | 2.64  |
| U   | 0.259     | 0.267 | 6.58        | 6.78  |

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

**BUL45F**  
**CASE 221D-02**  
**(ISOLATED TO-220 TYPE)**  
**ISSUE D**

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