

# Designer's™ Data Sheet

## SWITCHMODE™

### NPN Bipolar Power Transistor

### For Switching Power Supply Applications

The BUL44/BUL44F have an applications specific state-of-the-art die designed for use in 220 V line operated Switchmode Power supplies and electronic light ballasts. These high voltage/high speed transistors offer the following:

- Improved Efficiency Due to Low Base Drive Requirements:
  - High and Flat DC Current Gain  $h_{FE}$
  - Fast Switching
  - No Coil Required in Base Circuit for Turn-Off (No Current Tail)
- Full Characterization at 125°C
- Tight Parametric Distributions are Consistent Lot-to-Lot
- Two Package Choices: Standard TO-220 or Isolated TO-220
- BUL44F, Case 221D, is UL Recognized to 3500 V<sub>RMS</sub>: File #E69369

#### MAXIMUM RATINGS

| Rating                                                   | Symbol         | BUL44       | BUL44F | 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                           | $I_C$          | 2.0         |        | Adc   |
| — Peak(1)                                                | $I_{CM}$       | 5.0         |        |       |
| Base Current — Continuous                                | $I_B$          | 1.0         |        | Adc   |
| — Peak(1)                                                | $I_{BM}$       | 2.0         |        |       |
| RMS Isolated Voltage(2)                                  | $V_{ISOL}$     | —           | 4500   | Volts |
| (for 1 sec, R.H. < 30%,<br>$T_C = 25^\circ\text{C}$ )    |                | —           | 3500   |       |
|                                                          |                | —           | 1500   |       |
| Total Device Dissipation<br>( $T_C = 25^\circ\text{C}$ ) | $P_D$          | 50          | 25     | Watts |
| Derate above 25°C                                        |                | 0.4         | 0.2    | W/°C  |
| Operating and Storage Temperature                        | $T_J, T_{stg}$ | - 65 to 150 |        | °C    |

#### THERMAL CHARACTERISTICS

| Rating                                                                           | Symbol          | BUL44 | BUL44F | Unit |
|----------------------------------------------------------------------------------|-----------------|-------|--------|------|
| Thermal Resistance — Junction to Case                                            | $R_{\theta JC}$ | 2.5   | 5.0    | °C/W |
| — Junction to Ambient                                                            | $R_{\theta JA}$ | 62.5  | 62.5   |      |
| Maximum Lead Temperature for Soldering<br>Purposes: 1/8" from Case for 5 Seconds | $T_L$           | 260   |        | °C   |

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

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

#### OFF CHARACTERISTICS

|                                                                                     |                |     |   |     |                 |
|-------------------------------------------------------------------------------------|----------------|-----|---|-----|-----------------|
| Collector-Emitter Sustaining Voltage ( $I_C = 100\text{ mA}$ , $L = 25\text{ mH}$ ) | $V_{CEO(sus)}$ | 400 | — | —   | Vdc             |
| Collector Cutoff Current ( $V_{CE} = \text{Rated } V_{CEO}$ , $I_B = 0$ )           | $I_{CEO}$      | —   | — | 100 | $\mu\text{Adc}$ |
| Collector Cutoff Current ( $V_{CE} = \text{Rated } V_{CES}$ , $V_{EB} = 0$ )        | $I_{CES}$      | —   | — | 100 | $\mu\text{Adc}$ |
| ( $T_C = 125^\circ\text{C}$ )                                                       |                | —   | — | 500 |                 |
| ( $V_{CE} = 500\text{ V}$ , $V_{EB} = 0$ ) ( $T_C = 125^\circ\text{C}$ )            |                | —   | — | 100 |                 |
| Emitter Cutoff Current ( $V_{EB} = 9.0\text{ Vdc}$ , $I_C = 0$ )                    | $I_{EBO}$      | —   | — | 100 | $\mu\text{Adc}$ |

(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.

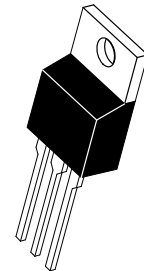
**Preferred** devices are Motorola recommended choices for future use and best overall value.

REV 1

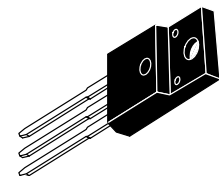
**BUL44\***  
**BUL44F\***

\*Motorola Preferred Device

**POWER TRANSISTOR**  
**2.0 AMPERES**  
**700 VOLTS**  
**40 and 100 WATTS**



**BUL44**  
**CASE 221A-06**  
**TO-220AB**



**BUL44F**  
**CASE 221D-02**  
**ISOLATED TO-220 TYPE**  
**UL RECOGNIZED**

# BUL44 BUL44F

## 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 ( $I_C = 0.4\text{ Adc}$ , $I_B = 40\text{ mAdc}$ )<br>( $I_C = 1.0\text{ Adc}$ , $I_B = 0.2\text{ Adc}$ )                                                                                                                                                                                                                                                                              | $V_{BE(sat)}$ | —<br>—                                  | 0.85<br>0.92                          | 1.1<br>1.25                      | Vdc  |
| Collector–Emitter Saturation Voltage<br>( $I_C = 0.4\text{ Adc}$ , $I_B = 40\text{ mAdc}$ )<br><br>( $I_C = 1.0\text{ Adc}$ , $I_B = 0.2\text{ Adc}$ )<br><br>( $T_C = 125^\circ\text{C}$ )<br><br>( $T_C = 125^\circ\text{C}$ )                                                                                                                                                                                        | $V_{CE(sat)}$ | —<br>—<br>—<br>—                        | 0.20<br>0.20<br>0.25<br>0.25          | 0.5<br>0.5<br>0.6<br>0.6         | Vdc  |
| DC Current Gain<br>( $I_C = 0.2\text{ Adc}$ , $V_{CE} = 5.0\text{ Vdc}$ )<br><br>( $I_C = 0.4\text{ Adc}$ , $V_{CE} = 1.0\text{ Vdc}$ )<br><br>( $I_C = 1.0\text{ Adc}$ , $V_{CE} = 1.0\text{ Vdc}$ )<br><br>( $I_C = 10\text{ mAdc}$ , $V_{CE} = 5.0\text{ Vdc}$ )<br><br>( $T_C = 125^\circ\text{C}$ )<br><br>( $T_C = 125^\circ\text{C}$ )<br><br>( $T_C = 125^\circ\text{C}$ )<br><br>( $T_C = 125^\circ\text{C}$ ) | $h_{FE}$      | 14<br>—<br>12<br>12<br>8.0<br>7.0<br>10 | —<br>32<br>20<br>20<br>14<br>13<br>22 | 34<br>—<br>—<br>—<br>—<br>—<br>— | —    |

## DYNAMIC CHARACTERISTICS

|                                                                                                                                                             |                                                                                   |                   |                               |                |   |      |     |     |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------|-------------------------------|----------------|---|------|-----|-----|
| Current Gain Bandwidth ( $I_C = 0.5\text{ Adc}$ , $V_{CE} = 10\text{ Vdc}$ , $f = 1.0\text{ MHz}$ )                                                         |                                                                                   |                   |                               | $f_T$          | — | 13   | —   | MHz |
| Output Capacitance ( $V_{CB} = 10\text{ Vdc}$ , $I_E = 0$ , $f = 1.0\text{ MHz}$ )                                                                          |                                                                                   |                   |                               | $C_{OB}$       | — | 38   | 60  | pF  |
| Input Capacitance ( $V_{EB} = 8.0\text{ V}$ )                                                                                                               |                                                                                   |                   |                               | $C_{IB}$       | — | 380  | 600 | pF  |
| Dynamic Saturation Voltage:<br>Determined 1.0 $\mu\text{s}$ and<br>3.0 $\mu\text{s}$ respectively after<br>rising $I_{B1}$ reaches 90% of<br>final $I_{B1}$ | $(I_C = 0.4\text{ Adc}$<br>$I_{B1} = 40\text{ mAdc}$<br>$V_{CC} = 300\text{ V}$ ) | 1.0 $\mu\text{s}$ | ( $T_C = 125^\circ\text{C}$ ) | $V_{CE(dsat)}$ | — | 2.5  | —   | Vdc |
|                                                                                                                                                             |                                                                                   | 3.0 $\mu\text{s}$ | ( $T_C = 125^\circ\text{C}$ ) |                | — | 1.3  | —   |     |
|                                                                                                                                                             | $(I_C = 1.0\text{ Adc}$<br>$I_{B1} = 0.2\text{ Adc}$<br>$V_{CC} = 300\text{ V}$ ) | 1.0 $\mu\text{s}$ | ( $T_C = 125^\circ\text{C}$ ) |                | — | 3.2  | —   |     |
|                                                                                                                                                             |                                                                                   | 3.0 $\mu\text{s}$ | ( $T_C = 125^\circ\text{C}$ ) |                | — | 7.5  | —   |     |
|                                                                                                                                                             |                                                                                   | 1.0 $\mu\text{s}$ | ( $T_C = 125^\circ\text{C}$ ) |                | — | 1.25 | —   |     |
|                                                                                                                                                             |                                                                                   | 3.0 $\mu\text{s}$ | ( $T_C = 125^\circ\text{C}$ ) |                | — | 1.6  | —   |     |

## SWITCHING CHARACTERISTICS: Resistive Load ( $D.C. \leq 10\%$ , Pulse Width = 20 $\mu\text{s}$ )

|               |                                                                                                                                                   |           |        |              |          |               |
|---------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-----------|--------|--------------|----------|---------------|
| Turn–On Time  | $(I_C = 0.4\text{ Adc}$ , $I_{B1} = 40\text{ mAdc}$<br>$I_{B2} = 0.2\text{ Adc}$ , $V_{CC} = 300\text{ V}$ )<br><br>( $T_C = 125^\circ\text{C}$ ) | $t_{on}$  | —<br>— | 40<br>40     | 100<br>— | ns            |
| Turn–Off Time |                                                                                                                                                   | $t_{off}$ | —<br>— | 1.5<br>2.0   | 2.5<br>— | $\mu\text{s}$ |
| Turn–On Time  | $(I_C = 1.0\text{ Adc}$ , $I_{B1} = 0.2\text{ Adc}$<br>$I_{B2} = 0.5\text{ Adc}$ , $V_{CC} = 300\text{ V}$ )<br><br>( $T_C = 125^\circ\text{C}$ ) | $t_{on}$  | —<br>— | 85<br>85     | 150<br>— | ns            |
| Turn–Off Time |                                                                                                                                                   | $t_{off}$ | —<br>— | 1.75<br>2.10 | 2.5<br>— | $\mu\text{s}$ |

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

|                |                                                                                                                           |          |          |             |           |               |
|----------------|---------------------------------------------------------------------------------------------------------------------------|----------|----------|-------------|-----------|---------------|
| Fall Time      | $(I_C = 0.4\text{ Adc}$ , $I_{B1} = 40\text{ mAdc}$<br>$I_{B2} = 0.2\text{ Adc}$ )<br><br>( $T_C = 125^\circ\text{C}$ )   | $t_{fi}$ | —<br>—   | 125<br>120  | 200<br>—  | ns            |
| Storage Time   |                                                                                                                           | $t_{si}$ | —<br>—   | 0.7<br>0.8  | 1.25<br>— | $\mu\text{s}$ |
| Crossover Time |                                                                                                                           | $t_c$    | —<br>—   | 110<br>110  | 200<br>—  | ns            |
| Fall Time      | $(I_C = 1.0\text{ Adc}$ , $I_{B1} = 0.2\text{ Adc}$<br>$I_{B2} = 0.5\text{ Adc}$ )<br><br>( $T_C = 125^\circ\text{C}$ )   | $t_{fi}$ | —<br>—   | 110<br>120  | 175<br>—  | ns            |
| Storage Time   |                                                                                                                           | $t_{si}$ | —<br>—   | 1.7<br>2.25 | 2.75<br>— | $\mu\text{s}$ |
| Crossover Time |                                                                                                                           | $t_c$    | —<br>—   | 180<br>210  | 300<br>—  | ns            |
| Fall Time      | $(I_C = 0.8\text{ Adc}$ , $I_{B1} = 160\text{ mAdc}$<br>$I_{B2} = 160\text{ mAdc}$ )<br><br>( $T_C = 125^\circ\text{C}$ ) | $t_{fi}$ | 70<br>—  | —<br>180    | 170<br>—  | ns            |
| Storage Time   |                                                                                                                           | $t_{si}$ | 2.6<br>— | —<br>4.2    | 3.8<br>—  | $\mu\text{s}$ |
| Crossover Time |                                                                                                                           | $t_c$    | —<br>—   | 190<br>350  | 300<br>—  | ns            |

# TYPICAL STATIC CHARACTERISTICS

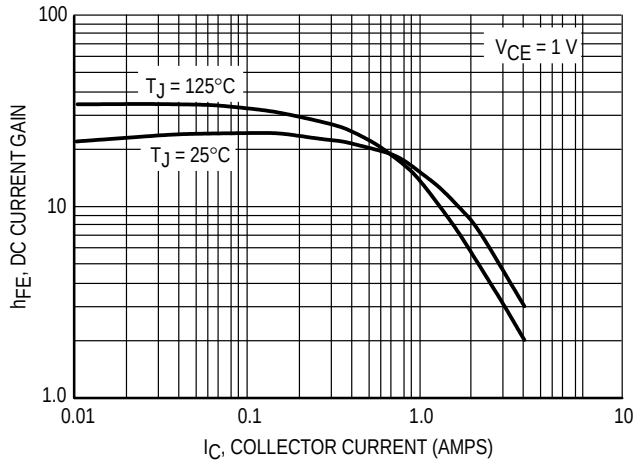


Figure 1. DC Current Gain at 1 Volt

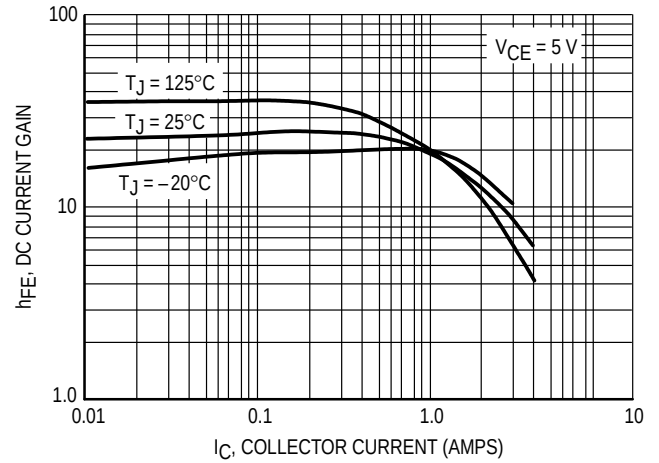


Figure 2. DC Current Gain at 5 Volts

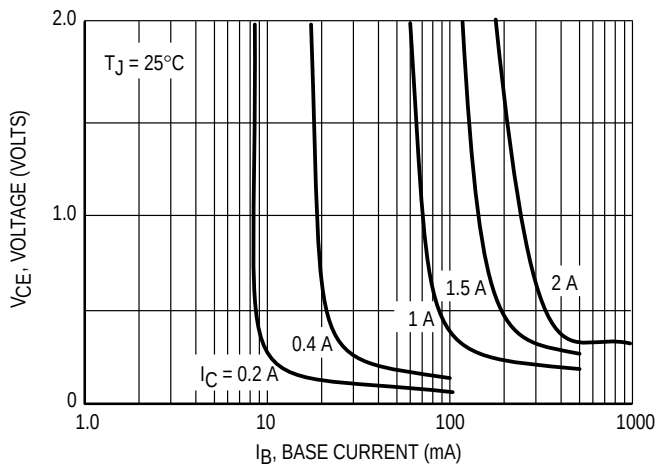


Figure 3. Collector Saturation Region

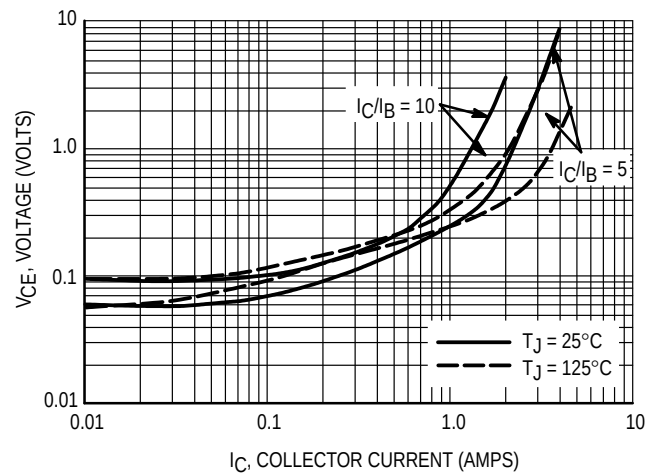


Figure 4. Collector-Emitter Saturation Voltage

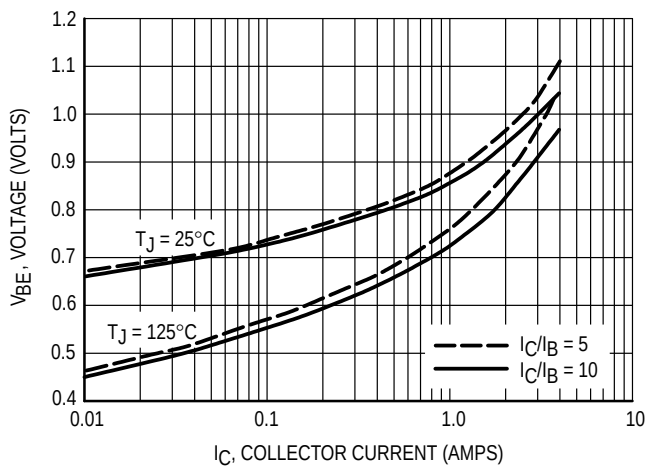


Figure 5. Base-Emitter Saturation Region

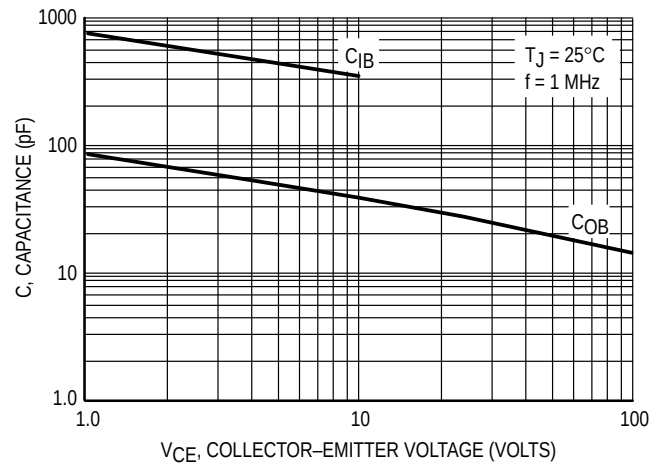


Figure 6. Capacitance

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

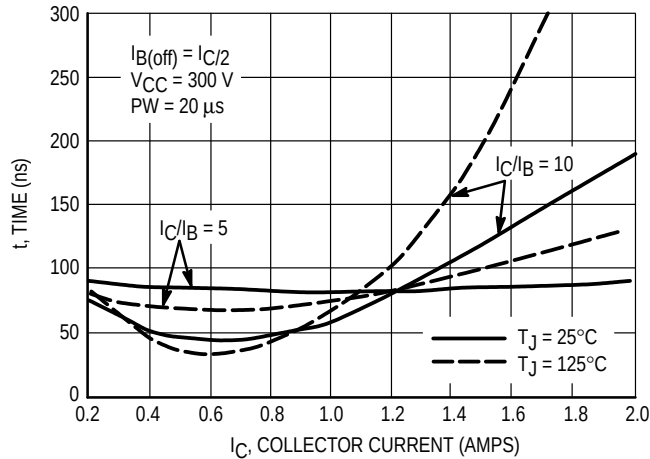
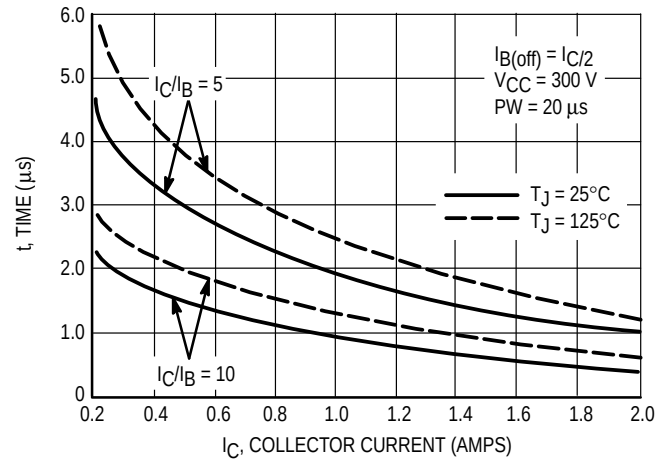
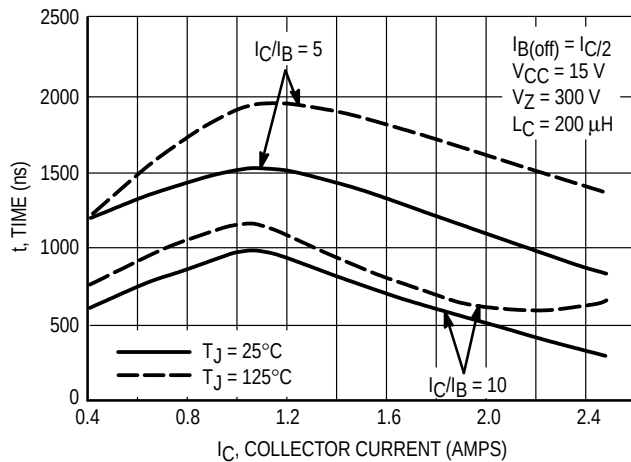
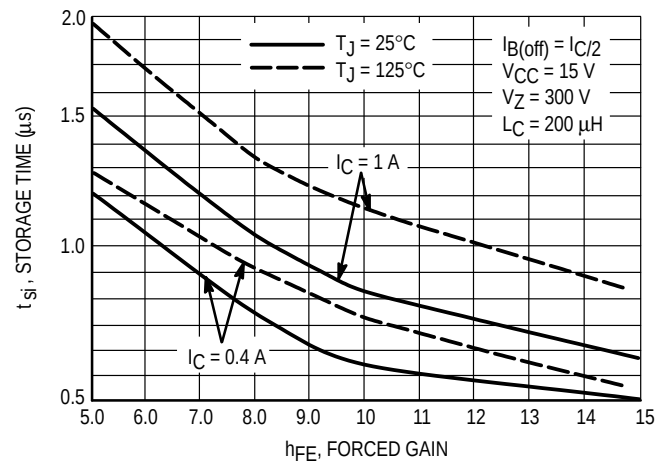
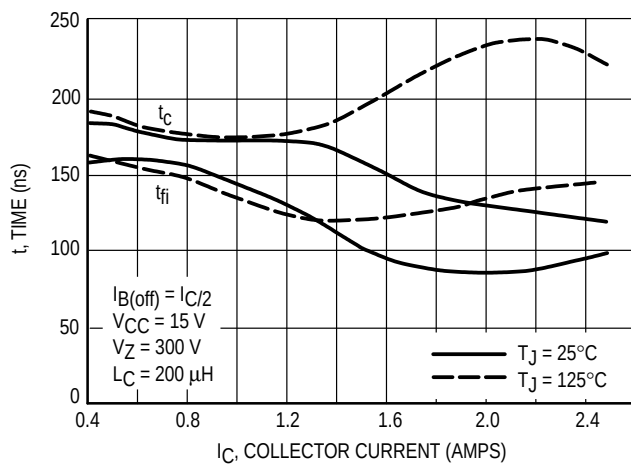
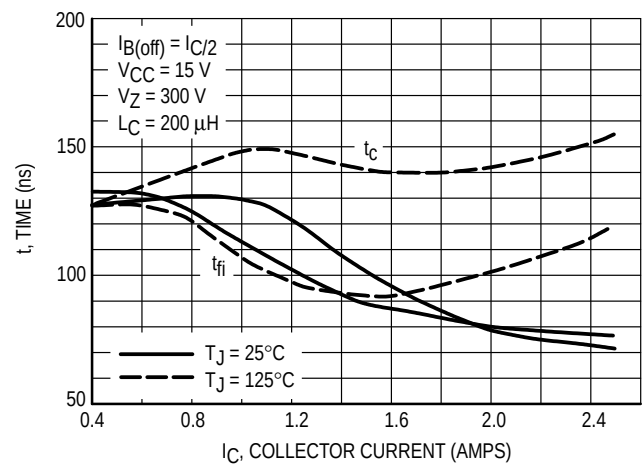
Figure 7. Resistive Switching,  $t_{on}$ Figure 8. Resistive Switching,  $t_{off}$ Figure 9. Inductive Storage Time,  $t_{si}$ 

Figure 10. Inductive Storage Time

Figure 11. Inductive Switching,  $t_c$  and  $t_{fi}$   $I_C/I_B = 5$ Figure 12. Inductive Switching,  $t_c$  and  $t_{fi}$   $I_C/I_B = 10$

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

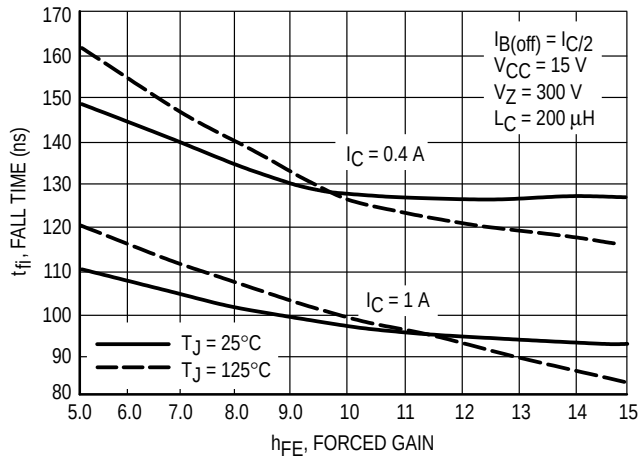


Figure 13. Inductive Fall Time

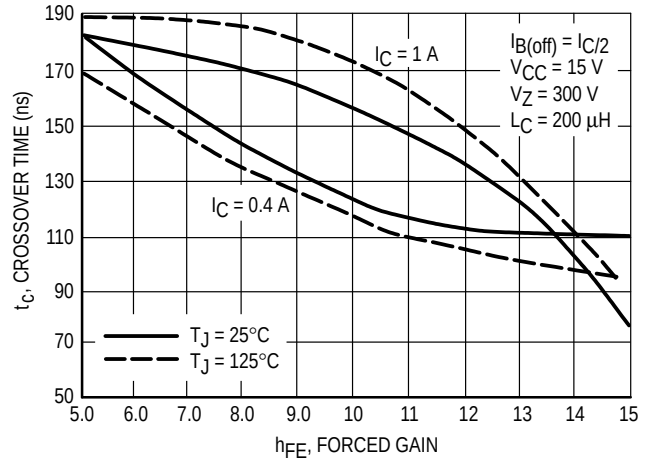


Figure 14. Inductive Crossover Time

### GUARANTEED SAFE OPERATING AREA INFORMATION

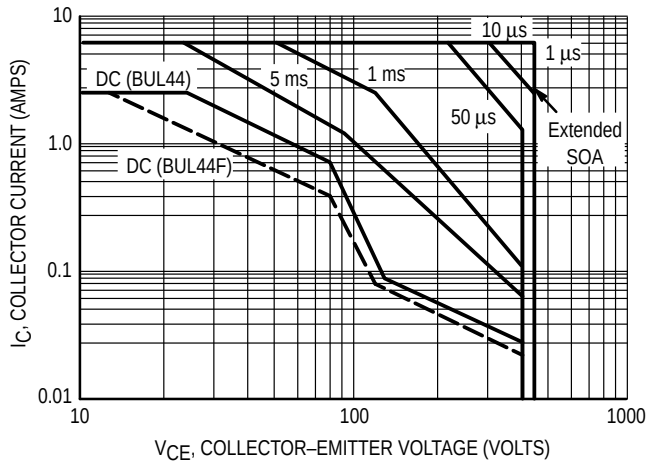


Figure 15. Forward Bias Safe Operating Area

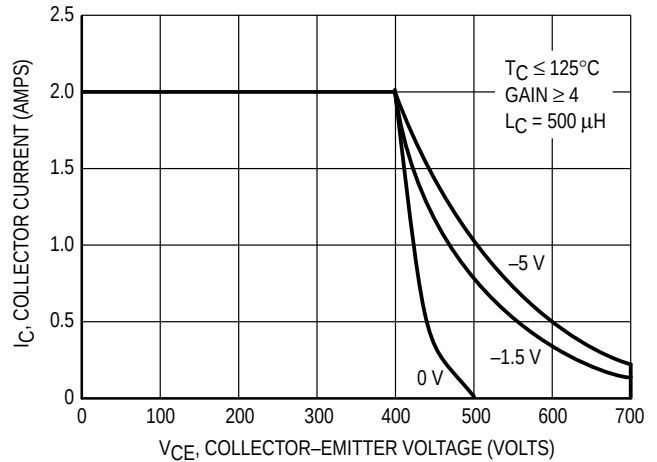


Figure 16. Reverse Bias Switching Safe Operating Area

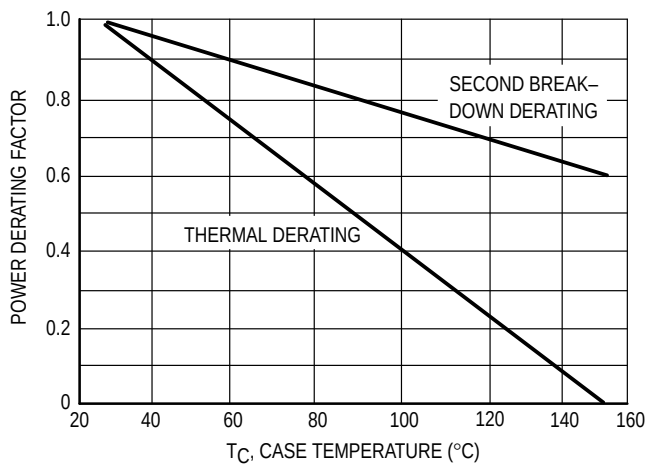


Figure 17. Forward Bias Power Derating

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  $T_C > 25^\circ\text{C}$ . Second breakdown limitations do not derate the same as thermal limitations. Allowable current at the voltages shown on 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 figure 20 and 21. At any case temperatures, thermal limitations will reduce the power than 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.

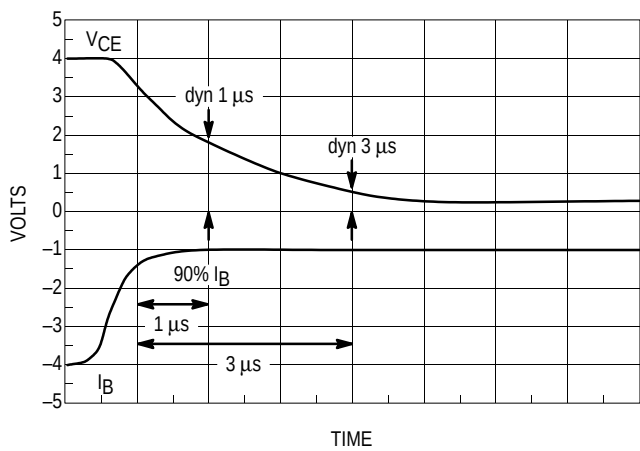


Figure 18. Dynamic Saturation Voltage Measurements

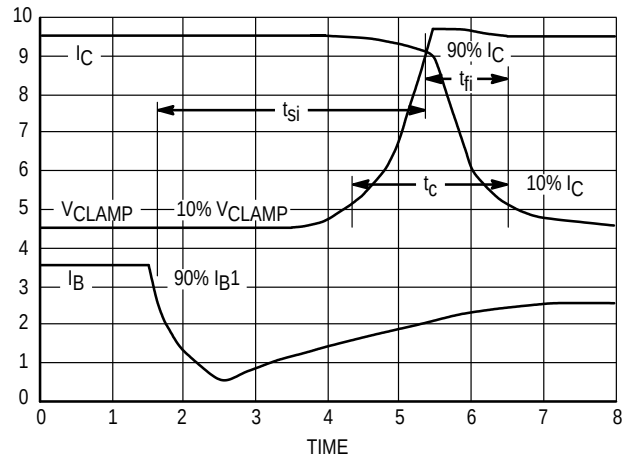
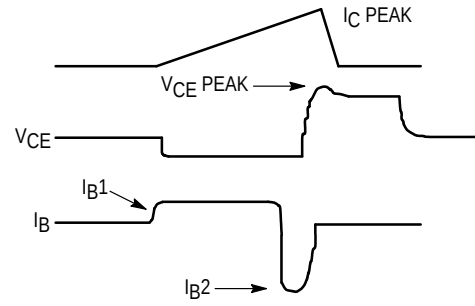
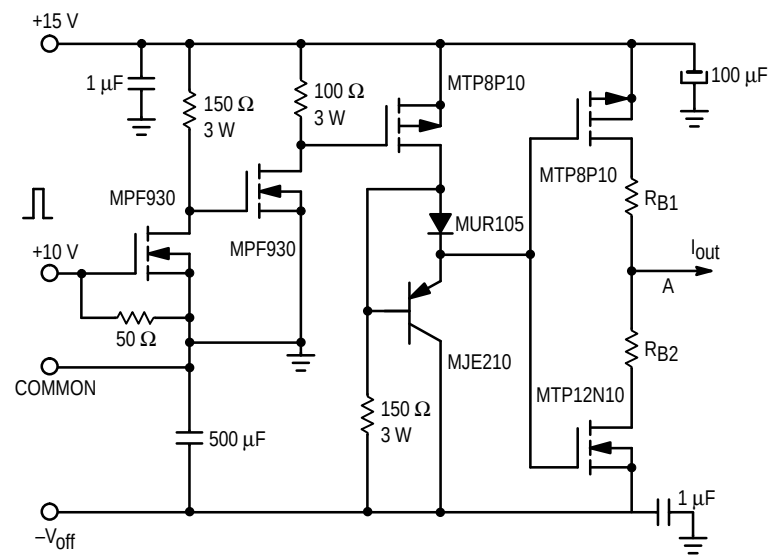


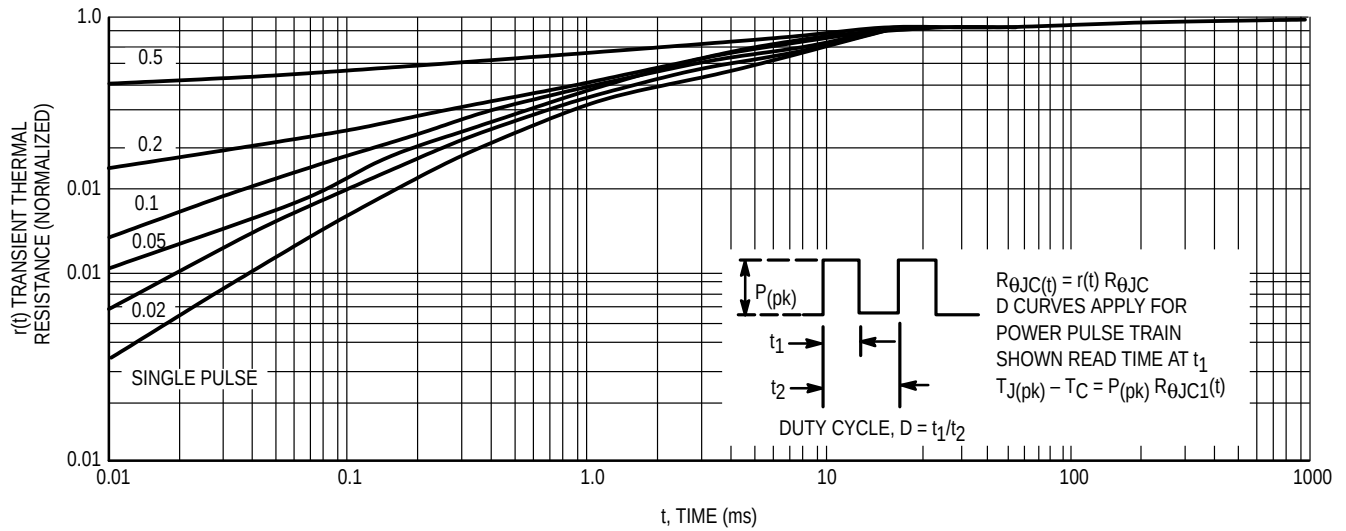
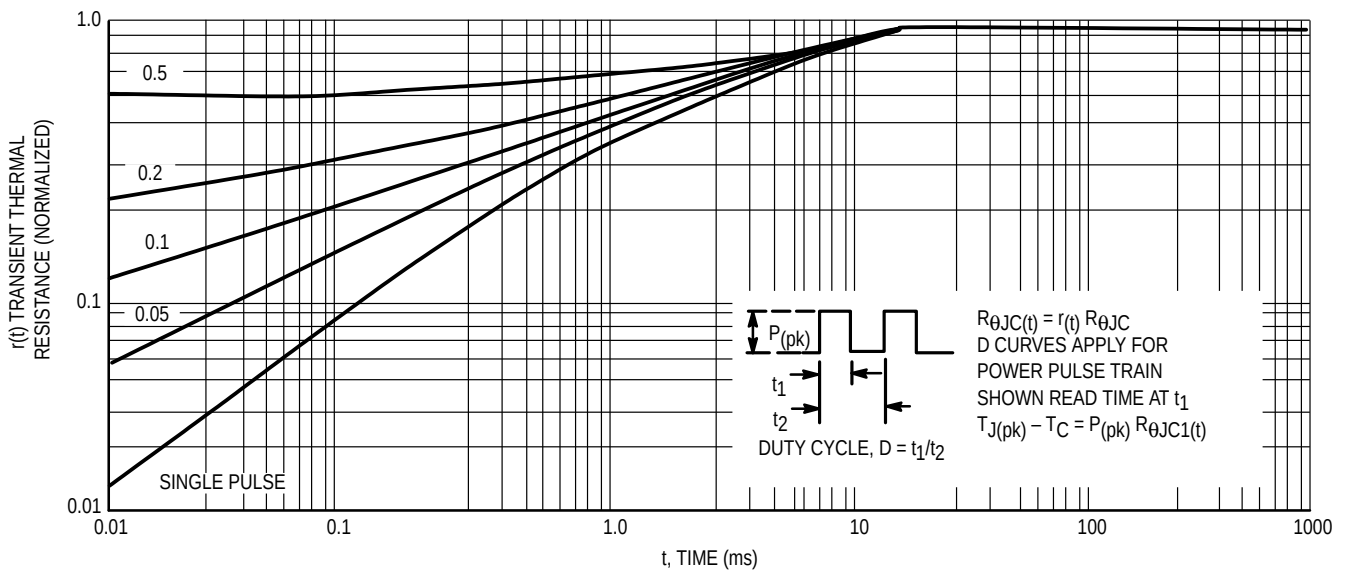
Figure 19. Inductive Switching Measurements



| 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 BUL44Figure 21. Typical Thermal Response ( $Z_{\theta JC}(t)$ ) for BUL44F

## TEST CONDITIONS FOR ISOLATION TESTS\*

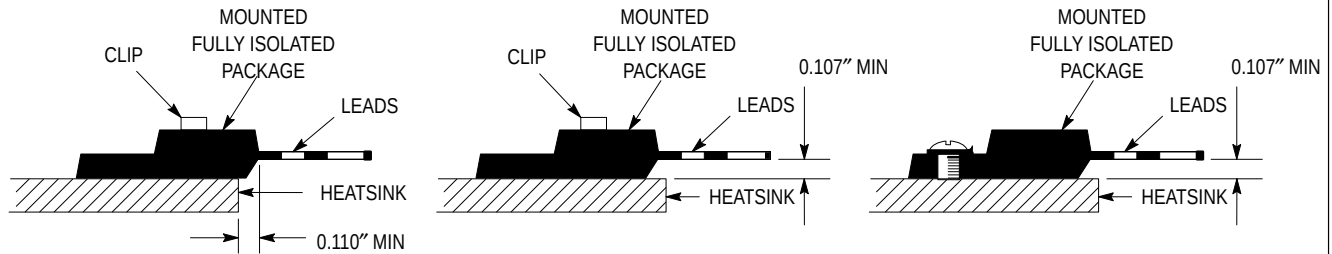


Figure 22a. Screw or Clip Mounting Position for Isolation Test Number 1

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\*\*

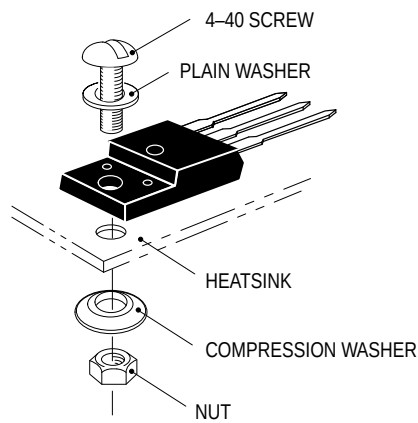


Figure 23a. Screw-Mounted

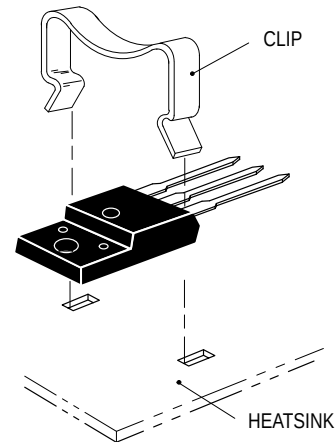


Figure 23b. Clip-Mounted

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.

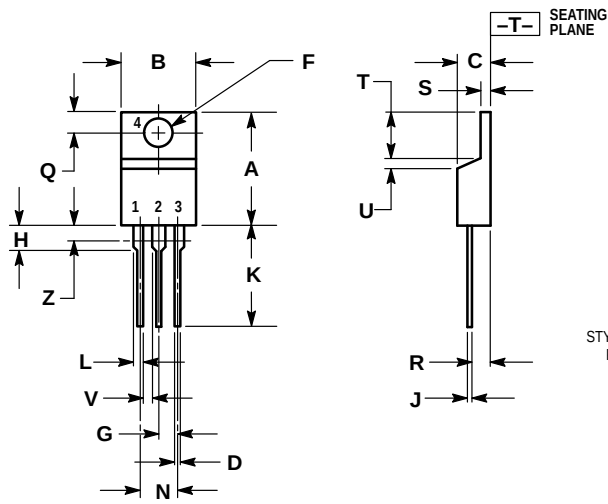
Destructive laboratory tests show that using a hex head 4-40 screw, without washers, and applying a torque in excess of 20 in · lbs will cause the plastic to crack around the mounting hole, resulting in a loss of isolation capability.

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.



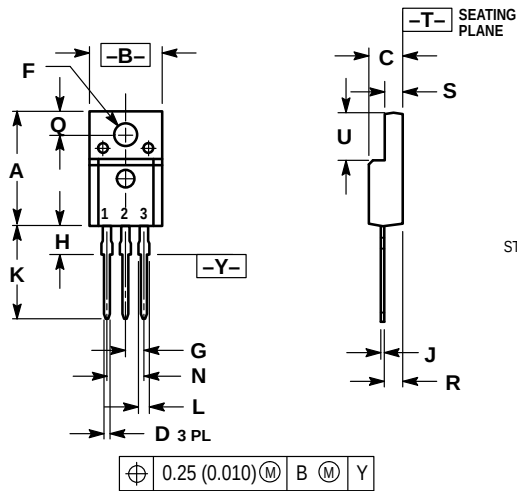
## PACKAGE DIMENSIONS



- 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  |

**BUL44**  
**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  |

**BUL44F**  
**CASE 221D-02**  
**(ISOLATED TO-220 TYPE)**  
**ISSUE D**

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