# *Designer's™ Data Sheet*
# SWITCHMODE™
## NPN Bipolar Power Transistor
## For Switching Power Supply Applications

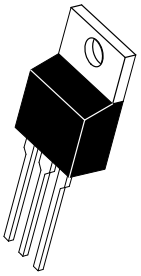
**BUL147***
**BUL147F***

*Motorola Preferred Device

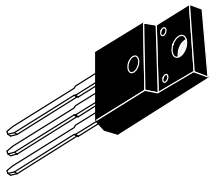
**POWER TRANSISTOR**
**8.0 AMPERES**
**700 VOLTS**
**45 and 125 WATTS**

The BUL147/BUL147F have an applications specific state–of–the–art die designed for use in electric fluorescent lamp ballasts to 180 Watts and in Switchmode Power supplies for all types of electronic equipment. These high–voltage/high–speed transistors offer the following:

- Improved Efficiency Due to Low Base Drive Requirements:
  - — High and Flat DC Current Gain
  - — Fast Switching
  - — No Coil Required in Base Circuit for Turn–Off (No Current Tail)
- Parametric Distributions are Tight and Consistent Lot–to–Lot
- Two Package Choices: Standard TO–220 or Isolated TO–220
- BUL147F, Isolated Case 221D, is UL Recognized to 3500 $V_{RMS}$: File #E69369



**BUL147**
**CASE 221A–06**
**TO–220AB**



**BUL147F**
**CASE 221D–02**
**ISOLATED TO–220 TYPE**
**UL RECOGNIZED**

### MAXIMUM RATINGS

| Rating | Symbol | BUL147 | BUL147F | 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>$I_{CM}$ | 8.0<br>16 | | Adc |
| Base Current — Continuous<br>— Peak(1) | $I_B$<br>$I_{BM}$ | 4.0<br>8.0 | | Adc |
| RMS Isolated Voltage(2) Test No. 1 Per Fig. 22a<br>(for 1 sec, R.H. < 30%, Test No. 2 Per Fig. 22b<br>$T_C$ = 25°C) Test No. 3 Per Fig. 22c | $V_{ISOL}$ | —<br>—<br>— | 4500<br>3500<br>1500 | Volts |
| Total Device Dissipation ($T_C$ = 25°C)<br>Derate above 25°C | $P_D$ | 125<br>1.0 | 45<br>0.36 | Watts<br>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<br>— Junction to Ambient | $R_{\theta JC}$<br>$R_{\theta JA}$ | 1.0<br>62.5 | 2.78<br>62.5 | °C/W |
| Maximum Lead Temperature for Soldering Purposes: 1/8″ from Case for 5 Seconds | $T_L$ | 260 | | °C |

### ELECTRICAL CHARACTERISTICS ($T_C$ = 25°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 ($V_{CE}$ = Rated $V_{CEO}$, $I_B$ = 0) | $I_{CEO}$ | — | — | 100 | μAdc |
| Collector Cutoff Current ($V_{CE}$ = Rated $V_{CES}$, $V_{EB}$ = 0)<br>($T_C$ = 125°C)<br>($V_{CE}$ = 500 V, $V_{EB}$ = 0) ($T_C$ = 125°C) | $I_{CES}$ | —<br>—<br>— | —<br>—<br>— | 100<br>500<br>100 | μAdc |
| Emitter Cutoff Current ($V_{EB}$ = 9.0 Vdc, $I_C$ = 0) | $I_{EBO}$ | — | — | 100 | μAdc |

(1) Pulse Test: Pulse Width = 5.0 ms, Duty Cycle ≤ 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**

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**ELECTRICAL CHARACTERISTICS — continued** ($T_C$ = 25°C unless otherwise noted)

| Characteristic | | | | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|---|
| **ON CHARACTERISTICS** | | | | | | | | |
| Base–Emitter Saturation Voltage | ($I_C$ = 2.0 Adc, $I_B$ = 0.2 Adc) | | | $V_{BE(sat)}$ | — | 0.82 | 1.1 | Vdc |
| | ($I_C$ = 4.5 Adc, $I_B$ = 0.9 Adc) | | | | — | 0.92 | 1.25 | |
| Collector–Emitter Saturation Voltage | | | | $V_{CE(sat)}$ | | | | Vdc |
| ($I_C$ = 2.0 Adc, $I_B$ = 0.2 Adc) | | | | | — | 0.25 | 0.5 | |
| | | | ($T_C$ = 125°C) | | — | 0.3 | 0.5 | |
| ($I_C$ = 4.5 Adc, $I_B$ = 0.9 Adc) | | | | | — | 0.35 | 0.7 | |
| | | | ($T_C$ = 125°C) | | — | 0.35 | 0.8 | |
| DC Current Gain | ($I_C$ = 1.0 Adc, $V_{CE}$ = 5.0 Vdc) | | | $h_{FE}$ | 14 | — | 34 | — |
| | | | ($T_C$ = 125°C) | | — | 30 | — | |
| | ($I_C$ = 4.5 Adc, $V_{CE}$ = 1.0 Vdc) | | | | 8.0 | 12 | — | |
| | | | ($T_C$ = 125°C) | | 7.0 | 11 | — | |
| | ($I_C$ = 2.0 Adc, $V_{CE}$ = 1.0 Vdc) | | ($T_C$ = 25°C to 125°C) | | 10 | 18 | — | |
| | ($I_C$ = 10 mAdc, $V_{CE}$ = 5.0 Vdc) | | | | 10 | 20 | — | |
| **DYNAMIC CHARACTERISTICS** | | | | | | | | |
| Current Gain Bandwidth ($I_C$ = 0.5 Adc, $V_{CE}$ = 10 Vdc, f = 1.0 MHz) | | | | $f_T$ | — | 14 | — | MHz |
| Output Capacitance ($V_{CB}$ = 10 Vdc, $I_E$ = 0, f = 1.0 MHz) | | | | $C_{ob}$ | — | 100 | 175 | pF |
| Input Capacitance ($V_{EB}$ = 8.0 V) | | | | $C_{ib}$ | — | 1750 | 2500 | pF |
| Dynamic Saturation Voltage: Determined 1.0 µs and 3.0 µs respectively after rising $I_{B1}$ reaches 90% of final $I_{B1}$ (see Figure 18) | ($I_C$ = 2.0 Adc $I_{B1}$ = 200 mAdc $V_{CC}$ = 300 V) | 1.0 µs | ($T_C$ = 125°C) | $V_{CE(dsat)}$ | — | 3.0 | — | Volts |
| | | | | | — | 5.5 | — | |
| | | 3.0 µs | ($T_C$ = 125°C) | | — | 0.8 | — | |
| | | | | | — | 1.4 | — | |
| | ($I_C$ = 5.0 Adc $I_{B1}$ = 0.9 Adc $V_{CC}$ = 300 V) | 1.0 µs | ($T_C$ = 125°C) | | — | 3.3 | — | |
| | | | | | — | 8.5 | — | |
| | | 3.0 µs | ($T_C$ = 125°C) | | — | 0.4 | — | |
| | | | | | — | 1.0 | — | |
| **SWITCHING CHARACTERISTICS: Resistive Load** (D.C. ≤ 10%, Pulse Width = 20 µs) | | | | | | | | |
| Turn–On Time | ($I_C$ = 2.0 Adc, $I_{B1}$ = 0.2 Adc $I_{B2}$ = 1.0 Adc, $V_{CC}$ = 300 V) | | ($T_C$ = 125°C) | $t_{on}$ | — | 200 | 350 | ns |
| | | | | | — | 190 | — | |
| Turn–Off Time | | | | $t_{off}$ | — | 1.0 | 2.5 | µs |
| | | | ($T_C$ = 125°C) | | — | 1.6 | — | |
| Turn–On Time | ($I_C$ = 4.5 Adc, $I_{B1}$ = 0.9 Adc $I_{B1}$ = 2.25 Adc, $V_{CC}$ = 300 V) | | ($T_C$ = 125°C) | $t_{on}$ | — | 85 | 150 | ns |
| | | | | | — | 100 | — | |
| Turn–Off Time | | | | $t_{off}$ | — | 1.5 | 2.5 | µs |
| | | | ($T_C$ = 125°C) | | — | 2.0 | — | |
| **SWITCHING CHARACTERISTICS: Inductive Load** ($V_{clamp}$ = 300 V, $V_{CC}$ = 15 V, L = 200 µH) | | | | | | | | |
| Fall Time | ($I_C$ = 2.0 Adc, $I_{B1}$ = 0.2 Adc $I_{B2}$ = 1.0 Adc) | | ($T_C$ = 125°C) | $t_{fi}$ | — | 100 | 180 | ns |
| | | | | | — | 120 | — | |
| Storage Time | | | | $t_{si}$ | — | 1.3 | 2.5 | µs |
| | | | ($T_C$ = 125°C) | | — | 1.9 | — | |
| Crossover Time | | | | $t_c$ | — | 210 | 350 | ns |
| | | | ($T_C$ = 125°C) | | — | 230 | — | |
| Fall Time | ($I_C$ = 4.5 Adc, $I_{B1}$ = 0.9 Adc $I_{B2}$ = 2.25 Adc) | | ($T_C$ = 125°C) | $t_{fi}$ | — | 80 | 150 | ns |
| | | | | | — | 100 | — | |
| Storage Time | | | | $t_{si}$ | — | 1.6 | 3.2 | µs |
| | | | ($T_C$ = 125°C) | | — | 2.1 | — | |
| Crossover Time | | | | $t_c$ | — | 170 | 300 | ns |
| | | | ($T_C$ = 125°C) | | — | 200 | — | |
| Fall Time | ($I_C$ = 4.5 Adc, $I_{B1}$ = 0.9 Adc $I_{B2}$ = 0.9 Adc) | | ($T_C$ = 125°C) | $t_{fi}$ | 60 | — | 180 | ns |
| | | | | | — | 150 | — | |
| Storage Time | | | | $t_{si}$ | 2.6 | — | 3.8 | µs |
| | | | ($T_C$ = 125°C) | | — | 4.3 | — | |
| Crossover Time | | | | $t_c$ | — | 200 | 350 | ns |
| | | | ($T_C$ = 125°C) | | — | 330 | — | |

## TYPICAL STATIC CHARACTERISTICS

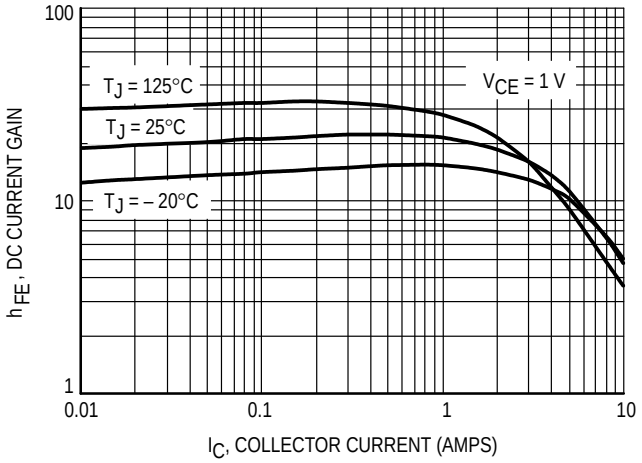



**Figure 1. DC Current Gain @ 1 Volt**

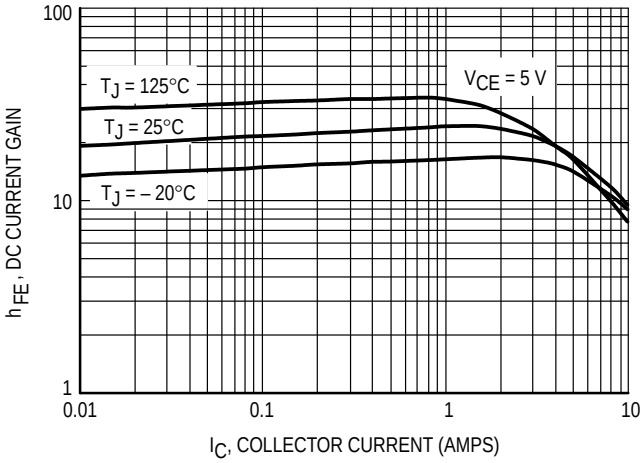



**Figure 2. DC Current Gain @ 5 Volts**

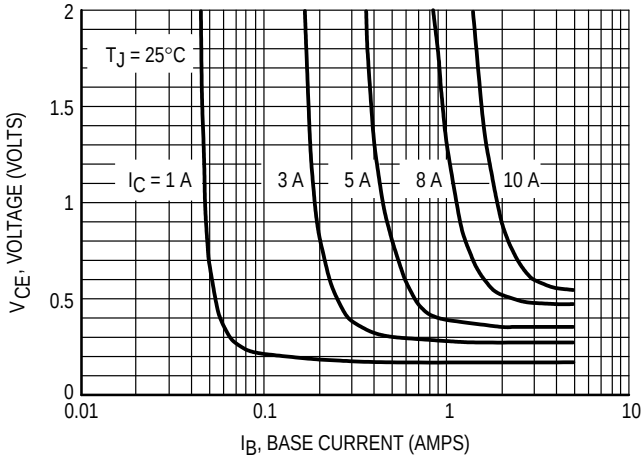



**Figure 3. Collector Saturation Region**

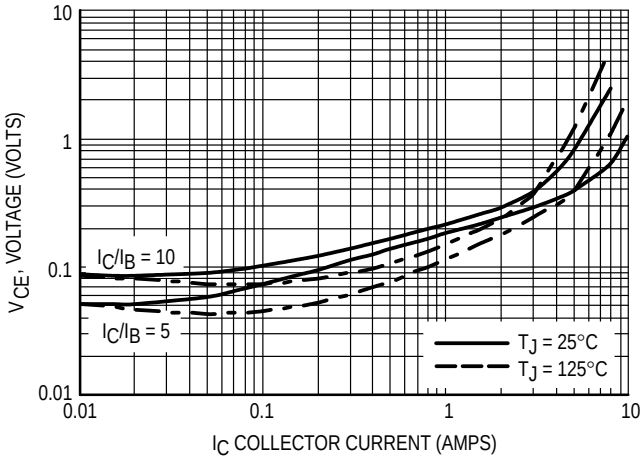



**Figure 4. Collector–Emitter Saturation Voltage**

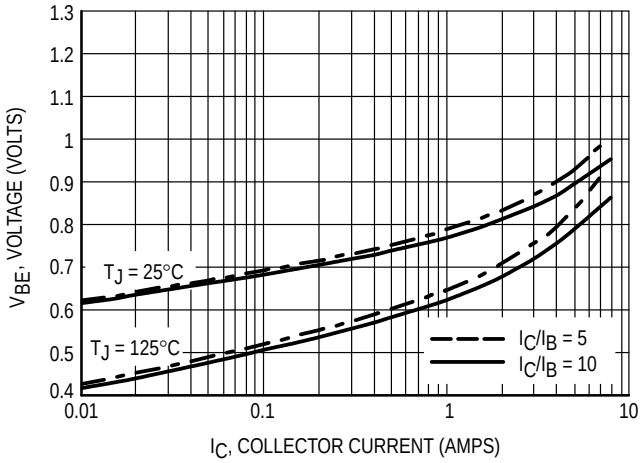



**Figure 5. Base–Emitter Saturation Region**

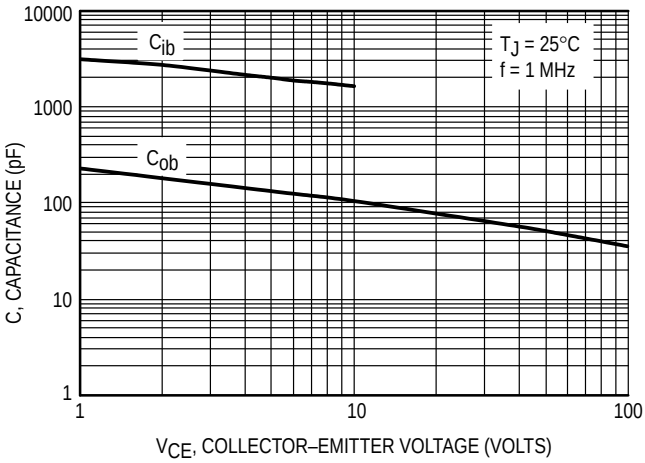



**Figure 6. Capacitance**

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

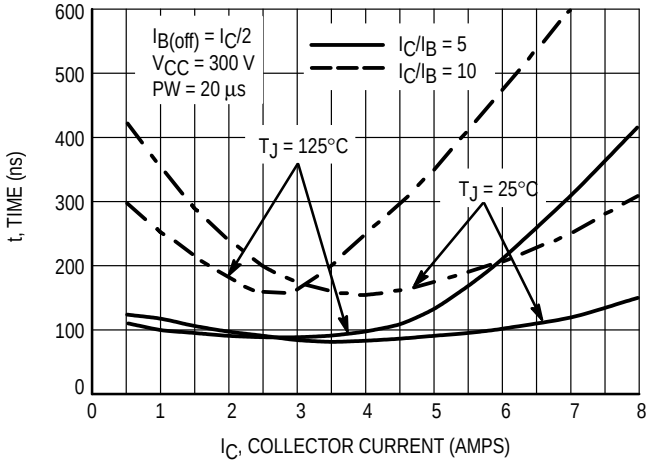



**Figure 7. Resistive Switching, $t_{on}$**

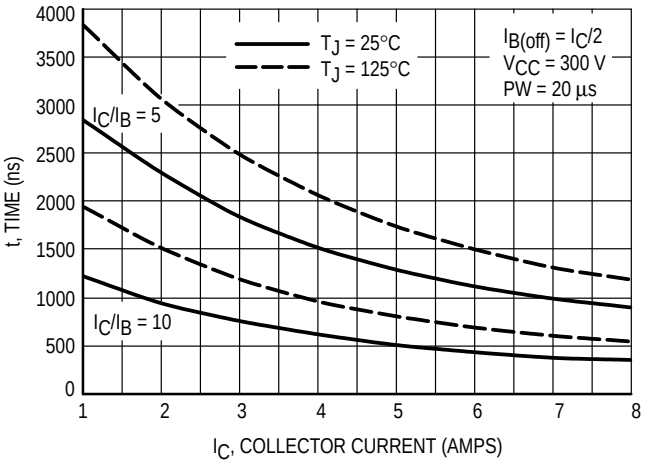



**Figure 8. Resistive Switching, $t_{off}$**

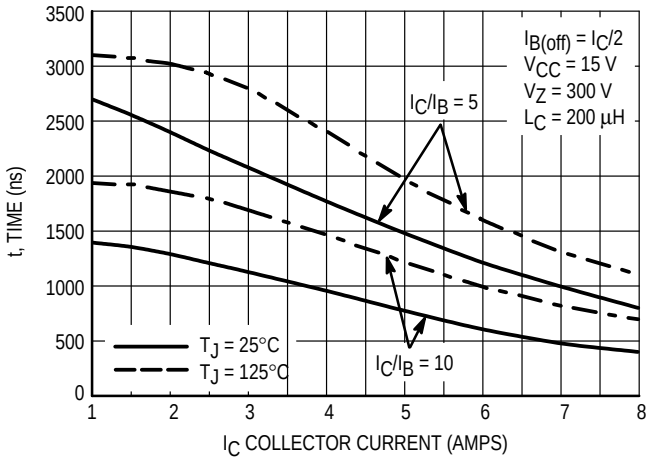



**Figure 9. Inductive Storage Time, $t_{si}$**

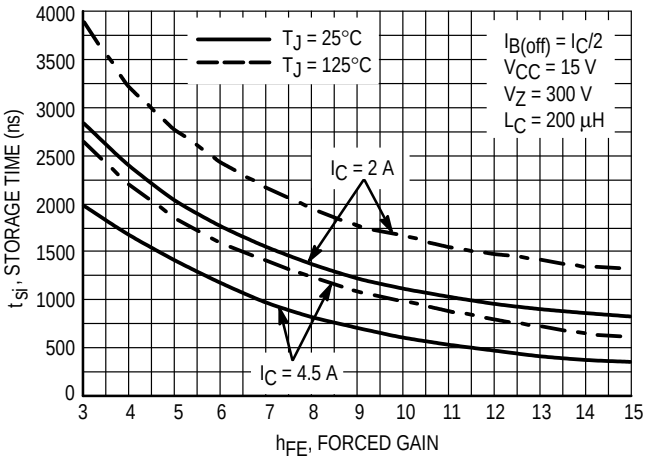



**Figure 10. Inductive Storage Time, $t_{si}(h_{FE})$**

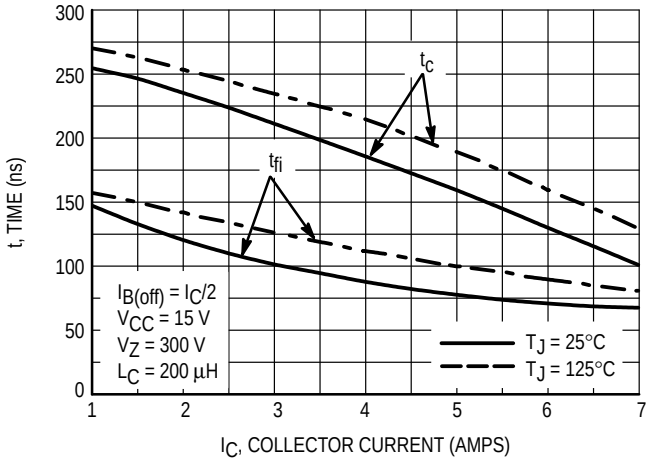



**Figure 11. Inductive Switching, $t_c$ and $t_{fi}$**
**$I_C/I_B = 5$**

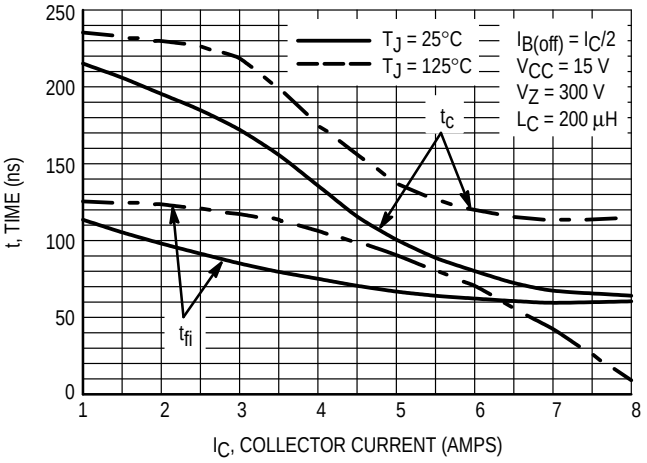



**Figure 12. Inductive Switching, $t_c$ and $t_{fi}$**
**$I_C/I_B = 10$**

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

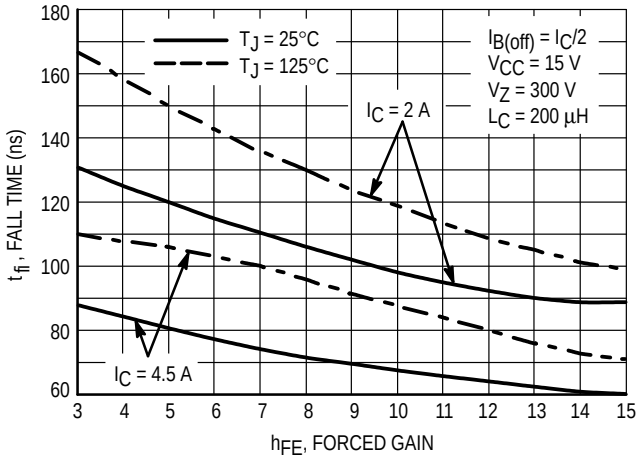



**Figure 13. Inductive Fall Time**

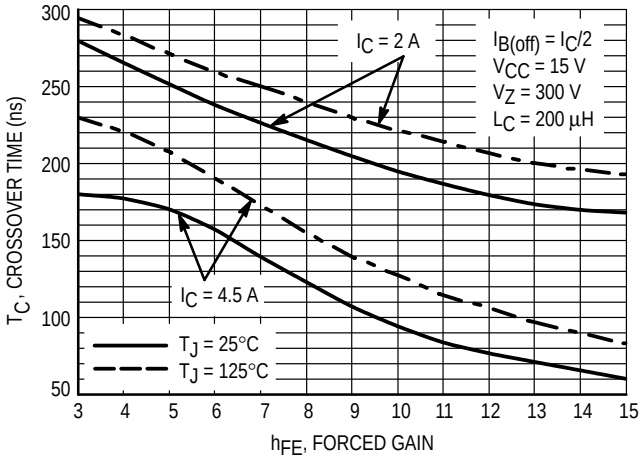



**Figure 14. Inductive Crossover Time**

## GUARANTEED SAFE OPERATING AREA INFORMATION

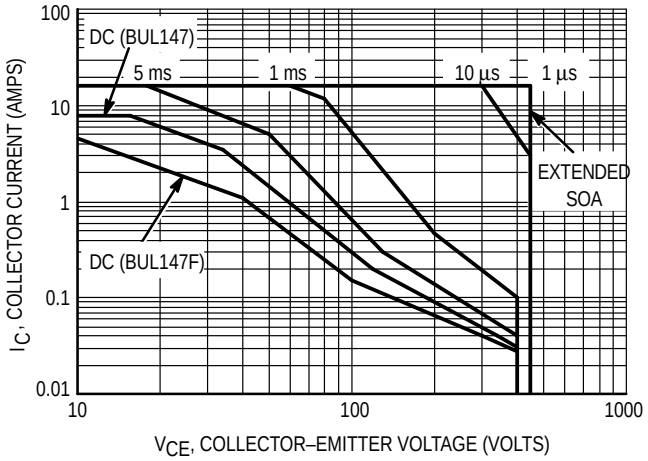



**Figure 15. Forward Bias Safe Operating Area**

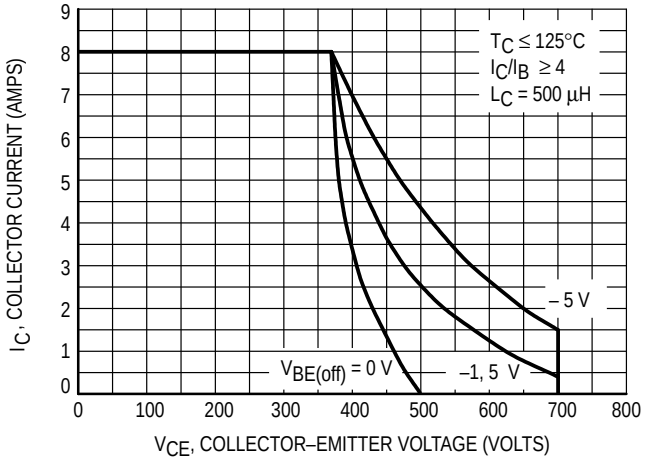



**Figure 16. Reverse Bias Switching Safe Operating Area**

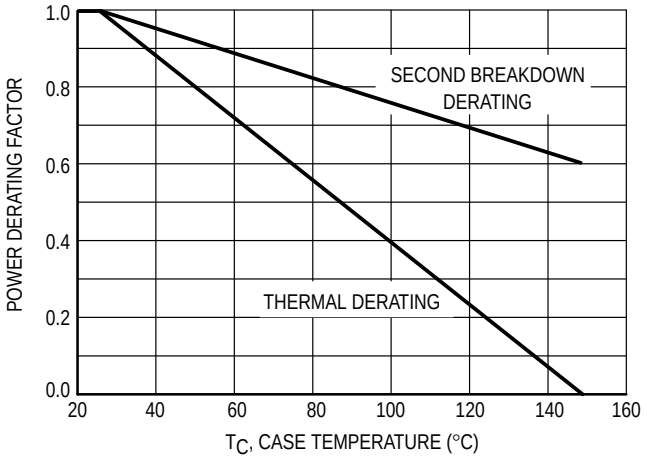



**Figure 17. Forward Bias Power Derating**

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°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°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 Figure 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.

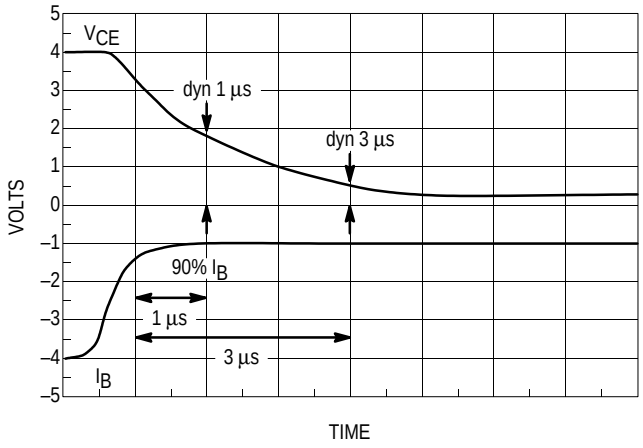



**Figure 18. Dynamic Saturation Voltage Measurements**

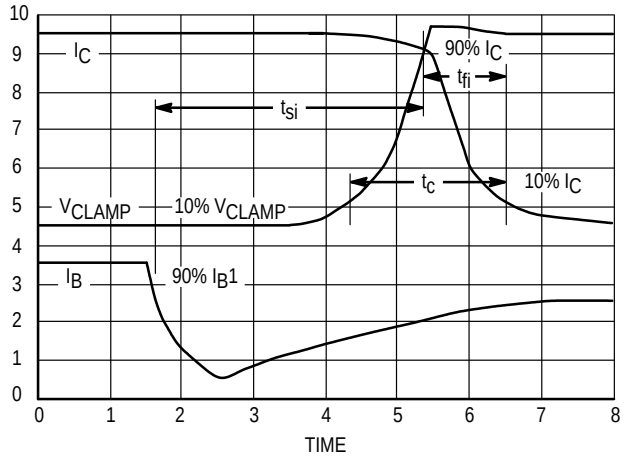
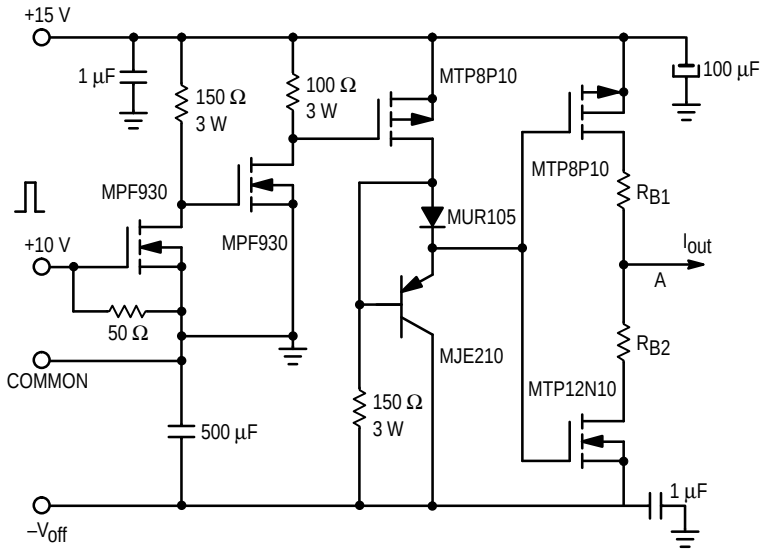
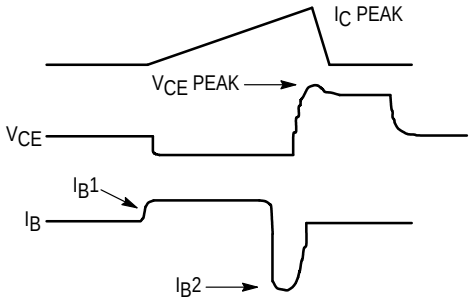



**Figure 19. Inductive Switching Measurements**




| V(BR)CEO(sus) | INDUCTIVE SWITCHING | RBSOA |
|---|---|---|
| L = 10 mH | L = 200 µH | L = 500 µH |
| RB2 = ∞ | RB2 = 0 | RB2 = 0 |
| $V_{CC}$ = 20 VOLTS | $V_{CC}$ = 15 VOLTS | $V_{CC}$ = 15 VOLTS |
| $I_C$(pk) = 100 mA | RB1 SELECTED FOR DESIRED $I_B1$ | RB1 SELECTED FOR DESIRED $I_B1$ |

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

## TYPICAL THERMAL RESPONSE

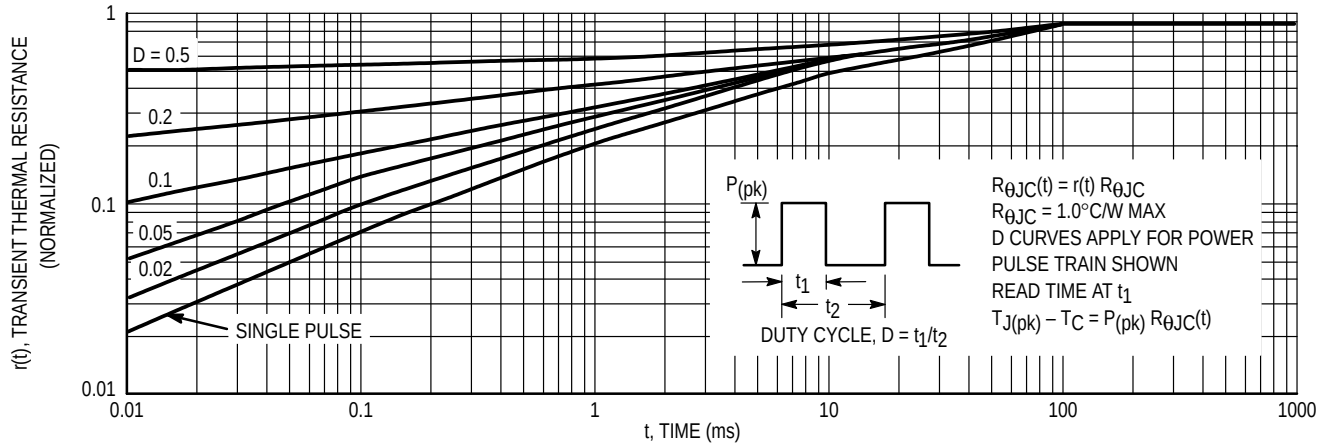



**Figure 20. Typical Thermal Response ($Z_{\theta JC}(t)$) for BUL147**

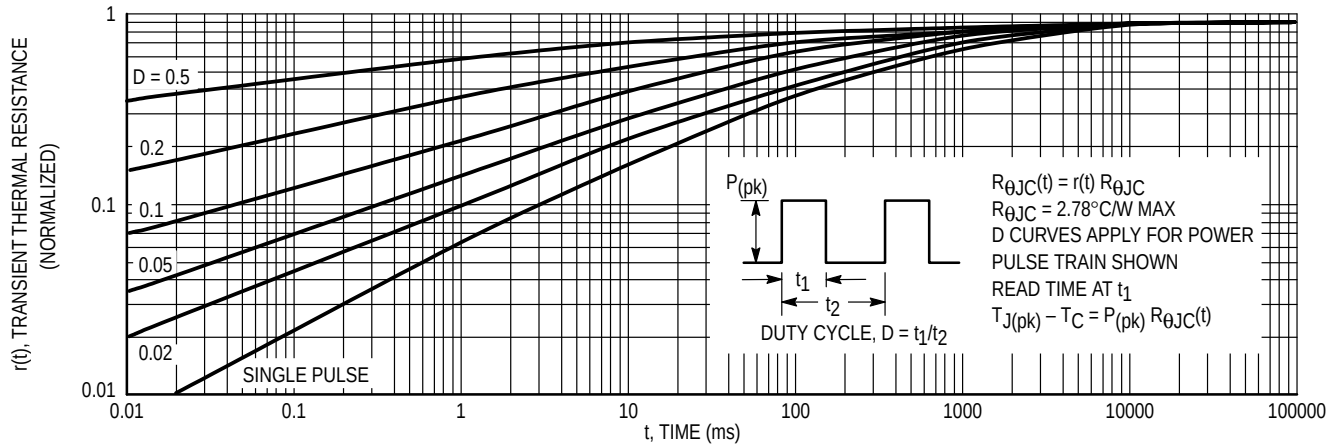



**Figure 21. Typical Thermal Response ($Z_{\theta JC}(t)$) for BUL147F**

## TEST CONDITIONS FOR ISOLATION TESTS*

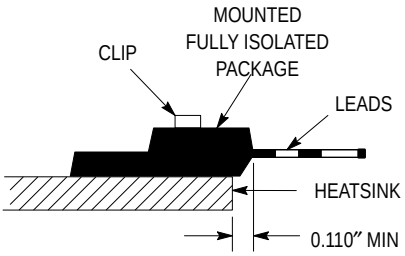



**Figure 22a. Screw or Clip Mounting Position for Isolation Test Number 1**

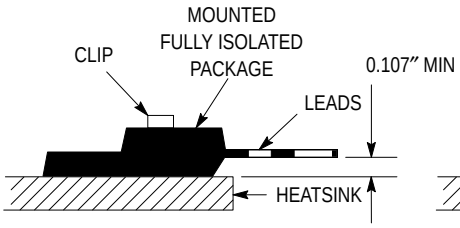



**Figure 22b. Clip Mounting Position for Isolation Test Number 2**

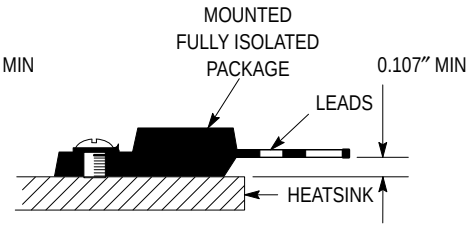



**Figure 22c. Screw Mounting Position for Isolation Test Number 3**

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

## MOUNTING INFORMATION**

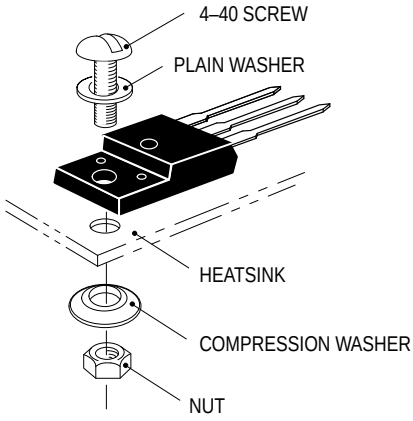



**Figure 23a. Screw–Mounted**

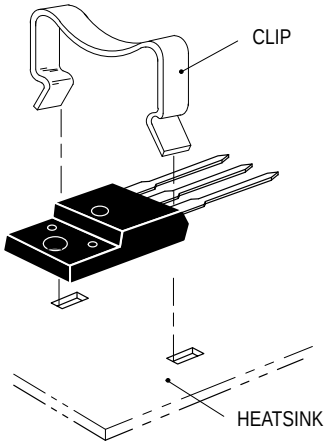



**Figure 23b. Clip–Mounted**

**Figure 23. Typical Mounting Techniques for Isolated Package**

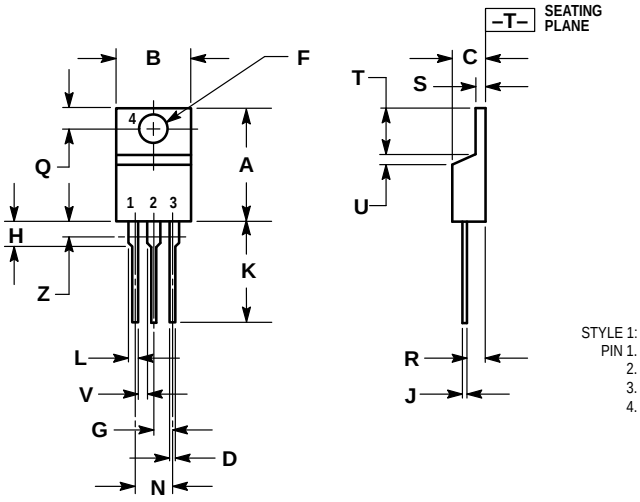
Laboratory tests on a limited number of samples indicate, when using the screw and compression washer mounting technique, a screw torque of 6 to 8 in · lbs is sufficient to provide maximum power dissipation capability. The compression washer helps to maintain a constant pressure on the package over time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

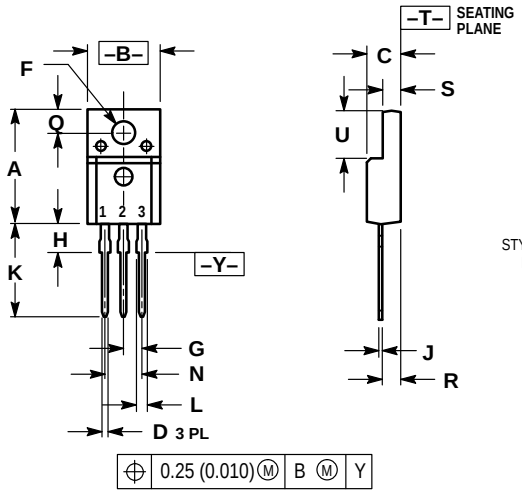



STYLE 1:
PIN 1. BASE
2. COLLECTOR
3. EMITTER
4. COLLECTOR

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.

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | 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**




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

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

| | INCHES | | MILLIMETERS | |
|---|---|---|---|---|
| DIM | 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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