ALPHANUMERIC INDEX — CROSS-REFERENCE (Continued)

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BUS12A	BUX47A		3-499
BUS13	BUX48		3-506
BUS13A	BUX48A		3-506
BUS14	BUX98		—
BUS14A	BUX98A		—
BUS46P		MJE16002	3-976
BUS47	BUX47		3-499
BUS47A	BUX47A		3-499
BUS47AP	BUV47A		3-462
BUS47P	BUV47		3-462
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BUS48A	BUX48A		3-506
BUS48AP	BUV48A		3-469
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BUS50	BUS50		3-382
BUS51	BUS51		3-384
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BUS97	MJ16010		3-758
BUS97A	MJ16010A		3-766
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BUV18		BUS50	3-382
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Industry Part Number	Motorola Direct Replacement	Motorola Similar Replacement	Page Number
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BUW13A	BUV48A		3-469
BUW24	BU326A		3-363
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BUW26	BUS326A		—
BUW34	BUX47		3-499
BUW35	BUX47		3-499
BUW36	BUX47A		3-499
BUW44	BUX48		3-506
BUW45	BUX48		3-506
BUW46	BUX48A		3-506
BUW72		MJE13008	3-950
BUW74	BUX47		3-499
BUW75	BUX47		3-499
BUW76	BUX47		3-499
BUW77	BUX47		3-499
BUW81	MJ10014		3-600
BUW81A	MJ10014		3-600
BUW84	MJE13003		3-938
BUW85	MJE13003		3-938
BUX13	BUX13		3-484
BUX14	BUX14		—
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BUX14CECCL	BUX14		—
BUX15	BUX47A		3-499
BUX15CECCF	BUX47A		3-499
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BUX43		BUX13	3-484
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BUX47A	BUX47A		3-499
BUX48	BUX48		3-506
BUX48A	BUX48A		3-506
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BUX66A	2N6212		3-161
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BUX67	2N3584		3-20
BUX67A	2N3584		3-20
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BUX67C	2N4240		3-20
BUX81		MJ13335	3-700

*Consult Motorola if a direct replacement is necessary.

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TABLE 1 — METAL TO-204, TO-204AE (continued)

I_C Cont Amps Max	$V_{CEO(sus)}$ Volts Min	Device Type NPN	Device Type PNP	h_{FE} Min/Max	@ I_C Amp	Resistive Switching t_s μs Max	Resistive Switching t_f μs Max	Resistive Switching @ I_C Amp	f_T MHz Min	P_D (Case) Watts @ 25°C
10	250	MJ15011	MJ15012	20/100	2					200
	300	MJ3041##		250 min	2.5					175
	325	MJ413		20/80	0.5				2.5	125
		MJ423		30/90	1				2.5	125
		MJ431		15/35	2.5				2.5	125
	350	BU323##		150 min	6	7.5 typ	5.2 typ	6		175
		MJ3042##		250 min	2.5					175
		MJ13014		8/20	5	2	0.5	5		150
		MJ10002##		3/300	5	2.5	1	5	10#	150
		MJ10006##		30/300	5	1.5	0.5	5	10#	150
	400	BU323A##		150 min	6	7.5 typ	5.2 typ	6		175
		MJ10007##		30/300	5	1.5	0.5	5	10#	150
		MJ10012##		100/2k	6	15	15	6		175
		MJ13015		8/20	5	2	0.5	5		150
	600	MJ10014##		10/250	10	2.5	0.8	10		175
	700	MJ8504		7.5 min	1.5	4	2	5		175
	800	MJ8505		7.5 min	1.5	4	2	5		175
		MJ16018		4 min	5	4.5 typ	0.2 typ	5		150
	950*	MJ12010		4.2 min	5		1	5		100
12	60	2N6057##	2N6050##	750/18k	6	1.6 typ	1.5 typ	6	4#	150
	80	2N6058##	2N6051##	750/18k	6	1.6 typ	1.5 typ	6	4#	150
	100	2N6059##	2N6052##	750/18k	6	1.6 typ	1.5 typ	6	4#	150
15	60	2N3055	MJ2955	20/70	4	0.7 typ	0.3 typ	4	2.5	115
		2N3055A	MJ2955A	20/70	4				0.8	115
		2N6576##		2k/20k	4	2	7	10	10–200#	120
		2N5881	2N5879	20/100	6	1	0.8	6	4	160
	80	2N5882	2N5880	20/100	6	1	0.8	6	4	160
	90	2N6577##		2k/20k	4	2	7	10	10-200#	120
	120	MJ15015	MJ15016	20/70	4				1	180
		2N6578##		2k/20k	4	2	7	10	10-200#	120
	140	MJ15001	MJ15002	25/150	4				2	200
	150	MJ11018##	MJ11017##	100 min	15				3#	175
	200	BUX41		8 min	8	1.5	0.4	8	8	120
		2N6249		10/50	10	3.5	1	10	2.5	175
		MJ11020##	MJ11019##	100 min	15				3#	175
	250	MJ11022##	MJ11021##	100 min	15				3#	175
	275	2N6250		8/50	10	3.5	1	10	2.5	175
	300	2N6546		6/30	10	4	0.7	10	6 to 24	175
	325	BUX13		8 min	8	2.5	0.8	8	8	150
	400	BUX48		8 min	10	2	0.4	10		175
		2N6547		6/30	10	4	0.7	10	6 to 24	175
		MJ13090		8 min	10	2.5	0.5	10		175
		MJ16110		6/20	15	0.8 typ	0.1 typ	10		175
	450	BUX48A		8 min	8	2	0.4	10		175
		MJ16010		5 min	15	1.2 typ	0.2 typ	10		175

* $V_{(BR)CEX}$, # $|h_{fe}|$ @ 1 MHz, ## Darlington

(continued)

JAN, JTX, JTXV Available

TABLE 14 — SWITCHMODE POWER TRANSISTORS (continued)

$V_{CEO(sus)}$ Volts Min	I_CCont Amps Max	V_{CEV} Volts Min	Device Type NPN unless otherwise noted	h_{FE} Min/Max	@ I_C Amp	Resistive Switching t_s μs Max	t_f μs Max	@ I_C Amp	f_T MHz Min	P_D (Case) Watts @ 25°C	Case JEDEC/MOT
450	15	1000	BUV48A	8 min	8	2	0.4	10		150	TO-218/340D
	9	1000	BUS47A	7 min	5	2	0.4	5		150	TO-204/1
		1000	BUS47AP	7 min	6	2	0.4	6		128	TO-218/340D
	8	850	2N6835★	7.5/3	5	2.5	0.25	5	10		TO-204/1
		850	MJE16080	5 min	8	2	0.5	5		80	TO-220/221A
		850	MJ12021★	5 min	8		0.1 typ	8			TO-204/1
		850	MJ16006★	5 min	8	2.5	0.25	5			TO-204/1
		850	MJ16008★	7 min	8	2.2	0.25	5			TO-204/1
		850	MJH16006★	5 min	8	2.5	0.25	5			TO-218/340
		850	MJH16008★	7 min	8	2.2	0.25	5			TO-218/340
		1000	BUW12A	6 min	5	4	0.8	5		125	TO-218/340
	5	850	2N6834★	10/30	3	2.7	0.35	3			TO-204/1
		850	MJ12020★	5 min	5		0.13 typ	3			TO-204/1
		850	MJ16002★	5 min	5	3	0.3	3	15		TO-204/1
		850	MJ16004★	8 min	3	2.7	0.35	3			TO-204/1
		850	MJE16002★	5 min	5	3	0.3	3			TO-220/221A
		850	MJE16004★	7 min	5	2.7	0.35	3			TO-220/221A
		850	MJH16002★	5 min	5	3	0.3	3			TO-218/340
		850	MJH16004★	7 min	5	2.7	0.35	3			TO-218/340
		1000	BUW11A	6 min	2.5	4	0.8	2.5		125	TO-218/340
	3	1000	BUX85	30 min	0.1	3.5	1.4	1	4	50	TO-220/221A
400	56	600	BUT33##	20 min	36	3.3	1.6	36		250	TO-204/197
	50	650	MJ10015##★	10 min	40	2.5	1	20			TO-204/197
	40	600	MJ10023##★	50/600	10	2.5	0.9	20			TO-204/197
	30	850	BUS98	8 min	20	2.3	0.4	20		250	TO-204/197
	28	600	BUT13##	20 min	20	2.6	0.8	18		175	TO-204/1
	20	500	MJ10001#★	40/400	10	3	1.8	10	10**		TO-204/1
		500	MJ10005#★	40/400	10	1.5	0.5	10	10**		TO-204/1
		500	MJ13333★	10/60	5	4	0.7	10			TO-204/1
	15	650	MJ13090★	8 min	10	2.5	0.5	10			TO-204/1
		650	MJ16110	6/20	15	0.8 typ	0.1 typ	10		175	TO-204/1
		650	MJH16110	6/20	15	0.8 typ	0.1 typ	10		135	TO-218/340
		850	2N6547★	6/30	10	4	0.7	10	6 to 24		TO-204/1
		850	BUX48	8 min	10	2	0.4	10		175	TO-204/1
		850	BUV48	8 min	10	2	0.4	10		150	TO-218/340D
	12	700	MJE13009★	6/30	8	3	0.7	8	4**		TO-220/221A
	10	950	MJ12010	4.2 min	5		1	5	6 typ		TO-204/1
		550	MJ10012#	100/2k	6	6	15	15	6		TO-204/1
		500	MJ10003#★	30/300	5	2.5	1	5	10**		TO-204/1
		500	MJ10007##★	30/300	5	1.1	0.25	5	10**		TO-204/1
		450	MJ13015★	8/20	5	2	0.5	5			TO-204/1
	9	850	BUS47	7 min	6	2	0.4	6		150	TO-204/1
		850	BUS47P	7 min	5	2	0.4	6		128	TO-218/340D

★ Designers Data Sheet characterization
Darlington ## Darlington with speed-up diode * t_{off} ** $|h_{fe}|$ @ 1 MHz

(continued)

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MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

BUX48
BUX48A

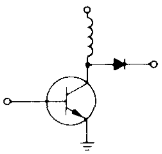
SWITCHMODE II SERIES
NPN SILICON POWER TRANSISTORS

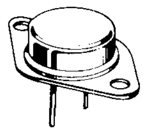
15 AMPERES
NPN SILICON
POWER TRANSISTORS
400 AND 450 VOLTS
V(BR)CEO
850 – 1000 VOLTS
V(BR)CEX
175 WATTS

The BUX 48/BUX 48A transistors are designed for high-voltage, high-speed, power switching in inductive circuits where fall time is critical. They are particularly suited for line-operated switchmode applications such as:

- Switching Regulators
- Inverters
- Solenoid and Relay Drivers
- Motor Controls
- Deflection Circuits

Fast Turn-Off Times
 60 ns Inductive Fall Time — 25°C (Typ)
 120 ns Inductive Crossover Time — 25°C (Typ)
Operating Temperature Range -65 to +200°C
100°C Performance Specified for:
 Reverse-Biased SOA with Inductive Loads
 Switching Times with Inductive Loads
 Saturation Voltage
 Leakage Currents (125°C)





CASE 1-06
TO-204AA
(TO-3)

MAXIMUM RATINGS

Rating	Symbol	BUX48	BUX48A	Unit
Collector-Emitter Voltage	$V_{CEO(sus)}$	400	450	Vdc
Collector-Emitter Voltage (V_{BE} = -1.5V)	V_{CEX}	850	1000	Vdc
Emitter Base Voltage	V_{EB}	7		Vdc
Collector Current — Continuous — Peak (1) — Overload	I_C I_{CM} I_{OI}	15 30 60		Adc
Base Current — Continuous — Peak (1)	I_B I_{BM}	5 20		Adc
Total Power Dissipation — T_C = 25°C — T_C = 100°C Derate above 25°C	P_D	175 100 1		Watts W/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +200		°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1	°C/W
Maximum Lead Temperature for Soldering Purposes: 1/8″ from Case for 5 Seconds	T_L	275	°C

(1) Pulse Test: Pulse Width ≤ 5 ms, Duty Cycle ≤ 10%.

Switchmode is a trademark of Motorola Inc.

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS (1)					
Collector-Emitter Sustaining Voltage (Table 1) (I_C = 200 mA, I_B = 0) L = 25 mH — BUX 48	$V_{CEO(sus)}$	400	—	—	Vdc
BUX 48A		450	—	—	
Collector Cutoff Current (V_{CEX} = Rated Value, $V_{BE(off)}$ = 1.5Vdc)	I_{CEX}	—	—	0.2	mAdc
(V_{CEX} = Rated Value, $V_{BE(off)}$ = 1.5Vdc, T_C = 125°C)		—	—	2	
Collector Cutoff Current (V_{CE} = Rated V_{CEX}, R_{BE} = 10 Ω) T_C = 25°C	I_{CER}	—	—	0.5	mAdc
T_C = 125°C		—	—	3	
Emitter Cutoff Current (V_{EB} = 5 Vdc, I_C = 0)	I_{EBO}	—	—	0.1	mAdc
Emitter-Base Breakdown Voltage (I_E = 50 mA I_C = 0)	$V_{(BR)EBO}$	7	—	—	Vdc
SECOND BREAKDOWN					
Second Breakdown Collector Current with Base Forward Biased	$I_{S/b}$	See Figure 12			
Clamped Inductive SOA with Base Reverse Biased	RBSOA	See Figure 13			
ON CHARACTERISTICS (1)					
DC Current Gain (I_C = 10 Adc, V_{CE} = 5 Vdc) BUX48	h_{FE}	8	—	—	
(I_C = 8 Adc, V_{CE} = 5 Vdc) BUX48A		8	—	—	
Collector-Emitter Saturation Voltage (I_C = 10 Adc, I_B = 2 Adc) BUX48	$V_{CE(sat)}$	—	—	1.5	Vdc
(I_C = 15 Adc, I_B = 3 Adc) BUX48		—	—	5	
(I_C = 10 Adc, I_B = 2 Adc, T_C = 100°C) BUX48		—	—	2	
(I_C = 8 Adc, I_B = 1.6 Adc) BUX48A		—	—	1.5	
(I_C = 12 Adc, I_B = 2.4 Adc) BUX48A		—	—	5	
(I_C = 8 Adc, I_B = 1.6 Adc, T_C = 100°C) BUX48A		—	—	2	
Base-Emitter Saturation Voltage (I_C = 10 Adc, I_B = 2 Adc) BUX48	$V_{BE(sat)}$	—	—	1.6	Vdc
(I_C = 10 Adc, I_B = 2 Adc, T_C = 100°C) BUX48		—	—	1.6	
(I_C = 8 Adc, I_B = 1.6 Adc) BUX48A		—	—	1.6	
(I_C = 8 Adc, I_B = 1.6 Adc, T_C = 100°C) BUX48A		—	—	1.6	
DYNAMIC CHARACTERISTICS					
Output Capacitance (V_{CB} = 10 Vdc, I_E = 0, f_{test} = 1 MHz)	C_{ob}	—	—	350	pF

SWITCHING CHARACTERISTICS

Resistive Load (Table 1)

Characteristic	Conditions	Symbol	Min	Typ	Max	Unit
Delay Time	I_C = 10A, I_{B1} = 2A BUX48	t_d	—	0.1	0.2	μs
Rise Time	I_C = 8A, I_{B1} = 1.6A BUX48A	t_r	—	0.4	0.7	
Storage Time	Duty Cycle ≤ 2%, $V_{BE(off)}$ = 5V	t_s	—	1.3	2	
Fall Time	T_p = 30μs, V_{CC} = 300V,	t_f	—	0.2	0.4	

Inductive Load, Clamped (Table 1)

Characteristic	Conditions		Symbol	Min	Typ	Max	Unit
Storage Time	I_C = 10A, I_{B1} = 2A **BUX 48**	(T_C = 25°C)	t_{sv}	—	1.3	—	μs
Fall Time			t_{fi}	—	0.06	—	
Storage Time	I_C = 8A, I_{B1} = 1.6A **BUX48A**	(T_C = 100°C)	t_{sv}	—	1.5	2.5	
Crossover Time			t_c	—	0.3	0.6	
Fall Time			t_{fi}	—	0.17	0.35	

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

Vcl = 300 V, $V_{BE(off)}$ = 5V, Lc = 180μH

DC CHARACTERISTICS

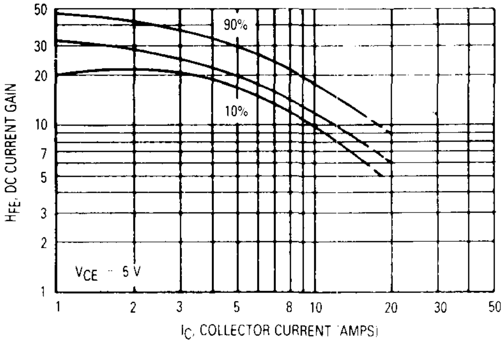


Figure 1. DC Current Gain

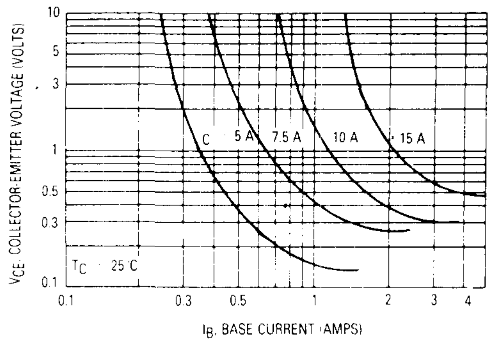


Figure 2. Collector Saturation Region

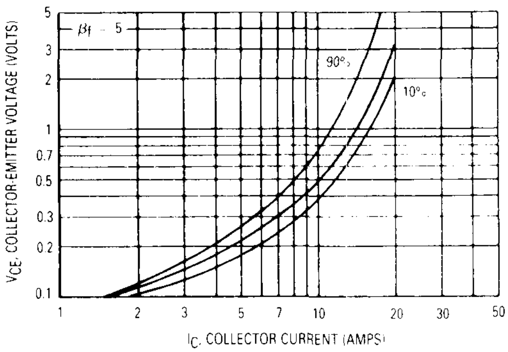


Figure 3. Collector-Emitter Saturation Voltage

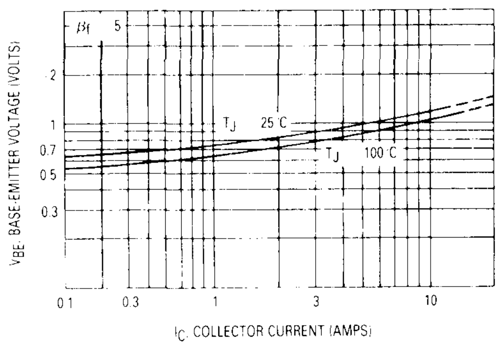


Figure 4. Base-Emitter Voltage

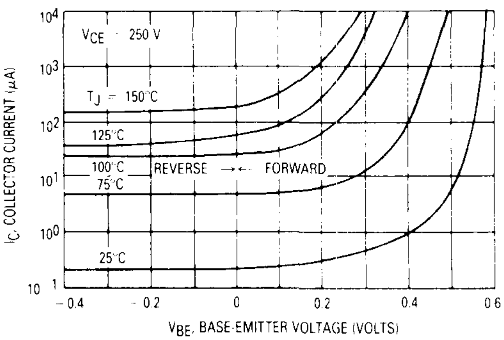


Figure 5. Collector Cutoff Region

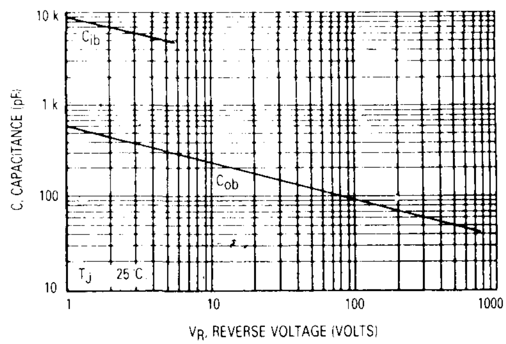
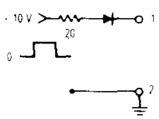
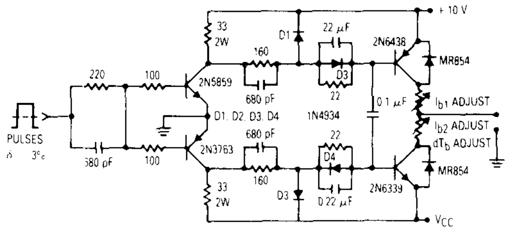
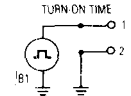
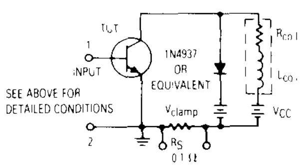
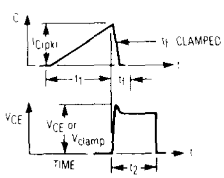
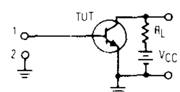


Figure 6. Capacitance

Table 1. Test Conditions for Dynamic Performance

	$V_{CEO(sus)}$	RBSOA and Inductive Switching	Resistive Switching
Input Conditions	 PW Varied to Attain I_C = 200 mA		 I_{B1} ADJUSTED TO OBTAIN THE FORCED h_{FE} DESIRED TURN-OFF TIME USE INDUCTIVE SWITCHING DRIVER AS THE INPUT TO THE RESISTIVE TEST CIRCUIT
Circuit Values	L_{coil} 25mH V_{CC} = 10 V R_{coil} 0.7 Ω	L_{coil} 180 μH R_{coil} 0.05 Ω V_{CC} 20 V V_{clamp} = 300 V R_B ADJUSTED TO ATTAIN DESIRED I_{B1}	V_{CC} = 300 V R_L 83 Ω PULSE WIDTH 10 μs
Test Circuits	**Inductive Test Circuit** 	**Output Waveforms**  t_1 ADJUSTED TO OBTAIN I_C $t_1 \approx \frac{L_{coil}(I_{Cpk})}{V_{CC}}$ $t_2 \approx \frac{L_{coil}(I_{Cpk})}{V_{Clamp}}$ TEST EQUIPMENT SCOPE — TEKTRONIX 475 OR EQUIVALENT	**Resistive Test Circuit** 

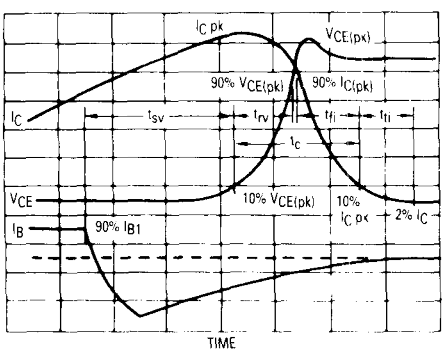


Figure 7. Inductive Switching Measurements

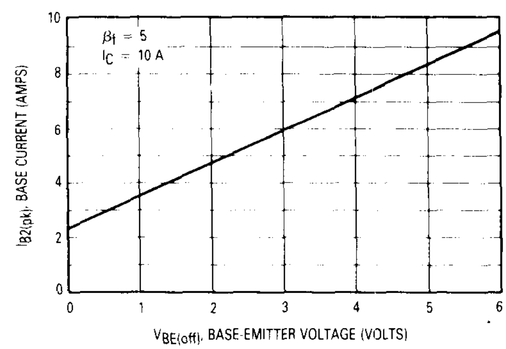


Figure 8. Peak-Reverse Current

3

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, $t_{rv} + t_{fi} \simeq t_c$. 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.

INDUCTIVE SWITCHING

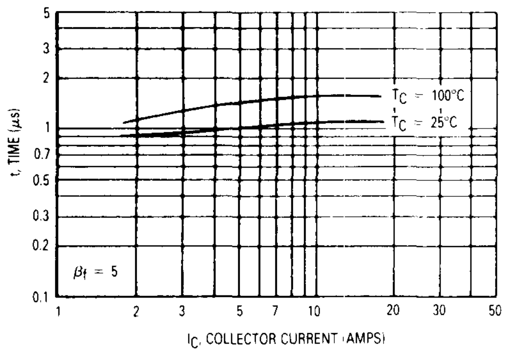


Figure 9. Storage Time, t_{sv}

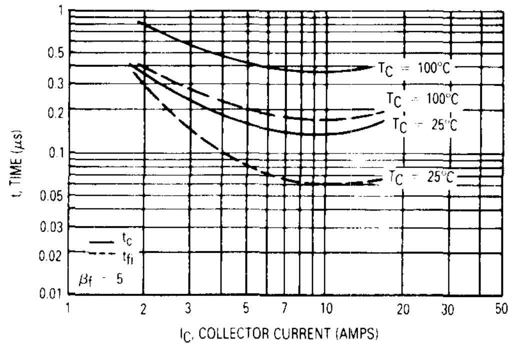


Figure 10. Crossover and Fall Times

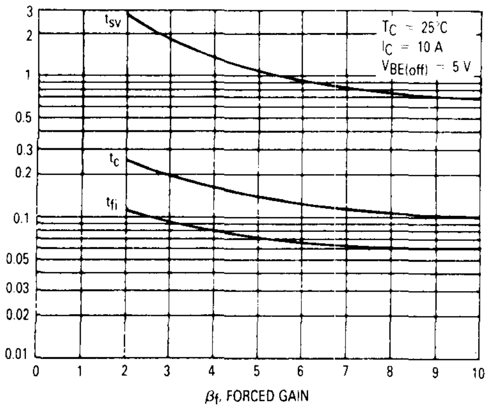


Figure 11a. Turn-Off Times versus Forced Gain

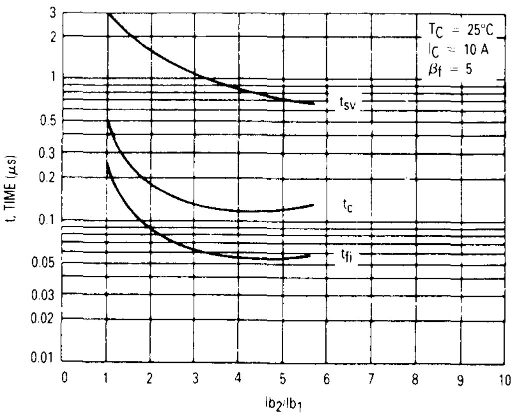


Figure 11b. Turn-Off Times versus I_{b2}/I_{b1}

The Safe Operating Area figures shown in Figures 12 and 13 are specified for these devices under the test conditions shown.

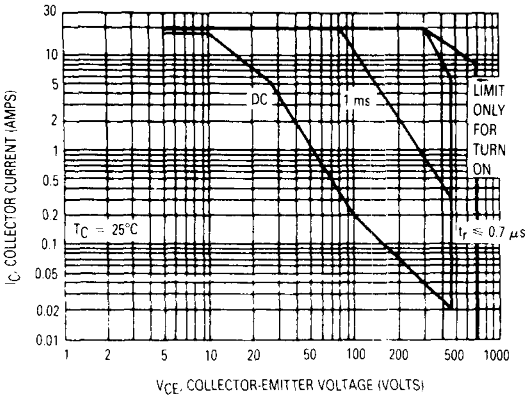


Figure 12. Forward Bias Safe Operating Area

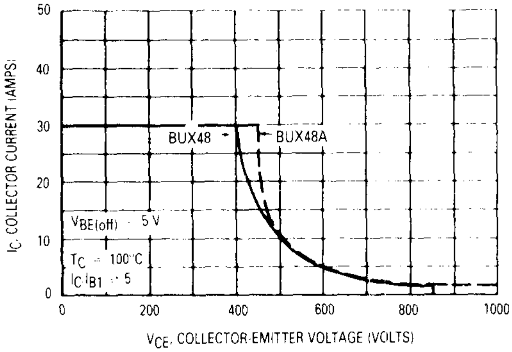


Figure 13. Reverse Bias Safe Operating Area

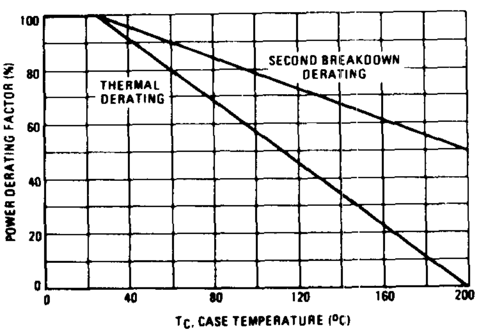


FIGURE 14 — POWER DERATING

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.

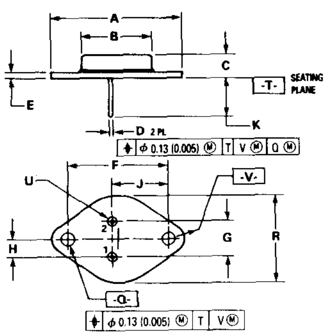
The data of Figure 12 is based on $T_C = 25°C$; $T_{J(pk)}$ is variable depending on power level. Second breakdown pulse limits are valid for duty cycles to 10% but must be derated when $T_C \geq 25°C$. Second breakdown limitations do not derate the same as thermal limitations. Allowable current at the voltages shown on Figure 12 may be found at any case temperature by using the appropriate curve on Figure 14.

$T_{J(pk)}$ may be calculated from the data in Figure 11. 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 13 gives RBSOA characteristics.

OUTLINE DIMENSIONS



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

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	—	39.37	—	1.550
B	—	21.08	—	0.830
C	6.35	8.25	0.250	0.325
D	0.97	1.09	0.038	0.043
E	1.40	1.77	0.055	0.070
F	30.15 BSC		1.187 BSC	
G	10.92 BSC		0.430 BSC	
H	5.46 BSC		0.215 BSC	
J	16.89 BSC		0.665 BSC	
K	11.18	12.19	0.440	0.480
Q	3.84	4.19	0.151	0.165
R	—	26.67	—	1.050
U	4.83	5.33	0.190	0.210
V	3.84	4.19	0.151	0.165

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. ALL RULES AND NOTES ASSOCIATED WITH REFERENCED TO-204AA OUTLINE SHALL APPLY.

CASE 1-06
TO-204AA
(TO-3)

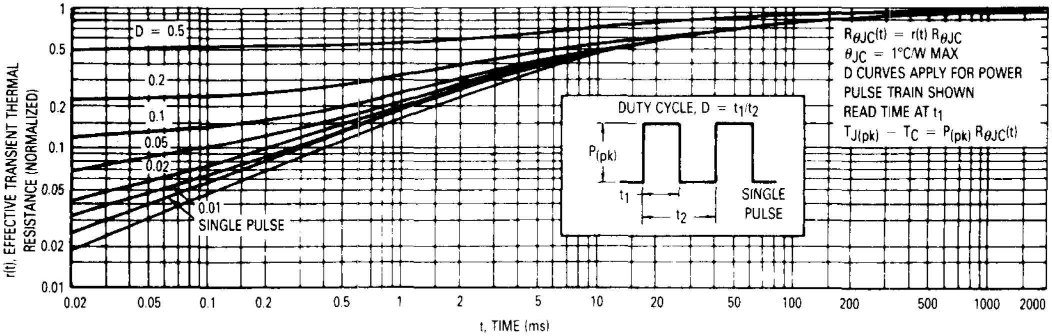


Figure 15. Thermal Response

OVERLOAD CHARACTERISTICS

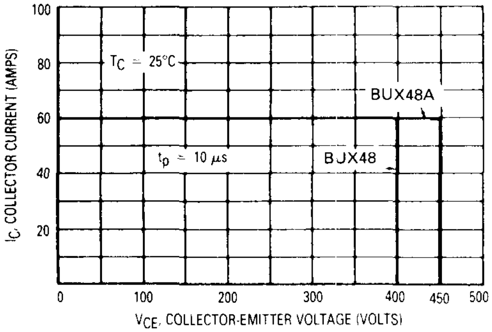


Figure 16. Rated Overload Safe Operating Area (OLSOA)

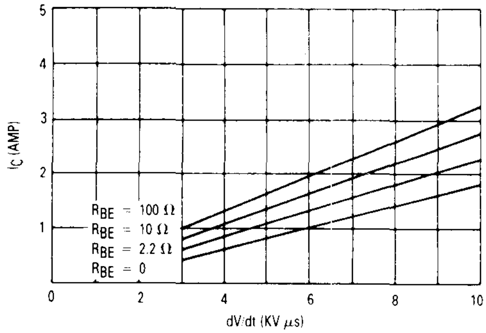


Figure 17. I_C = f(dV/dt)

OLSOA

OLSOA applies when maximum collector current is limited and known. A good example is a circuit where an inductor is inserted between the transistor and the bus, which limits the rate of rise of collector current to a known value. If the transistor is then turned off within a specified amount of time, the magnitude of collector current is also known.

Maximum allowable collector-emitter voltage versus collector current is plotted for several pulse widths. (Pulse width is defined as the time lag between the fault condition and the removal of base drive.) Storage time of the transistor has been factored into the curve. Therefore, with bus voltage and maximum collector current known, Figure 16 defines the maximum time which can be allowed for fault detection and shutdown of base drive.

OLSOA is measured in a common-base circuit (Figure 18) which allows precise definition of collector-emitter voltage and collector current. This is the same circuit that is used to measure forward-bias safe operating area.

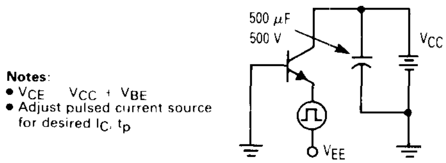


Figure 18. Overload SOA Test Circuit