ALPHANUMERIC INDEX — CROSS-REFERENCE (Continued)

Industry Part Number	Motorola Direct Replacement	Motorola Similar Replacement	Page Number
2N6410		MJE200	3-866
2N6411		MJE210	3-866
2N6412		MJE180	3-862
2N6413		MJE181	3-862
2N6414		MJE170	3-862
2N6415		MJE171	3-862
2N6416		MJE243	3-870
2N6417		MJE243	3-870
2N6418		MJE253	3-870
2N6419		MJE253	3-870
2N6420	2N6420		3-20
2N6421	2N6421		3-20
2N6422	2N6422		3-20
2N6423		2N6212	3-161
2N6424		2N6212	3-161
2N6425		2N6212	3-161
2N6436	2N6436		3-203
2N6437	2N6437		3-203
2N6437JAN	2N6437JAN		3-203
2N6437JTX	2N6437JTX		3-203
2N6437JTXV	2N6437JTXV		3-203
2N6438	2N6438		3-203
2N6438JAN	2N6438JAN		3-203
2N6438JTX	2N6438JTX		3-203
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2N6465		MJE15030	3-972
2N6466		MJE15030	3-972
2N6467		MJE15031	3-972
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2N6469		2N5879	3-123
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2N6473		MJE15028	3-972
2N6474		MJE15028	3-972
2N6475		MJE15029	3-972
2N6476		MJE15029	3-972
2N6477		MJE15028	3-972
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2N6486	2N6486		3-207
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2N6498	2N6498		3-211
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2N6500		2N5430	3-101
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2N6535		TIP102	3-1091
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2N6544	2N6545		3-221
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2N6555		2N4919	3-75
2N6556		2N4919	3-75
2N6557		MJE340	3-876
2N6558		MJE340	3-876
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2N6575		2N6547	3-225
2N6576	2N6576		3-229
2N6577	2N6577		3-229
2N6578	2N6578		3-229
2N6609	2N6609		3-52
2N6648	2N6648		3-195
2N6648JAN	2N6648JAN		3-195
2N6648JTX	2N6648JTX		3-195
2N6648JTXV	2N6648JTXV		3-195
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2N6649JAN	2N6649JAN		—
2N6649JTX	2N6649JTX		—
2N6649JTXV	2N6649JTXV		—
2N6650JAN	2N6650JAN		—
2N6650JTX	2N6650JTX		—
2N6650JTXV	2N6650JTXV		—
2N6666		2N6667	3-232
2N6667	2N6667		3-232
2N6668	2N6668		3-232
2N6671JAN	2N6671JAN		—
2N6671JTX	2N6671JTX		—
2N6671JTXV	2N6671JTXV		—
2N6673JAN	2N6673JAN		—
2N6673JTX	2N6673JTX		—
2N6673JTXV	2N6673JTXV		—
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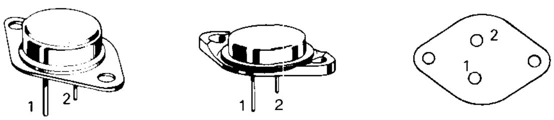
*Consult Motorola if a direct replacement is necessary.

1

Bipolar Power Transistors

TABLE 1 — METAL TO-204 (Formerly TO-3), TO-204AE



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

CASE 1-06 — 40 mil pins (TO-204AA)
CASE 197-01 — 60 mil pins (TO-204AE TYPE)
CASE 197A-02 — 60 mil pins (TO-204AE)

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
2.5	800	MJ8501		7.5 min	0.5	4	2	1		125
	1500*	MJ12002		1.11 min	2		1	2	4 typ	75
3.5	325	2N3902		30/90	1	1.2 typ	0.1 typ	1	2.8	100
4	1500*	MJ12003		2.5 min	3		1	3		100
5	200	MJ410		30/90	1				2.5	100
	250	MJ3029		30 min	0.4		1	3		125
	300	MJ411		30/90	1				2.5	100
	400	2N6543 MJ13070		7/35 8 min	3 3	4 1.5	0.8 0.5	3 3	6	100 125
	450	MJ16002 MJ16004 2N6834		5 min 7 min 10/30	5 5 3	3 2.7 2.7	0.3 0.35 0.35	3 3 3	 15	125 125 125
	500	MJ16002A		5 min	5	3	0.3	3		125
	700	MJ8502		7.5 min	1	4	2	2.5		150
	800	MJ8503		7.5 min	1	4	2	2.5		150
	850*	MJ12020		5 min	5		0.13 typ	3	15	125
	1500*	BU208 BU208A BU208D† MJ12004		2.25 min 2.25 min 2.25 min 2.5 min	4.5 4.5 4.5 4.5	8 typ	0.6 typ 0.4 typ 0.6 typ 1	4.5 4.5 4.5 4.5	4 typ 4 typ 4 typ 4	60 90 60 100
6	100	2N5758		25/100	3	0.7 typ	0.5 typ	3	1	150
	120	2N5759		20/80	3	0.7 typ	0.5 typ	3	1	150
	140	2N5760		15/60	3	0.7 typ	0.5 typ	3	1	150

$|h_{fe}|$ @ 1 MHz, ## Darlington
* $V_{(BR)CEX}$ or $V_{(BR)CES}$
† D Suffix on this device signifies internal C-E Diode

(continued)

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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
400	8	850	2N6545★	7/35	5	4	1	5	6		TO-204/1
		800	MJE5742#	200/400	4	8 typ	2 typ	6			TO-220/221A
		800	MJE16080	5 min	8	2	0.5	5		80	TO-220/221A
		850	BUW12	6 min	6	4	0.8	5		125	TO-218/340
		850	BUX84	30 min	0.1	3.5	1.4	1	4	50	TO-220/221A
		700	MJE13007★	6/30	5	3	0.7	5	4		TO-220/221A
		650	MJ13080★	8 min	5	1.5	0.5	5			TO-204/1
		650	MJE16106	6/25	8	2 typ	0.1 typ	5		100	TO-220/221A
		650	MJH16106	6/25	8	2 typ	0.1 typ	5		125	TO-218/340
		450	MJ6503-PNP★	15 min	2	2	0.5	4			TO-204/1
		450	MJE5852-PNP★	15 min	2	2	0.5	4			TO-220/221A
	6	900	BU326A	30 typ	0.6	3.5	1**	2.5	6	90	TO-204/1
		900	BU426A	30 typ	0.6	2 typ	0.5 typ	2.5	6 typ	113	TO-218/340D
	5	850	2N6543★	7/35	3	4	0.8	3	6		TO-204/1
		850	BUW11	6 min	3	4	0.8	3		125	TO-218/340
		650	MJ13070★	8 min	3	1.5	0.5	3			TO-204/1
		650	MJE13070★	8 min	3	1.5	0.5	3			TO-220/221A
	4	700	MJE13005★	6/30	3	3	0.7	3	4		TO-220/221A
	1.5	700	MJE13003★	5/25	1	4	0.7	1	5		TO-225AA/77R
	0.5	400	MJ4647-PNP	20 min	0.5	0.72*		0.05	40		TO-205AD/79
375	6	800	BU326	30 typ	0.6	3.5	1**	2.5	6	90	TO-204/1
		800	BU426	30 typ	0.6	2 typ	0.5 typ	2.5	6 typ	113	TO-218/340D
350	40	450	MJ10022##★	50/600	10	2.5	0.9	20			TO-204/197
	20	450	MJ10000#★	40/400	10	3	1.8	10	10**		TO-204/1
		450	MJ10004##★	40/400	10	1.5	0.5	10	10**		TO-204/1
	15	375	2N6251	6/50	10	3.5	1	10	2.5		TO-204/1
	10	450	MJ10002#★	30/300	5	2.5	1	5	10**		TO-204/1
		450	MJ10006##★	30/300	5	1.5	0.5	5	10**		TO-204/1
		400	MJ13014★	8/20	5	2	0.5	5			TO-204/1
	8	700	2N6308	12/60	3	1.6	0.4	5	5		TO-204/1
		700	MJE5741#	200/400	4	8 typ	2 typ	6			TO-220/221A
		400	MJE5851-PNP	15 min	2	2	0.5	4			TO-220/221A
	2	400	2N6213-PNP	10/100	1	2.5	0.6	1	4		TO-213AA/80
325	30	400	BUV23	8 min	16	1.8	0.4	16	8	250	TO-204/197
	15	400	BUX13	8 min	8	2.5	0.8	8	8	150	TO-204/1
	5	350	2N6235	25/125	1	3.5	0.5	1	20		TO-213AA/80
300	15	650	2N6546★	6/30	10	4	0.7	10	6 to 24		TO-204/1
	12	600	MJE13008★	6/30	8	3	0.7	8	4**		TO-220/221A
	8	600	2N6307	15/75	3	1.6	0.4	3	5		TO-204/1
		600	MJE13006★	6/30	5	3	0.7	5	4		TO-220/221A
		600	MJE5740	200/400	4	8 typ	2 typ	6			TO-220/221A
		350	MJE5850-PNP★	15 min	2	2	0.5	4			TO-220/221A
	5	400	2N6498	10/75	2.5	1.8	0.8	2.5	5		TO-220/221A
	4	600	MJE13004★	6/30	3	3	0.7	3	4		TO-220/221A
	2	500	2N3585	25/100	1	4	3	1	10		TO-213AA/80
		500	2N6422-PNP	25/100	1	4	3	1	10		TO-213AA/80
		350	2N6212-PNP	10/100	1	2.5	0.6	1	4		TO-213AA/80
	1.5	600	MJE13002★	5/25	1	4	0.7	1	5		TO-225AA/77R

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

(continued)

2

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

2N6543

Designer's Data Sheet

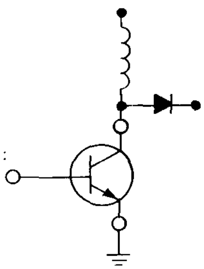
5 AMPERE
NPN SILICON
POWER TRANSISTOR
400 VOLTS
100 WATTS

SWITCHMODE SERIES
NPN SILICON POWER TRANSISTORS

This device is designed for high-voltage, high-speed, power switching inductive circuits where fall time is critical. It is particularly suited for 115 and 200 volt line operated SWITCHMODE applications such as:

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

Specification Features –
High Temperature Performance Specified for:
Reversed Biased SOA with Inductive Loads
Switching Times with Inductive Loads
Saturation Voltages
Leakage Currents



Designer's Data for "Worst Case" Conditions

The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit data – representing device characteristics boundaries – are given to facilitate "worst case" design.

*MAXIMUM RATINGS

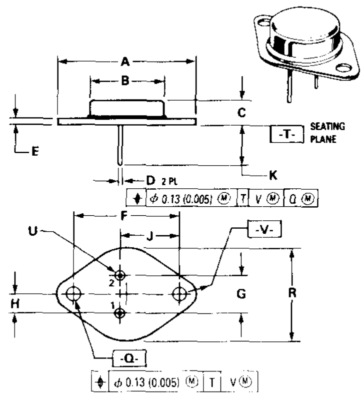
Rating	Symbol	2N6543	Unit
Collector-Emitter Voltage	$V_{CEO(sus)}$	400	Vdc
Collector-Emitter Voltage	$V_{CEX(sus)}$	450	Vdc
Collector-Emitter Voltage	V_{CEV}	850	Vdc
Emitter Base Voltage	V_{EB}	8.0	Vdc
Collector Current – Continuous – Peak (1)	I_C I_{CM}	5.0 10	Adc
Base Current – Continuous – Peak (1)	I_B I_{BM}	5.0 10	Adc
Emitter Current – Continuous – Peak (1)	I_E I_{EM}	10 20	Adc
Total Power Dissipation @ $T_C = 25°C$ @ $T_C = 100°C$ Derate above 25°C	P_D	100 57.2 0.57	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	$R_{\theta JC}$	1.75	°C/W
Maximum Lead Temperature for Soldering Purposes: 1/8" from Case for 5 Seconds	T_L	275	°C

*Indicates JEDEC Registered Data

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



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.

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES 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

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

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

3

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

Characteristic	Symbol	Min	Max	Unit
OFF CHARACTERISTICS (1)				
Collector-Emitter Sustaining Voltage (Table 2) (I_C = 100 mA, I_B = 0)	$V_{CEO(sus)}$	400	–	Vdc
Collector-Emitter Sustaining Voltage (Table 2, Figure 12) (I_C = 2.6 A, V_{clamp} = Rated V_{CEX}, T_C = 100°C)	$V_{CEX(sus)}$	450	–	Vdc
(I_C = 5.0 Adc, V_{clamp} = Rated V_{CEO} -100 V, T_C = 100°C)		300	–	
Collector Cutoff Current	I_{CEV}			mAdc
(V_{CEV} = Rated Value, $V_{BE(off)}$ = 1.5 Vdc)		–	0.5	
(V_{CEV} = Rated Value, $V_{BE(off)}$ = 1.5 Vdc, T_C = 100°C)		–	3.0	
Collector Cutoff Current (V_{CE} = Rated V_{CEV}, R_{BE} = 50 Ω, T_C = 100°C)	I_{CER}	–	3.0	mAdc
Emitter Cutoff Current (V_{EB} = 8.0 Vdc, I_C = 0)	I_{EBO}	–	1.0	mAdc
SECOND BREAKDOWN				
Second Breakdown Collector Current with base forward biased t = 1.0 s (non-repetitive) (V_{CE} = 100 Vdc)	$I_{S/b}$	0.2 (See Figure 11)	–	Adc
Clamped Inductive SOA with base reverse biased	RBSOA	(See Figure 12)		
ON CHARACTERISTICS (1)				
DC Current Gain	h_{FE}			–
(I_C = 1.5 Adc, V_{CE} = 2.0 Vdc)		12	60	
(I_C = 3.0 Adc, V_{CE} = 2.0 Vdc)		7.0	35	
Collector-Emitter Saturation Voltage	$V_{CE(sat)}$			Vdc
(I_C = 3.0 Adc, I_B = 0.6 Adc)		–	1.0	
(I_C = 5.0 Adc, I_B = 1.0 Adc)		–	5.0	
(I_C = 3.0 Adc, I_B = 0.6 Adc, T_C = 100°C)		–	2.0	
Base-Emitter Saturation Voltage	$V_{BE(sat)}$			Vdc
(I_C = 3.0 Adc, I_B = 0.6 Adc)		–	1.4	
(I_C = 3.0 Adc, I_B = 0.6 Adc, T_C = 100°C)		–	1.4	
DYNAMIC CHARACTERISTICS				
Current-Gain — Bandwidth Product (I_C = 200 mAdc, V_{CE} = 10 Vdc, f_{test} = 1.0 MHz)	f_T	6.0	28	MHz
Output Capacitance (V_{CB} = 10 Vdc, I_E = 0, f_{test} = 1.0 MHz)	C_{ob}	50	200	pF
SWITCHING CHARACTERISTICS				
Resistive Load (Table 2)				
Delay Time (V_{CC} 250 Vdc, I_C 3.0 A, I_{B1} = I_{B2} = 0.6 A, t_p = 100 μs, Duty Cycle ≤ 2.0%)	t_d	–	0.05	μs
Rise Time	t_r	–	0.7	μs
Storage Time	t_s	–	4.0	μs
Fall Time	t_f	–	0.8	μs
Inductive Load, Clamped (Table 2)	**Symbol**	**Typ**	**Max**	**Unit**
Storage Time (I_C = 3.0 A(pk), V_{clamp} = Rated V_{CEX}, I_{B1} = 0.6 A, $V_{BE(off)}$ = 5.0 Vdc, T_C = 100°C)	t_{sv}	–	4.0	μs
Crossover Time	t_c	0.6	–	μs
Fall Time	t_{fi}	–	0.8	μs
Storage Time (I_C = 3.0 A(pk), V_{clamp} = Rated V_{CEX}, I_{B1} = 0.6 A, $V_{BE(off)}$ = 5.0 Vdc, T_C = 25°C)	t_{sv}	0.8	–	μs
Crossover Time	t_c	0.3	–	μs
Fall Time	t_{fi}	0.2	–	μs

*Indicates JEDEC Registered Data.

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

3

DC CHARACTERISTICS

FIGURE 1 – DC CURRENT GAIN

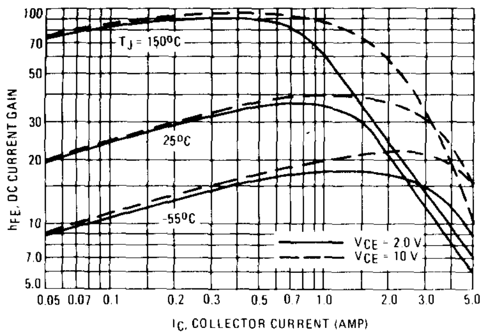


FIGURE 2 – COLLECTOR SATURATION REGION

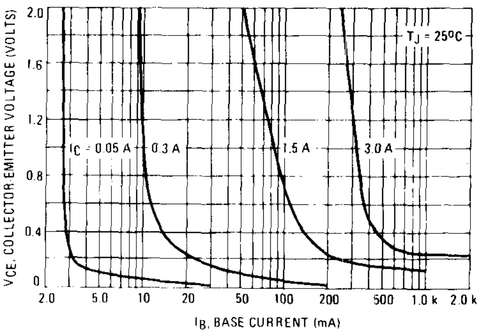


FIGURE 3 – "ON" VOLTAGE

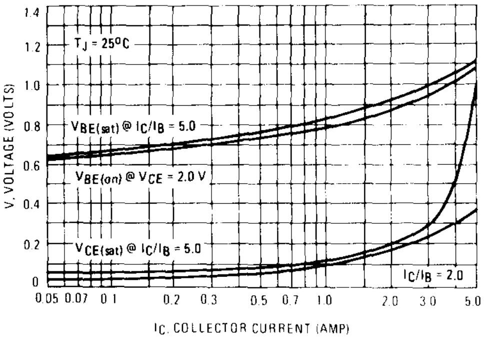


FIGURE 4 – TEMPERATURE COEFFICIENTS

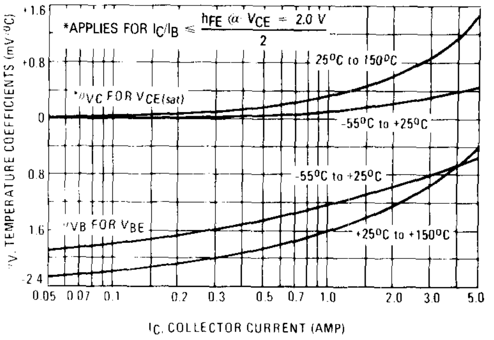


FIGURE 5 – COLLECTOR CUTOFF REGION

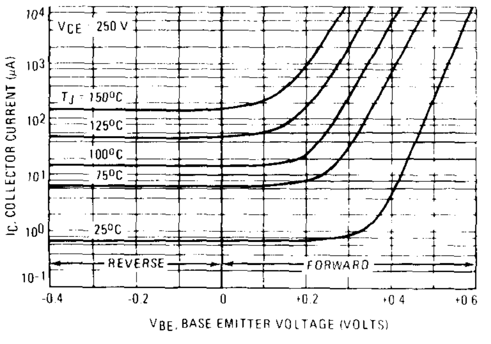


FIGURE 6 – CAPACITANCE

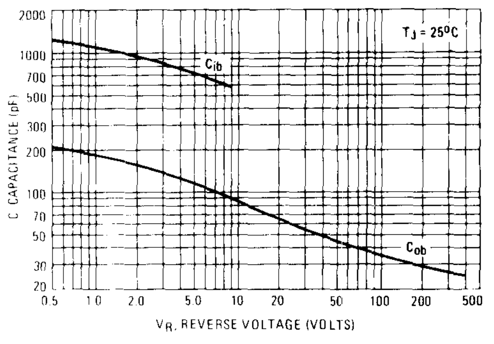


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FIGURE 7 — INDUCTIVE SWITCHING MEASUREMENTS

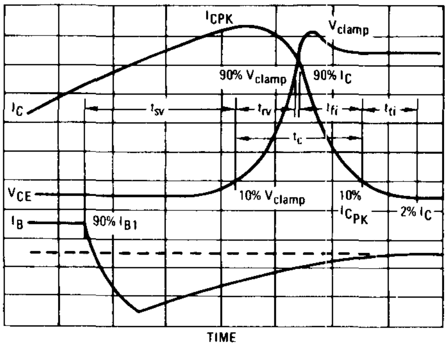

TABLE 1 — INDUCTIVE SWITCHING PERFORMANCE

I_C (A)	T_C °C	t_{sv} μs	t_{rv} μs	t_{fi} μs	t_{ti} μs	t_c μs
1.0	25	0.70	0.22	0.21	0.23	0.66
	100	1.20	0.37	0.19	0.39	0.95
3.0	25	1.10	0.09	0.12	0.08	0.29
	100	1.60	0.42	0.19	0.40	1.01
5.0	25	1.10	0.16	0.19	0.11	0.46
	100	1.70	0.45	0.37	0.26	1.08

Note: All Data Recorded in the Inductive Switching Circuit Shown in Table 2.

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.

RESISTIVE SWITCHING PERFORMANCE

FIGURE 8 — TURN-ON TIME

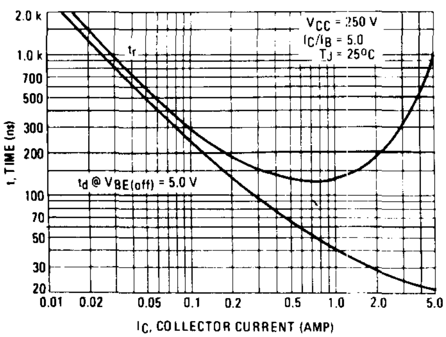

FIGURE 9 — TURN-OFF TIME

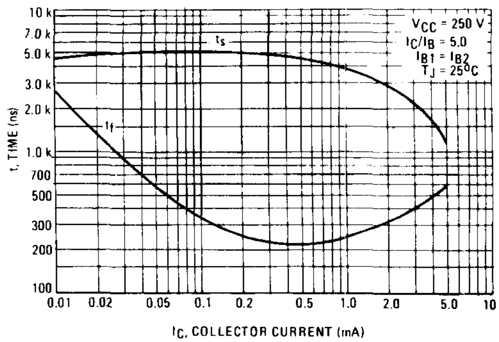

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TABLE 2 – TEST CONDITIONS FOR DYNAMIC PERFORMANCE

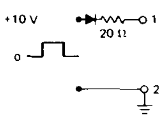
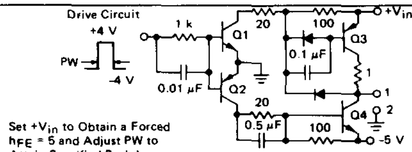
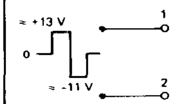
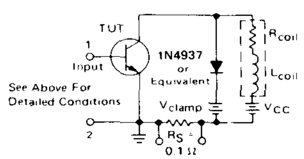
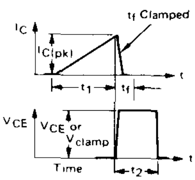
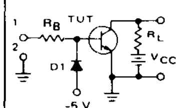
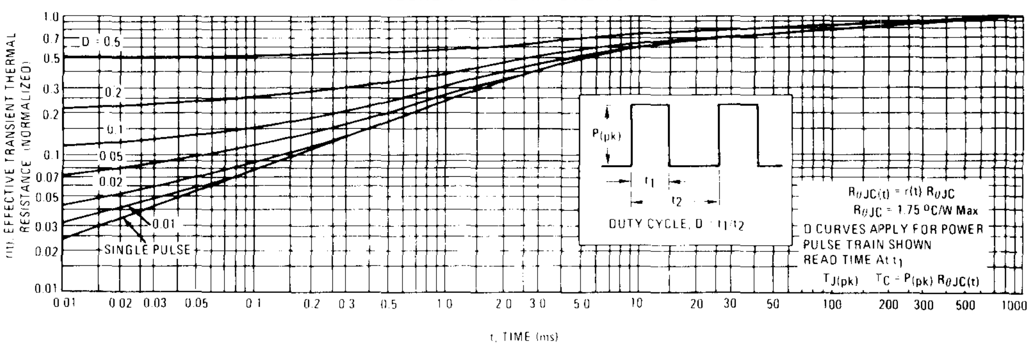
	$V_{CEO(sus)}$	$V_{CEX(sus)}$ AND INDUCTIVE SWITCHING	RESISTIVE SWITCHING
INPUT CONDITIONS	 PW Varied to Attain I_C = 100 mA	 Set $+V_{in}$ to Obtain a Forced h_{FE} = 5 and Adjust PW to Attain Specified Peak I_C. Duty Cycle ≤ 3%, f ≈ 1 kHz. Q1 2N6408, Q2 2N6406, Q3 2N5875, Q4 2N5877, Diodes 1N4933	 I_C = 3A PW ≈ 100 μs t_r ≤ 5 ns t_f ≤ 50 ns Duty Cycle ≤ 2%
CIRCUIT VALUES	L_{coil} 80 mH V_{CC} = 10 V R_{coil} = 0.7 Ω V_{clamp} (Unclamped)	L_{coil} = 180 μH R_{coil} = 0.05 Ω V_{CC} = 20 V V_{clamp} = Rated V_{CEX} Value	V_{CC} ≈ 250 V R_L = 83 Ω D1 = 1N5820 or Equiv. R_B = 20 Ω
TEST CIRCUITS	INDUCTIVE TEST CIRCUIT  See Above For Detailed Conditions	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 Tektronics 475 or Equivalent	RESISTIVE TEST CIRCUIT 

FIGURE 10 – THERMAL RESPONSE



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

FIGURE 11 – FORWARD BIAS SAFE OPERATING AREA

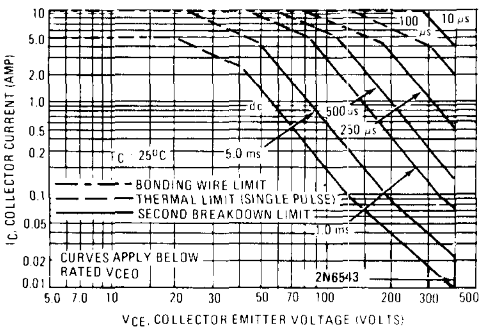


FIGURE 12 – REVERSE BIAS SAFE OPERATING AREA

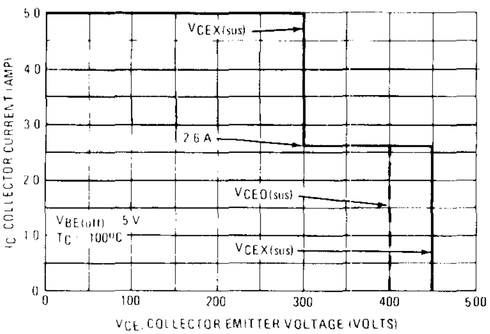
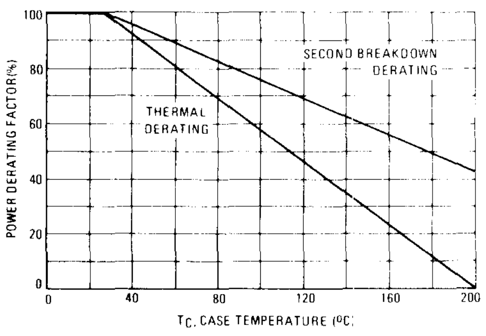


FIGURE 13 – POWER DERATING



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 11 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 $T_C \geqslant 25°C$. Second breakdown limitations do not derate the same as thermal limitations. Allowable current at the voltages shown on Figure 11 may be found at any case temperature by using the appropriate curve on Figure 13.

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

REVERSE BIAS

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

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