ALPHANUMERIC INDEX — CROSS-REFERENCE (Continued)

Industry Part Number	Motorola Direct Replacement	Motorola Similar Replacement	Page Number
MJ723		MJ12002	3-637
MJ802	MJ802		3-526
MJ804		MJ12004	3-644
MJ8100		*2N6193*	*3-158*
MJ8500	MJ8501		3-546
MJ8501	MJ8501		3-546
MJ8502	MJ8502		3-552
MJ8503	MJ8503		3-552
MJ8504	MJ8504		3-558
MJ8505	*MJ8505*		3-558
MJ900	MJ900		3-528
MJ901	MJ901		3-528
MJ920		2N6298	3-147
MJ921		2N6299	3-147
MJD112	MJD112		3-816
MJD112-1	MJD112-1		3-816
MJD117	MJD117		3-816
MJD117-1	MJD117-1		3-816
MJD122	MJD122		3-822
MJD122-1	MJD122-1		3-822
MJD127	*MJD127*		3-822
MJD127-1	MJD127-1		3-822
MJD13003	MJD13003		3-854
MJD13003-1	MJD13003-1		3-822
MJD148	MJD148		3-828
MJD148-1	MJD148-1		—
MJD200	*MJD200*		3-832
MJD200-1	MJD200-1		3-832
MJD210	MJD210		3-832
MJD210-1	MJD210-1		3-832
MJD29	MJD31		3-797
MJD29-1	MJD31-1		3-797
MJD2955	*MJD2955*		3-844
MJD2955-1	MJD2955-1		3-844
MJD29C	MJD31C		3-797
MJD29C1	MJD31C1		3-797
MJD30	MJD32		3-797
MJD30-1	MJD32-1		3-797
MJD3055	*MJD3055*		3-844
MJD3055-1	MJD3055-1		3-844
MJD30C	MJD32C		3-797
MJD30C1	MJD32C1		3-797
MJD31	MJD31		3-797
MJD31-1	MJD31-1		3-797
MJD31C	*MJD31C*		3-797
MJD31C1	MJD31C1		3-797
MJD32	MJD32		3-797
MJD32-1	MJD32-1		3-797
MJD32C	MJD32C		3-797
MJD32C1	MJD32C1		3-797
MJD340	MJD340		3-840
MJD340-1	MJD340-1		3-840
MJD350	MJD350		3-840
MJD350-1	MJD350-1		3-840
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MJD41C1	MJD41C1		3-840
MJD42C	MJD42C		3-801
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MJD44E3	MJD44E3		3-805
MJD44E3-1	MJD44E3-1		3-805
MJD44H11	MJD44H11		3-808
MJD44H11-1	MJD44H11-1		3-808
MJD45H11	MJD45H11		3-808
MJD45H11-1	*MJD45H11-1*		*3-808*
MJD47	MJD47		3-812
MJD47-1	MJD47-1		3-812
MJD50	MJD50		3-812
MJD50-1	MJD50-1		3-812
MJD6036	MJD6036		3-848
MJD6036-1	*MJD6036-1*		3-848
MJD6039	MJD6039		3-848
MJD6039-1	MJD6039-1		3-848
MJE101		MJE2955	3-904
MJE102		MJE2955	3-904
MJE103		MJE2955	3-904
MJE104		MJE2955	3-904
MJE105	MJE105		3-860
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MJE1090	MJE1090		—
MJE1091	MJE1093		—
MJE1092	*MJE1092*		—
MJE1093	MJE1093		—
MJE1100	MJE1100		—
MJE1101	MJE1101		—
MJE1102	MJE1102		—
MJE1103	MJE1103		—
MJE12007	*MJE12007*		3-936
MJE1290		2N5988	3-131
MJE1291		2N5988	3-131
MJE13002	MJE13002		3-938
MJE13003	MJE13003		3-938
MJE13004	MJE13004		3-944
MJE13005	*MJE13005*		3-944
MJE13006	MJE13006		3-950
MJE13007	MJE13007		3-950
MJE13008	MJE13008		3-958
MJE13009	MJE13009		3-958
MJE13070	MJE13070		3-966
MJE13071		*MJE16002*	3-976
MJE1320	MJE1320		3-892
MJE15028	MJE15028		3-972
MJE15029	MJE15029		3-972
MJE15030	MJE15030		3-972
MJE15031	MJE15031		3-972
MJE16002	*MJE16002*		3-976
MJE16004	MJE16004		3-976
MJE16032	MJE16032		3-984
MJE16034	MJE16034		3-984
MJE1660	MJE1660		3-898
MJE1661	MJE1661		3-898
MJE170	MJE170		3-862
MJE171	MJE171		3-862
MJE172	MJE172		3-862
MJE180	MJE180		3-862
MJE181	MJE181		3-862
MJE182	MJE182		3-862
MJE200	MJE200		3-866
MJE201		MJE3055	3-904
MJE2010		TIP42	3-1083
MJE2011		TIP42A	3-1083

*Consult Motorola if a direct replacement is necessary.

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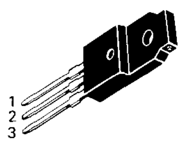
TABLE 5 — PLASTIC TO-220 (continued)

I_CCont Amps Max	$V_{CEO(sus)}$ Volts Min	Device Type		h_{FE} Min/Max	@ I_C Amp	Resistive Switching			f_T MHz Min	P_D (Case) Watts @ 25°C
		NPN	PNP			t_s µs Max	t_f µs Max	@ I_C Amp		
10	60	D44H7	D45H7	20 min	4					50
		D44H8	D45H8	40 min	4					50
			D45H9	40 min	4					50
		MJE2801T		25/100	3					75
		MJE3055T	MJE2955T	20/70	4					75
		2N6387##	2N6667##	1k/20k	5				20#	65
		SE9300##	SE9400##	1k min	4				1#	70
	80	BDX33B##	BDX34B##	750 min	3				3	70
		BD809	BD810	15 min	4				1.5	90
		D44E3##		1000 min	5	2 typ	0.5 typ	10		50
			D45H12	40 min	4					50
		2N6388##	2N6668##	1k/20k	5				20#	65
		D44H10	D45H10	20 min	4	0.5 typ	0.14 typ	5	50 typ	50
		D44H11	D45H11	40 min	4	0.5 typ	0.14 typ	5	50 typ	50
		SE9301##	SE9401##	1k min	4				1#	70
	100	BDX33C##	BDX34C##	750 min	3				3	70
		SE9302##	SE9402##	1k min	4				1#	70
12	300	MJE13008		6/30	8	3	0.7	8	4	100
	400	MJE13009		6/30	8	3	0.7	8	4	100
15	30	D44VH1	D45VH1	20 min	4	0.7	0.09	8	50 typ	83
	40	2N6486	2N6489	20/150	5	0.6 typ	0.3 typ	5	5	75
	45	BDW39	BDW44	1 k min	5	1 typ	1.5 typ	5	4	85
		D44VH4	D45VH4	20 min	4	0.5	0.09	8	50 typ	83
	60	2N6487	2N6490	20/150	5	0.6 typ	0.3 typ	5	5	75
		BDW40	BDW45	1 k min	5	1 typ	1.5 typ	5	4	85
		D44VH7		20 min	4	0.5	0.09	8	50 typ	85
	80	2N6488	2N6491	20/150	5	0.6 typ	0.3 typ	5	5	75
		BDW41	BDW46	1 k min	5	1 typ	1.5 typ	5	4	85
		D44VH10	D45VH10	20 min	4	0.5	0.09	8	50 typ	83
	100	BDW42	BDW47	1 k min	5	1 typ	1.5 typ	5	4	85
	120	BDW43	BDW48	1 k min	5	1 typ	1.5 typ	5	4	85

$|h_{fe}|$ @ 1 MHz, ## Darlington

TABLE 6 — PLASTIC Full Pak (TO-220 Type)



CASE 221C-02

I_CCont Amps Max	$V_{CEO(sus)}$ Volts Min	Device Type		h_{FE} Min/Max	@ I_C Amp	Resistive Switching			f_T MHz Min	P_D (Case) Watts @ 25°C
		NPN	PNP			t_s µs Max	t_f µs Max	@ I_C Amp		
1	250	MJF47		30/150	0.3	2 typ	0.17 typ	0.3	10	28
5	100	MJF122##	MJF127##	2000 min	3	1.5 typ	1.5 typ	3	4#	28
8	80		MJF6107	30/90	2	0.5 typ	0.13 typ	2	4	35
	100	MJF102##	MJF107##	3000 min	3	1.5 typ	1.5 typ	3	4#	35
	150	MJF15030	MJF15031	40 min	3	1 typ	0.15 typ	3	30	35
10	60	MJF3055	MJF2955	20/100	4				2	40

$|h_{fe}|$ @ 1 MHz, ## Darlington

TABLE 14 — SWITCHMODE POWER TRANSISTORS (continued)

						Resistive Switching					
$V_{CEO(sus)}$ Volts Min	I_CCont Amps Max	V_{CEV} Volts Min	Device Type NPN unless otherwise noted	h_{FE} Min/Max	@ I_C Amp	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)

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

MJE13008
MJE13009

Designers Data Sheet

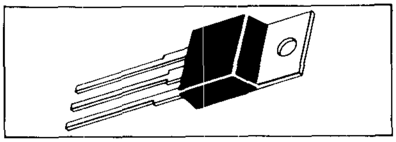
SWITCHMODE SERIES
NPN SILICON POWER TRANSISTORS

The MJE13008 and MJE13009 are designed for high-voltage, high-speed power switching inductive circuits where fall time is critical. They are particularly suited for 115 and 220 V switch-mode applications such as Switching Regulators, Inverters, Motor Controls, Solenoid/Relay drivers and Deflection circuits.

SPECIFICATION FEATURES:

- $V_{CEO(sus)}$ 400 V and 300 V
- Reverse Bias SOA with Inductive Loads @ $T_C = 100^{\circ}C$
- Inductive Switching Matrix 3 to 12 Amp, 25 and $100^{\circ}C$
  . . . t_c @ 8 A, $100^{\circ}C$ is 120 ns (Typ).
- 700 V Blocking Capability
- SOA and Switching Applications Information.

12 AMPERE
NPN SILICON
POWER TRANSISTORS
300 and 400 VOLTS
100 WATTS



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.

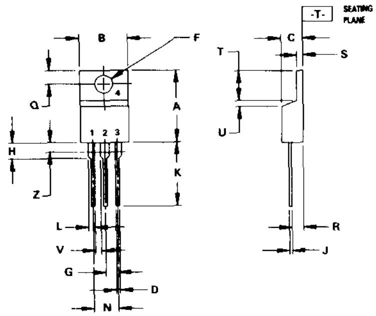
MAXIMUM RATINGS

Rating	Symbol	MJE13008	MJE13009	Unit
Collector-Emitter Voltage	$V_{CEO(sus)}$	300	400	Vdc
Collector-Emitter Voltage	V_{CEV}	600	700	Vdc
Emitter Base Voltage	V_{EBO}	9		Vdc
Collector Current — Continuous — Peak (1)	I_C I_{CM}	12 24		Adc
Base Current — Continuous — Peak (1)	I_B I_{BM}	6 12		Adc
Emitter Current — Continuous — Peak (1)	I_E I_{EM}	18 36		Adc
Total Power Dissipation @ $T_A = 25^{\circ}C$ Derate above $25^{\circ}C$	P_D	2 16		Watts $mW/^{\circ}C$
Total Power Dissipation @ $T_C = 25^{\circ}C$ Derate above $25^{\circ}C$	P_D	100 800		Watts $mW/^{\circ}C$
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +150		$^{\circ}C$

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.25	$^{\circ}C/W$
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	62.5	$^{\circ}C/W$
Maximum Lead Temperature for Soldering Purposes: 1/8" from Case for 5 Seconds	T_L	275	$^{\circ}C$

(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. DIM Z DEFINES A ZONE WHERE ALL BODY AND LEAD IRREGULARITIES ARE ALLOWED.

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	14.48	15.75	0.570	0.620
B	9.66	10.28	0.380	0.405
C	4.07	4.82	0.160	0.190
D	0.64	0.88	0.025	0.035
F	3.61	3.73	0.142	0.147
G	2.42	2.66	0.095	0.105
H	2.80	3.93	0.110	0.155
J	0.46	0.71	0.018	0.028
K	12.70	14.27	0.500	0.562
L	1.15	1.39	0.045	0.055
N	4.83	5.33	0.190	0.210
Q	2.54	3.04	0.100	0.120
R	2.04	2.79	0.080	0.110
S	1.15	1.39	0.045	0.055
T	5.97	6.47	0.235	0.255
U	0.00	1.27	0.000	0.050
V	1.15	—	0.045	—
Z	—	2.04	—	0.080

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

CASE 221A-04
TO-220AB

3

ELECTRICAL CHARACTERISTICS ($T_C = 25^\circ C$ unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
***OFF CHARACTERISTICS**					
Collector-Emitter Sustaining Voltage ($I_C = 10$ mA, $I_B = 0$) MJE13008	$V_{CEO(sus)}$	300	–	–	Vdc
MJE13009		400	–	–	
Collector Cutoff Current (V_{CEV} = Rated Value, $V_{BE(off)} = 1.5$ Vdc)	I_{CEV}	–	–	1	mAdc
(V_{CEV} = Rated Value, $V_{BE(off)} = 1.5$ Vdc, $T_C = 100^\circ C$)		–	–	5	
Emitter Cutoff Current ($V_{EB} = 9$ Vdc, $I_C = 0$)	I_{EBO}	–	–	1	mAdc
SECOND BREAKDOWN					
Second Breakdown Collector Current with base forward biased	$I_{S/b}$	See Figure 1			
Clamped Inductive SOA with Base Reverse Biased	–	See Figure 2			
***ON CHARACTERISTICS**					
DC Current Gain ($I_C = 5$ Adc, $V_{CE} = 5$ Vdc)	h_{FE}	8		40	
($I_C = 8$ Adc, $V_{CE} = 5$ Vdc)		6		30	
Collector-Emitter Saturation Voltage ($I_C = 5$ Adc, $I_B = 1$ Adc)	$V_{CE(sat)}$			1	Vdc
($I_C = 8$ Adc, $I_B = 1.6$ Adc)			-	1.5	
($I_C = 12$ Adc, $I_B = 3$ Adc)				3	
($I_C = 8$ Adc, $I_B = 1.6$ Adc, $T_C = 100^\circ C$)				2	
Base-Emitter Saturation Voltage ($I_C = 5$ Adc, $I_B = 1$ Adc)	$V_{BE(sat)}$	–	–	1.2	Vdc
($I_C = 8$ Adc, $I_B = 1.6$ Adc)		–	–	1.6	
($I_C = 8$ Adc, $I_B = 1.6$ Adc, $T_C = 100^\circ C$)		–	–	1.5	
DYNAMIC CHARACTERISTICS					
Current-Gain – Bandwidth Product ($I_C = 500$ mAdc, $V_{CE} = 10$ Vdc, f = 1 MHz)	f_T	4	–	–	MHz
Output Capacitance ($V_{CB} = 10$ Vdc, $I_E = 0$, f = 0.1 MHz)	C_{ob}	–	180	–	pF
SWITCHING CHARACTERISTICS					
Resistive Load (Table 1)					
Delay Time ($V_{CC} = 125$ Vdc, $I_C = 8$ A, $I_{B1} = I_{B2} = 1.6$ A, $t_p = 25\ \mu s$, Duty Cycle $\le 1\%$)	t_d	–	0.06	0.1	μs
Rise Time	t_r	–	0.45	1	μs
Storage Time	t_s	–	1.3	3	μs
Fall Time	t_f	–	0.2	0.7	μs
Inductive Load, Clamped (Table 1, Figure 13)					
Voltage Storage Time ($I_C = 8$ A, $V_{clamp} = 300$ Vdc, $I_{B1} = 1.6$ A, $V_{BE(off)} = 5$ Vdc, $T_C = 100^\circ C$)	t_{sv}	–	0.92	2.3	μs
Crossover Time	t_c	–	0.12	0.7	μs

*Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2%.

3

FIGURE 1 – FORWARD BIAS SAFE OPERATING AREA

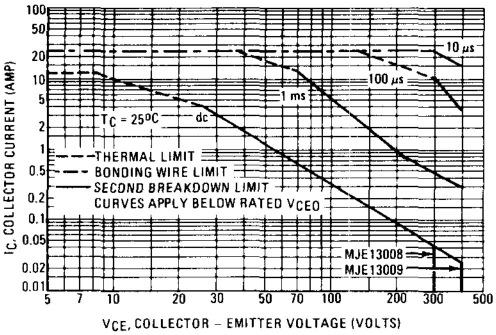
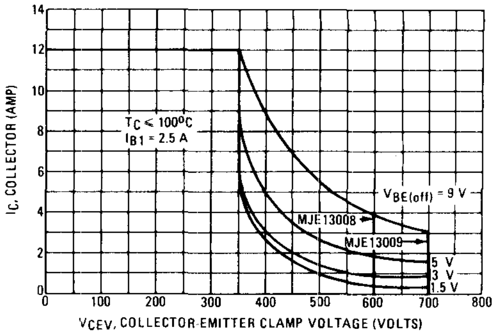
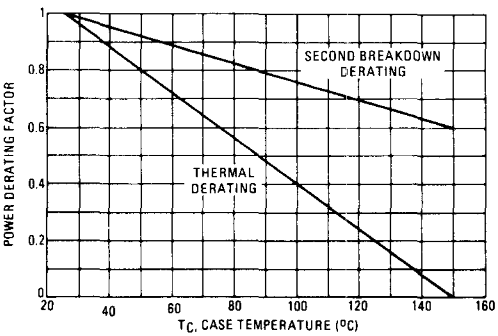


FIGURE 2 – REVERSE BIAS SWITCHING SAFE OPERATING AREA



The Safe Operating Area figures shown in Figures 1 and 2 are specified ratings for these devices under the test conditions shown.

FIGURE 3 – 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 1 is based on $T_C = 25^oC$; $T_{J(pk)}$ is variable depending on power level. Second breakdown pulse limits are valid for duty cycles to 10% but must be derated when $T_C \geq 25^oC$. Second breakdown limitations do not derate the same as thermal limitations. Allowable current at the voltages shown on Figure 1 may be found at any case temperature by using the appropriate curve on Figure 3.

$T_{J(pk)}$ may be calculated from the data in Figure 4. At high case temperatures, thermal limitations will reduce the power that can be handled to values less than the limitations imposed by second breakdown.

Use of reverse biased safe operating area data (Figure 2) is discussed in the applications information section.

FIGURE 4 – TYPICAL THERMAL RESPONSE [$Z_{\theta JC}(t)$]

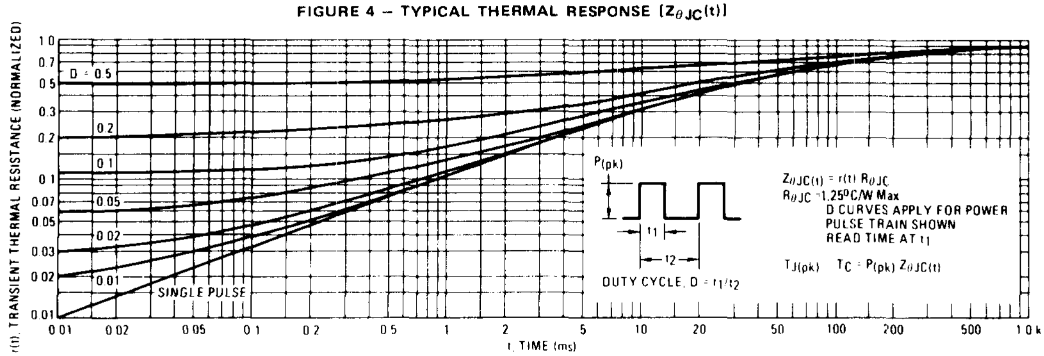


FIGURE 5 – DC CURRENT GAIN

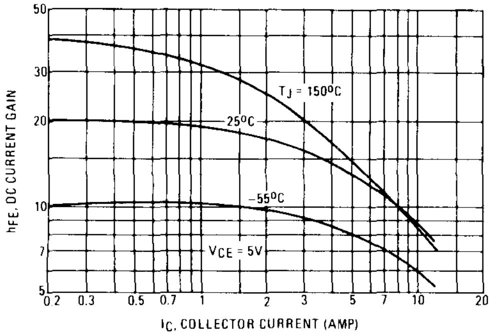


FIGURE 6 – COLLECTOR SATURATION REGION

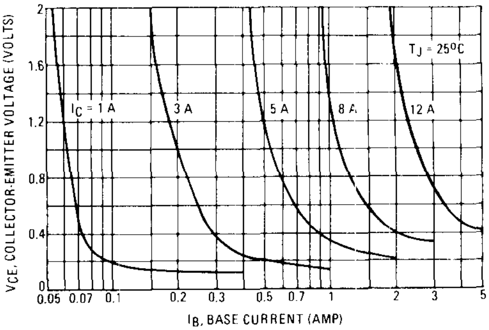


FIGURE 7 – BASE-EMITTER SATURATION VOLTAGE

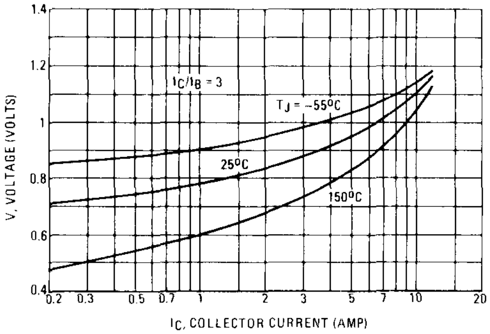


FIGURE 8 – COLLECTOR-EMITTER SATURATION VOLTAGE

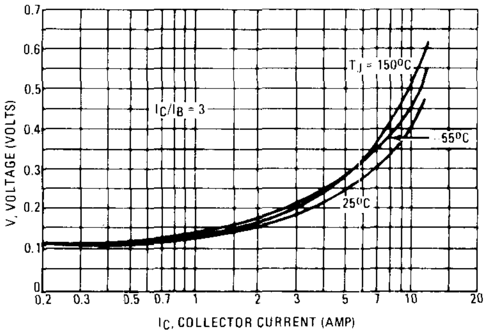


FIGURE 9 – COLLECTOR CUTOFF REGION

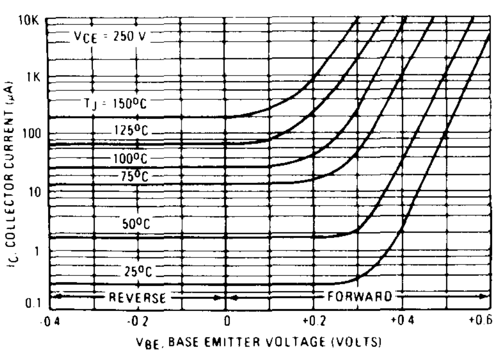


FIGURE 10 – CAPACITANCE

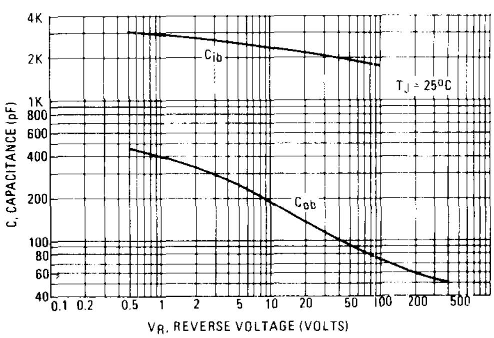


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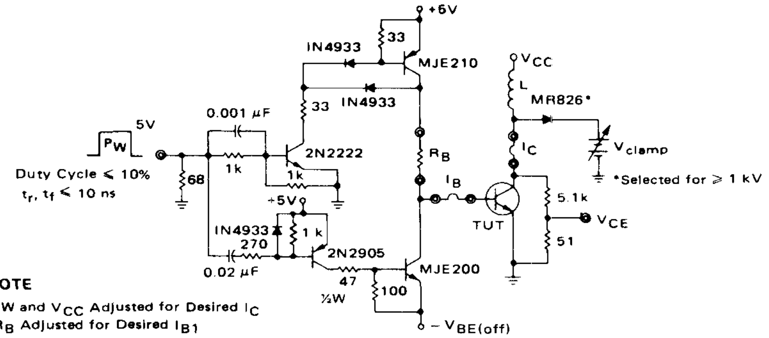
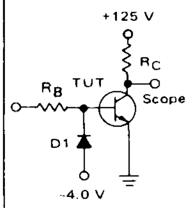
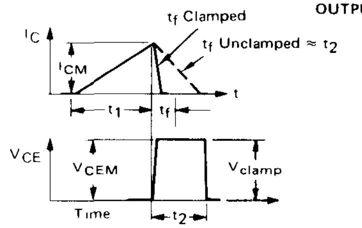
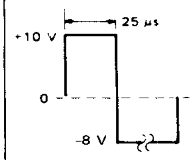
TABLE 1 – TEST CONDITIONS FOR DYNAMIC PERFORMANCE

	REVERSE BIAS SAFE OPERATING AREA AND INDUCTIVE SWITCHING	RESISTIVE SWITCHING
TEST CIRCUITS	 NOTE: PW and V_{CC} Adjusted for Desired I_C; R_B Adjusted for Desired I_{B1}	
CIRCUIT VALUES	Coil Data: Ferroxcube Core #6656, Full Bobbin (~16 Turns) #16; GAP for 200 μH/20A, L_{coil} = 200 μH; V_{CC} = 20 V, V_{clamp} = 300 Vdc	V_{CC} = 125 V, R_C = 15 Ω, D1 = 1N5820 or Equiv, R_B = 5.6 Ω
TEST WAVEFORMS	OUTPUT WAVEFORMS  t_1 Adjusted to Obtain I_C; $t_1 \approx \frac{L_{coil}(I_{CM})}{V_{CC}}$; $t_2 \approx \frac{L_{coil}(I_{CM})}{V_{clamp}}$; Test Equipment Scope – Tektronix 475 or Equivalent	 t_r, t_f < 10 ns; Duty Cycle = 1.0%; R_B and R_C adjusted for desired I_B and I_C

APPLICATIONS INFORMATION FOR SWITCHMODE SPECIFICATIONS

3

INTRODUCTION

The primary considerations when selecting a power transistor for SWITCHMODE applications are voltage and current ratings, switching speed, and energy handling capability. In this section, these specifications will be discussed and related to the circuit examples illustrated in Table 2.(1)

VOLTAGE REQUIREMENTS

Both blocking voltage and sustaining voltage are important in SWITCHMODE applications.

Circuits B and C in Table 2 illustrate applications that require high blocking voltage capability. In both circuits the switching transistor is subjected to voltages substantially higher than V_{CC} after the device is completely off (see load line diagrams at $I_C = I_{leakage} \approx 0$ in Table 2). The blocking capability at this point depends on the base to emitter conditions and the device junction temperature. Since the highest device capability occurs when the base to emitter junction is reverse biased (V_{CEV}), this is the recommended and specified use condition. Maximum I_{CEV} at rated V_{CEV} is specified at a relatively low reverse bias (1.5 Volts) both at 25°C and 100°C. Increasing the reverse bias will give some improvement in device blocking capability.

The sustaining or active region voltage requirements in switching applications occur during turn-on and turn-off. If the load contains a significant capacitive component, high current and voltage can exist simultaneously during turn-on and the pulsed forward bias SOA curves (Figure 1) are the proper design limits.

For inductive loads, high voltage and 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 a Reverse Bias Safe Operating Area (Figure 2) which represents voltage-current conditions that can be sustained during reverse biased turn-off. This rating is verified under clamped conditions so that the device is never subjected to an avalanche mode.

In the four application examples (Table 2) load lines are shown in relation to the pulsed forward and reverse biased SOA curves.

(1) For detailed information on specific switching applications, see Motorola Application Notes An-719, AN-737A, AN-752, AN-767.

VOLTAGE REQUIREMENTS (continued)

In circuits A and D, inductive reactance is clamped by the diodes shown. In circuits B and C the voltage is clamped by the output rectifiers, however, the voltage induced in the primary leakage inductance is not clamped by these diodes and could be large enough to destroy the device. A snubber network or an additional clamp may be required to keep the turn-off load line within the Reverse Bias SOA curve.

Load lines that fall within the pulsed forward biased SOA curve during turn-on and within the reverse bias SOA curve during turn-off are considered safe, with the following assumptions:

(1) The device thermal limitations are not exceeded.
(2) The turn-on time does not exceed 10 μs (see standard pulsed forward SOA curves in Figure 1).
(3) The base drive conditions are within the specified limits shown on the Reverse Bias SOA curve (Figure 2).

CURRENT REQUIREMENTS

An efficient switching transistor must operate at the required current level with good fall time, high energy handling capability and low saturation voltage. On this data sheet, these parameters have been specified at 8 amperes which represents typical design conditions for these devices. The current drive requirements are usually dictated by the $V_{CE(sat)}$ specification because the maximum saturation voltage is specified at a forced gain condition which must be duplicated or exceeded in the application to control the saturation voltage.

SWITCHING REQUIREMENTS

In many switching applications, a major portion of the transistor power dissipation occurs during the fall time (t_{fi}). For this reason considerable effort is usually devoted to reducing the fall time. The recommended way to accomplish this is to reverse bias the base-emitter junction during turn-off. The reverse biased switching characteristics for inductive loads are discussed in Figure 11 and Table 3 and resistive loads in Figures 13 and 14. Usually the inductive load component will be the dominant factor in SWITCHMODE applications and the inductive switching data will more closely represent the device performance in actual application. The inductive switching characteristics are derived from the same circuit used to specify the reverse biased SOA curves, (See Table 1) providing correlation between test procedures and actual use conditions.

RESISTIVE SWITCHING PERFORMANCE

FIGURE 11 — TURN-ON TIME

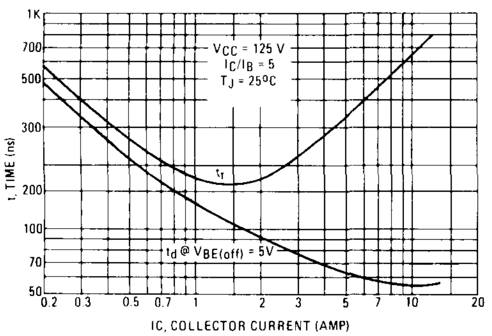


FIGURE 12 — TURN-OFF TIME

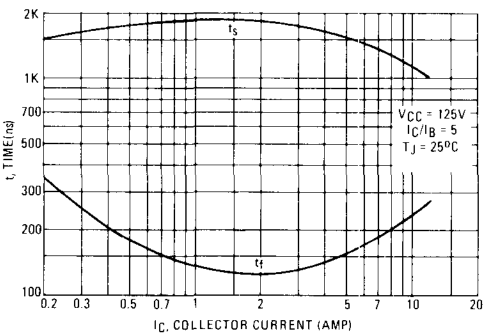


FIGURE 13 — INDUCTIVE SWITCHING MEASUREMENTS

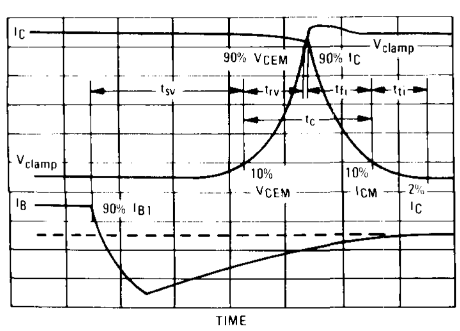


FIGURE 14 — TYPICAL INDUCTIVE SWITCHING WAVEFORMS (at 300 V and 12 A with I_{B1} = 2.4 A and $V_{BE(off)}$ = 5 V)

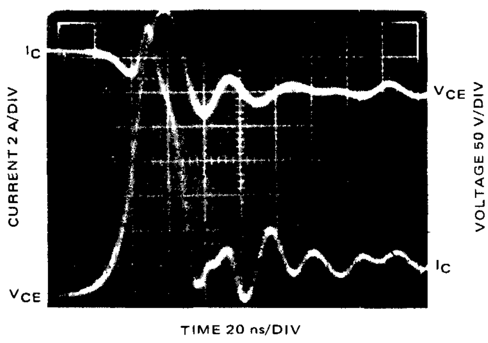


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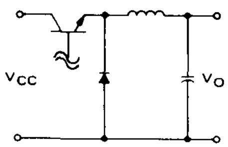
TABLE 2 – APPLICATIONS EXAMPLES OF SWITCHING CIRCUITS

<table>
<tr><th></th><th>CIRCUIT</th><th>LOAD LINE DIAGRAMS</th><th>TIME DIAGRAMS</th></tr>
<tr><td>A</td><td>

SERIES SWITCHING REGULATOR



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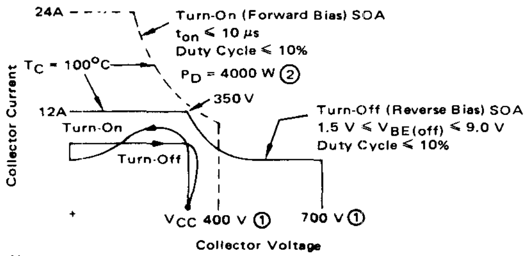
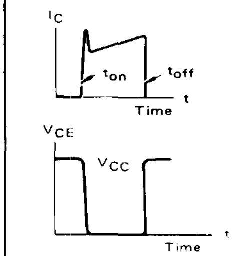
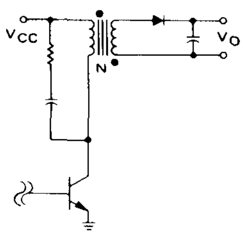


Notes:
① MJE13009 Voltage Ratings ($V_{CEO(sus)}$ and V_{CEV}) are shown, MJE13008 Ratings are 100 V Lower.
② See AN-569 for Pulse Power Derating Procedure.
</td><td>



</td></tr>
<tr><td>B</td><td>

RINGING CHOKE INVERTER



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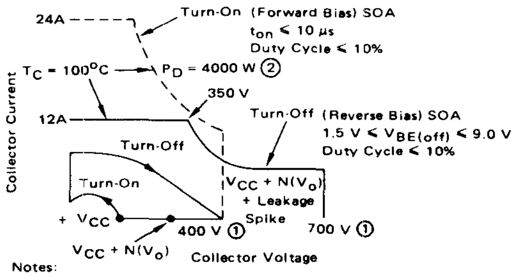

Notes:
① MJE13009 Voltage Ratings ($V_{CEO(sus)}$ and V_{CEV}) are shown, MJE13008 Ratings are 100 V Lower.
② See AN-569 For Pulse Power Derating Procedure
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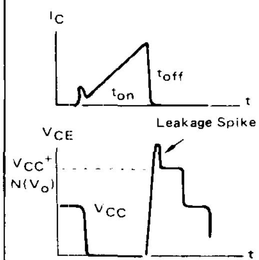

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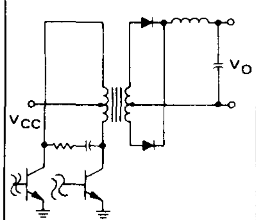
<tr><td>C</td><td>

PUSH-PULL INVERTER/CONVERTER



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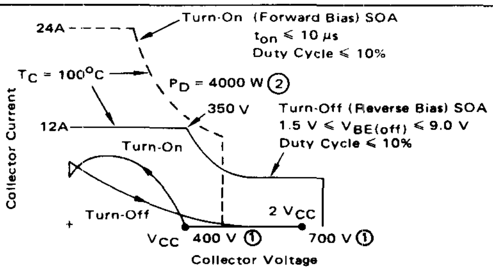

Notes:
① MJE13009 Voltage Ratings ($V_{CEO(sus)}$ and V_{CEV}) are shown, MJE13008 Ratings are 100 V Lower.
② See AN-569 for Pulse Power Derating Procedure.
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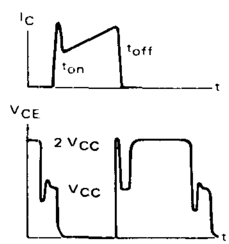

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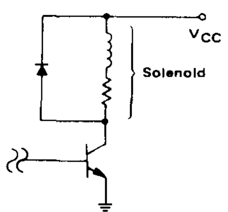
<tr><td>D</td><td>

SOLENOID DRIVER



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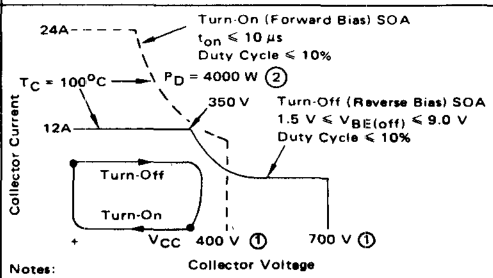

Notes:
① MJE13009 Voltage Ratings ($V_{CEO(sus)}$ and V_{CEV}) are shown, MJE13008 Ratings are 100 V Lower.
② See AN-569 for Pulse Power Derating Procedure.
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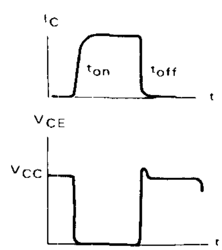

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TABLE 3 – TYPICAL INDUCTIVE SWITCHING PERFORMANCE

I_C AMP	T_C °C	t_{sv} ns	t_{rv} ns	t_{fi} ns	t_{ti} ns	t_c ns
3	25	770	100	150	200	240
	100	1000	230	160	200	320
5	25	630	72	26	10	100
	100	820	100	55	30	180
8	25	720	55	27	2	77
	100	920	70	50	8	120
12	25	640	20	17	2	41
	100	800	32	24	4	54

NOTE: All Data recorded in the inductive Switching Circuit in Table 1.

SWITCHING TIME NOTES

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_{CEM}
t_{rv} = Voltage Rise Time, 10–90% V_{CEM}
t_{fi} = Current Fall Time, 90–10% I_{CM}
t_{ti} = Current Tail, 10–2% I_{CM}
t_c = Crossover Time, 10% V_{CEM} to 10% I_{CM}

An enlarged portion of the turn-off waveforms is shown in Figure 13 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:

$$P_{SWT} = 1/2\ V_{CC} I_C (t_c)\ f$$

Typical inductive switching waveforms are shown in Figure 14. 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.