MJE13009G

Switch-mode Series NPN Silicon Power Transistors

The MJE13009G is 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.

Features

- $V_{CEO(sus)}$ 400 V and 300 V
- Reverse Bias SOA with Inductive Loads @ $T_C = 100°C$
- Inductive Switching Matrix 3 to 12 Amp, 25 and $100°C$ t_c @ 8 A, $100°C$ is 120 ns (Typ)
- 700 V Blocking Capability
- SOA and Switching Applications Information
- These Devices are Pb−Free and are RoHS Compliant*

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector−Emitter Voltage	$V_{CEO(sus)}$	400	Vdc
Collector−Emitter Voltage	V_{CEV}	700	Vdc
Emitter−Base Voltage	V_{EBO}	9	Vdc
Collector Current — Continuous — Peak (Note 1)	I_C I_{CM}	12 24	Adc
Base Current — Continuous — Peak (Note 1)	I_B I_{BM}	6 12	Adc
Emitter Current — Continuous — Peak (Note 1)	I_E I_{EM}	18 36	Adc
Total Device Dissipation @ $T_A = 25°C$ Derate above 25°C	P_D	2 0.016	W W/°C
Total Device Dissipation @ $T_C = 25°C$ Derate above 25°C	P_D	100 0.8	W W/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−65 to +150	°C

THERMAL CHARACTERISTICS

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

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.
1. Pulse Test: Pulse Width = 5 ms, Duty Cycle ≤ 10%.

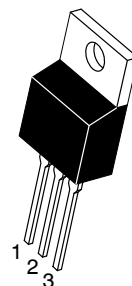*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.
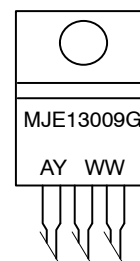
ON Semiconductor®

http://onsemi.com

**12 AMPERE
NPN SILICON
POWER TRANSISTOR
400 VOLTS – 100 WATTS**

TO−220AB
CASE 221A−09
STYLE 1

MARKING DIAGRAM

MJE13009G
AY   WW

A	= Assembly Location
Y	= Year
WW	= Work Week
G	= Pb−Free Package

ORDERING INFORMATION

Device	Package	Shipping
MJE13009G	TO−220 (Pb−Free)	50 Units / Rail

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

Characteristic	Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS (Note 2)					
Collector−Emitter Sustaining Voltage (I_C = 10 mA, I_B = 0)	$V_{CEO(sus)}$	400	–	–	Vdc
Collector Cutoff Current (V_{CEV} = Rated Value, $V_{BE(off)}$ = 1.5 Vdc) (V_{CEV} = Rated Value, $V_{BE(off)}$ = 1.5 Vdc, T_C = 100°C)	I_{CEV}	 – –	 – –	 1 5	mAdc
Emitter Cutoff Current (V_{EB} = 9 Vdc, I_C = 0)	I_{EBO}	–	–	1	mAdc
SECOND BREAKDOWN					
Second Breakdown Collector Current with base forward biased Clamped Inductive SOA with Base Reverse Biased	$I_{S/b}$ –	See Figure 1 See Figure 2			
ON CHARACTERISTICS (Note 2)					
DC Current Gain (I_C = 5 Adc, V_{CE} = 5 Vdc) (I_C = 8 Adc, V_{CE} = 5 Vdc)	h_{FE}	 8 6	 – –	 40 30	
Collector−Emitter Saturation Voltage (I_C = 5 Adc, I_B = 1 Adc) (I_C = 8 Adc, I_B = 1.6 Adc) (I_C = 12 Adc, I_B = 3 Adc) (I_C = 8 Adc, I_B = 1.6 Adc, T_C = 100°C)	$V_{CE(sat)}$	 – – – –	 – – – –	 1 1.5 3 2	Vdc
Base−Emitter Saturation Voltage (I_C = 5 Adc, I_B = 1 Adc) (I_C = 8 Adc, I_B = 1.6 Adc) (I_C = 8 Adc, I_B = 1.6 Adc, T_C = 100°C)	$V_{BE(sat)}$	 – – –	 – – –	 1.2 1.6 1.5	Vdc
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		t_d	–	0.06	0.1	μs
Rise Time	(V_{CC} = 125 Vdc, I_C = 8 A,	t_r	–	0.45	1	μs
Storage Time	I_{B1} = I_{B2} = 1.6 A, t_p = 25 μs,	t_s	–	1.3	3	μs
Fall Time	Duty Cycle ≤ 1%)	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,	t_{sv}	–	0.92	2.3	μs
Crossover Time	I_{B1} = 1.6 A, $V_{BE(off)}$ = 5 Vdc, T_C = 100°C)	t_c	–	0.12	0.7	μs

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

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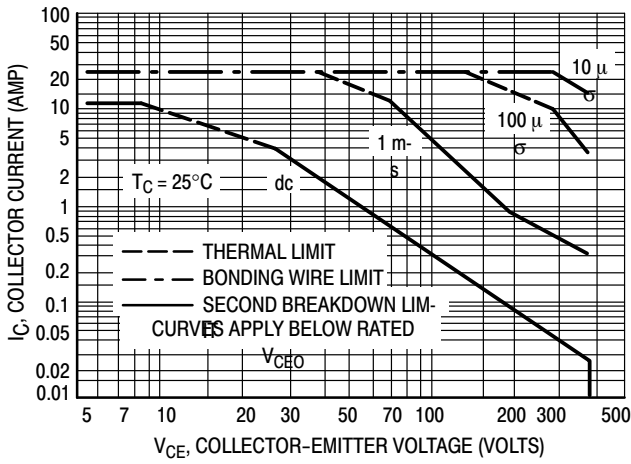
Figure 1. Forward Bias Safe Operating Area

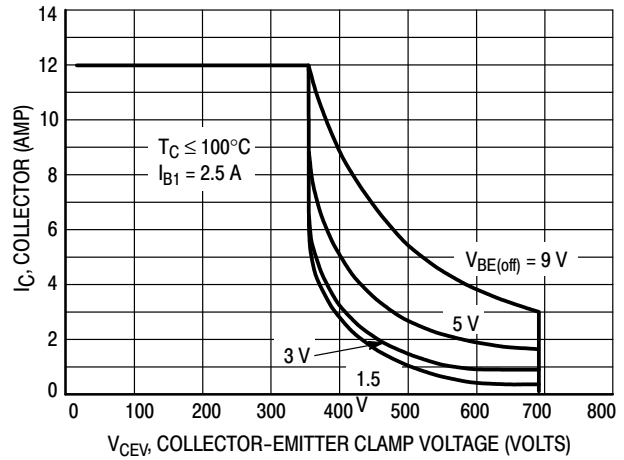Axes: I_C, COLLECTOR CURRENT (AMP) vs V_{CE}, COLLECTOR–EMITTER VOLTAGE (VOLTS)

Labels: 10 μs, 100 μs, 1 ms, dc, $T_C = 25°C$

— — — THERMAL LIMIT
— · — BONDING WIRE LIMIT
——— SECOND BREAKDOWN LIM-
CURVES APPLY BELOW RATED
V_{CEO}

Figure 2. Reverse Bias Switching Safe Operating Area

Axes: I_C, COLLECTOR CURRENT (AMP) vs V_{CEV}, COLLECTOR–EMITTER CLAMP VOLTAGE (VOLTS)

$T_C \leq 100°C$
$I_{B1} = 2.5$ A

$V_{BE(off)} = 9$ V, 5 V, 3 V, 1.5

The Safe Operating Area figures shown in Figures 1 and 2 are specified ratings for these devices under the test conditions shown.
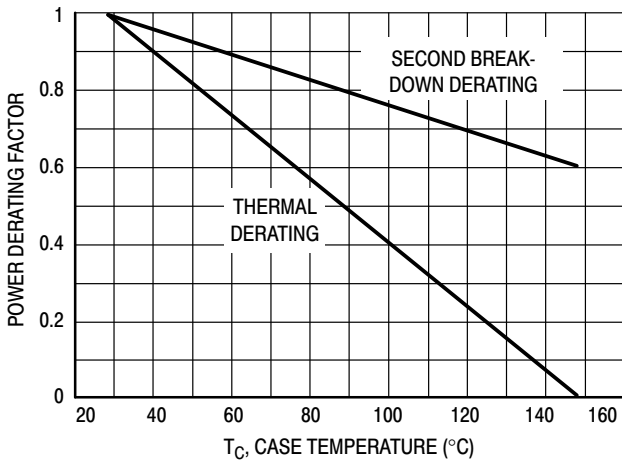
Figure 3. Forward Bias Power Derating

Axes: POWER DERATING FACTOR vs T_C, CASE TEMPERATURE (°C)

SECOND BREAK-DOWN DERATING
THERMAL 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 $T_C = 25°C$; $T_{J(pk)}$ 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 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.
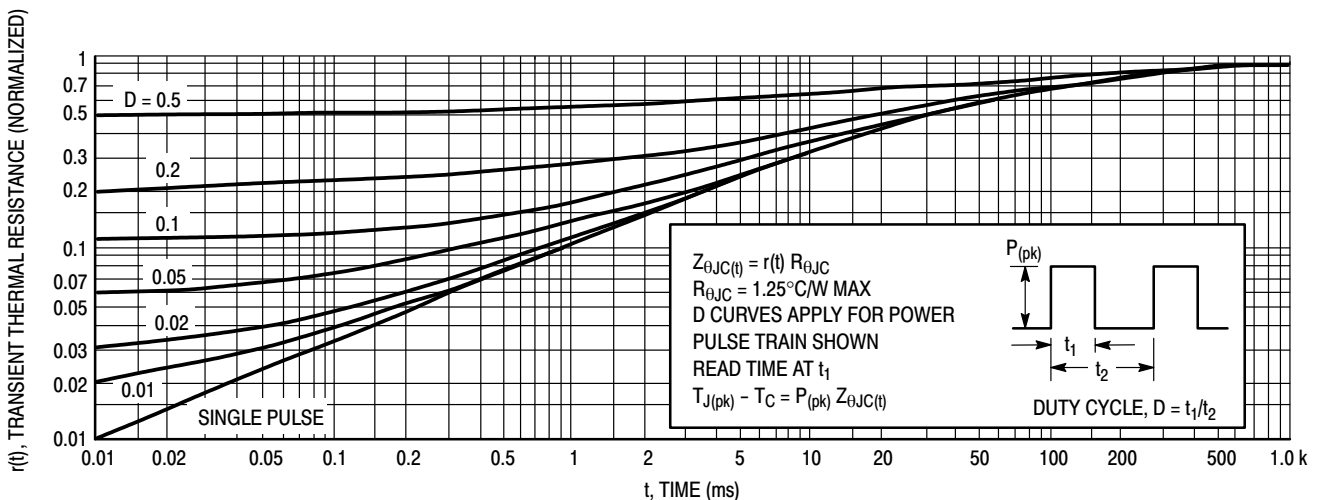

$Z_{\theta JC(t)} = r(t) R_{\theta JC}$
$R_{\theta JC} = 1.25°C/W$ MAX
D CURVES APPLY FOR POWER
PULSE TRAIN SHOWN
READ TIME AT t_1
$T_{J(pk)} - T_C = P_{(pk)} Z_{\theta JC(t)}$

DUTY CYCLE, $D = t_1/t_2$

Axes: $r(t)$, TRANSIENT THERMAL RESISTANCE (NORMALIZED) vs t, TIME (ms)

D = 0.5, 0.2, 0.1, 0.05, 0.02, 0.01, SINGLE PULSE

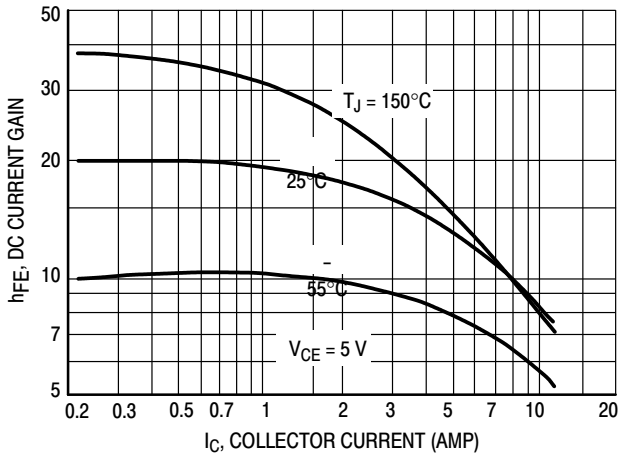Figure 4. Typical Thermal Response [$Z_{\theta JC}(t)$]
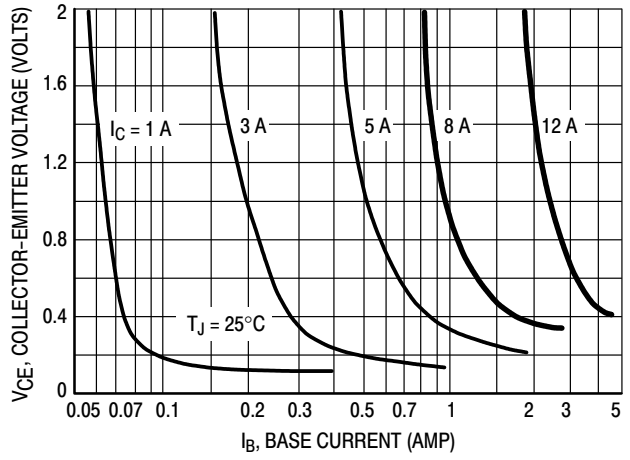
Figure 5. DC Current Gain

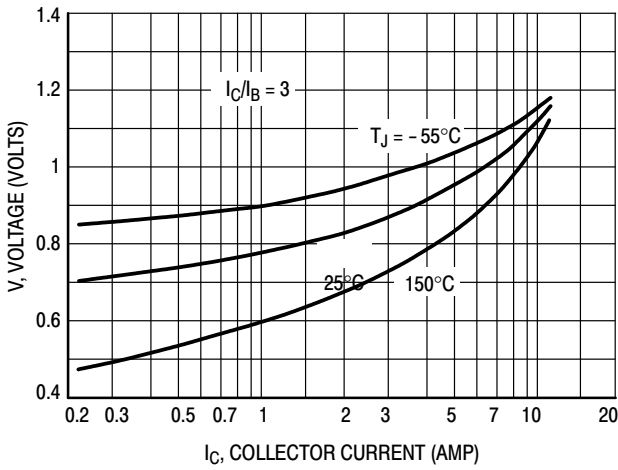Figure 6. Collector Saturation Region
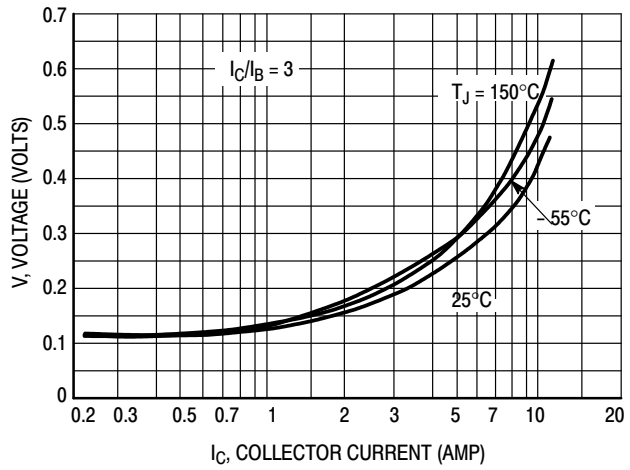
Figure 7. Base−Emitter Saturation Voltage

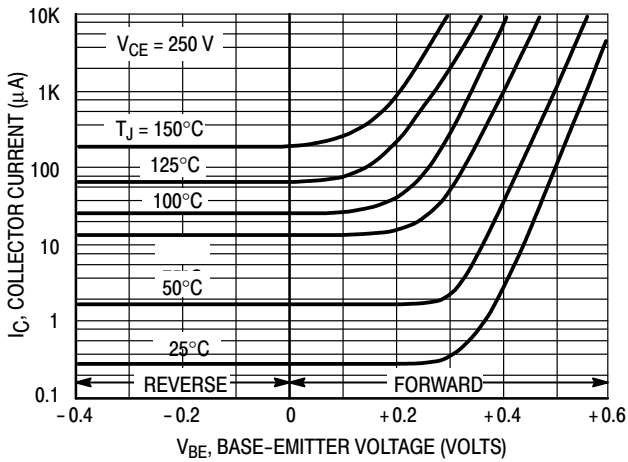Figure 8. Collector−Emitter Saturation
Voltage
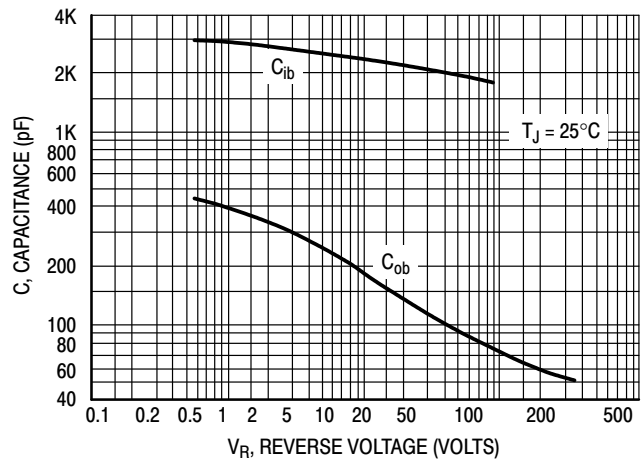
Figure 9. Collector Cutoff Region

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

DUTY CYCLE ≤ 10%
$t_r, t_f ≤ 10$ ns

NOTE
PW and V_{CC} Adjusted for Desired I_C
R_B Adjusted for Desired I_{B1}

*SELECTED FOR ≥ 1 kV

CIRCUIT VALUES

Coil Data:
Ferroxcube Core #6656
Full Bobbin (~16 Turns) #16

GAP for 200 µH/20 A
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 = Ω

TEST WAVEFORMS

OUTPUT WAVEFORMS

t_1 ADJUSTED TO OBTAIN I_C

$$t_1 ≈ \frac{L_{coil}(I_{CM})}{V_{CC}}$$

$$t_2 ≈ \frac{L_{coil}(I_{CM})}{V_{clamp}}$$

Test Equipment
Scope–Tektronics
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

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APPLICATIONS INFORMATION FOR SWITCH-MODE SPECIFICATIONS

INTRODUCTION

The primary considerations when selecting a power transistor for switch-mode 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. (Note 3)

VOLTAGE REQUIREMENTS

Both blocking voltage and sustaining voltage are important in switch-mode 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 V) 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.

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 switch-mode 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.

3. For detailed information on specific switching applications, see ON Semiconductor Application Notes AN−719, AN−767.
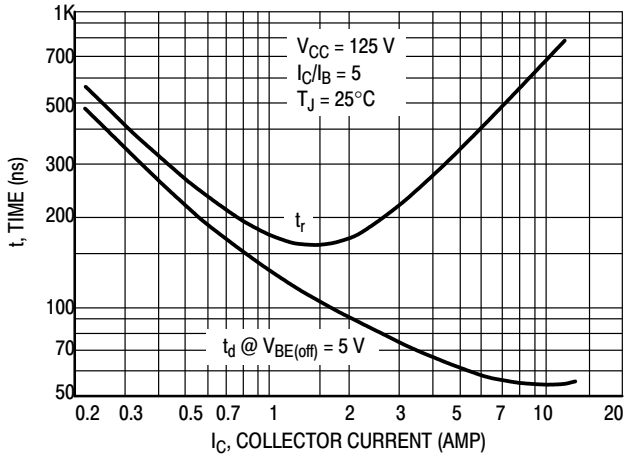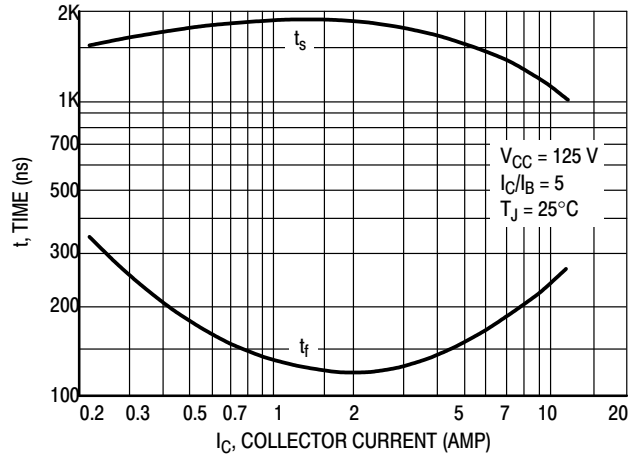
RESISTIVE SWITCHING PERFORMANCE

$V_{CC} = 125$ V
$I_C/I_B = 5$
$T_J = 25°C$

t_r

t_d @ $V_{BE(off)} = 5$ V

t, TIME (ns)

I_C, COLLECTOR CURRENT (AMP)

Figure 11. Turn−On Time

t_s

$V_{CC} = 125$ V
$I_C/I_B = 5$
$T_J = 25°C$

t_f

t, TIME (ns)

I_C, COLLECTOR CURRENT (AMP)

Figure 12. Turn−Off Time

I_C

90% V_{CEM} 90% I_C

V_{clamp}

t_{sv} t_{rv} t_{fi} t_{ti}

t_c

V_{clamp}

10% V_{CEM} 10% I_{CM} 2% I_C

I_B 90% I_{B1}
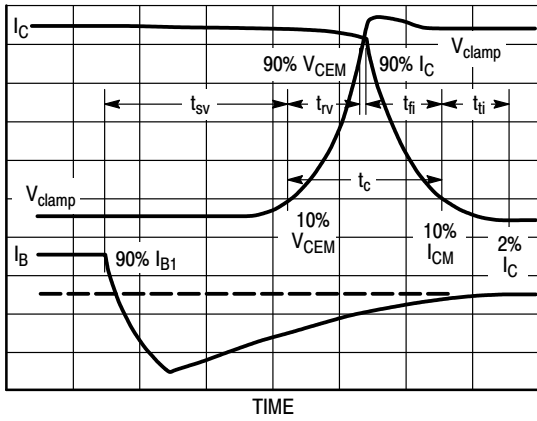
TIME

**Figure 13. Inductive Switching
Measurements**

I_C

V_{CE}

CURRENT 2 A/DIV

VOLTAGE 50 V/DIV

V_{CE}

I_C

TIME 20 ns/DIV
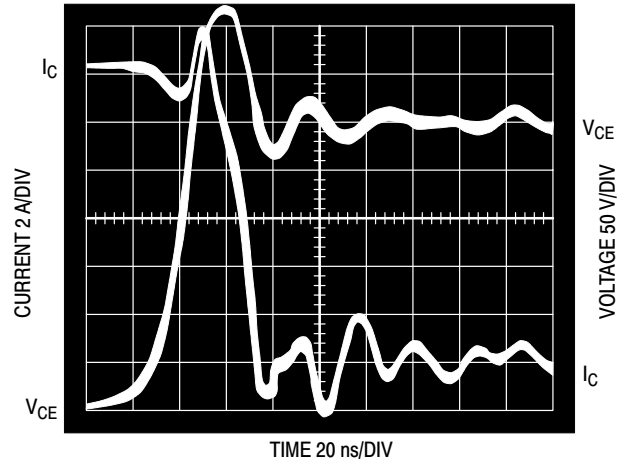
**Figure 14. Typical Inductive Switching Waveforms
(at 300 V and 12 A with I_{B1} = 2.4 A and $V_{BE(off)}$ = 5 V)**

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Table 2. Applications Examples of Switching Circuits
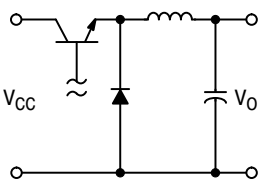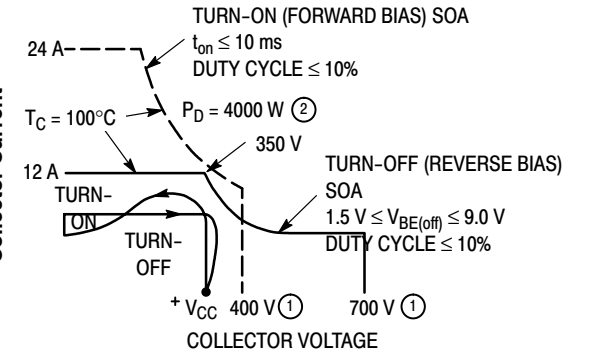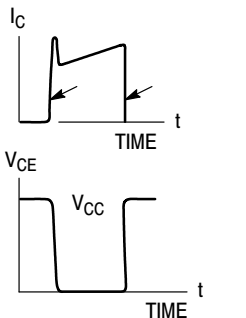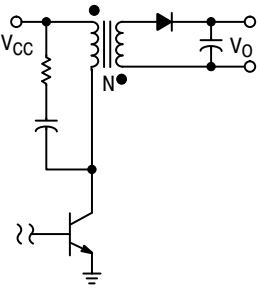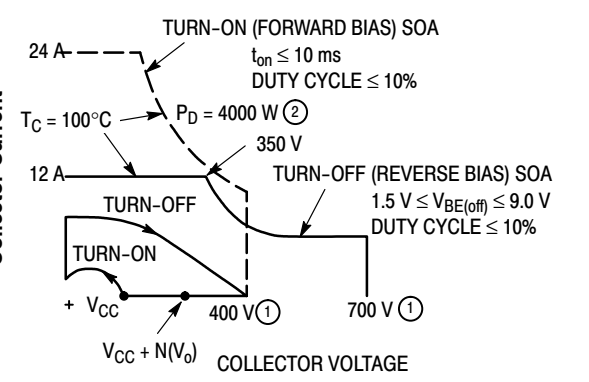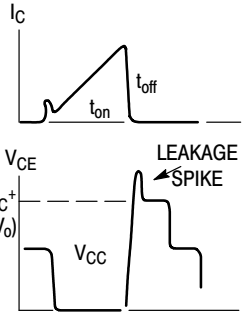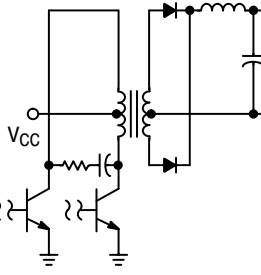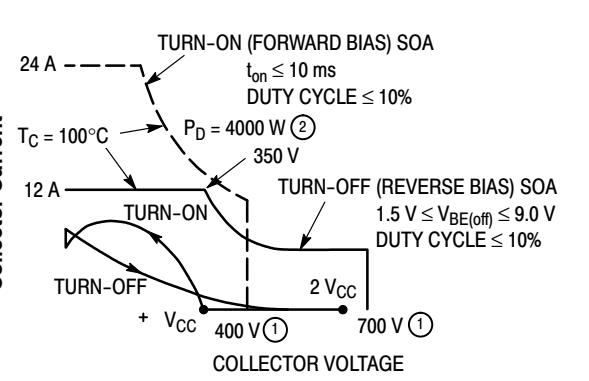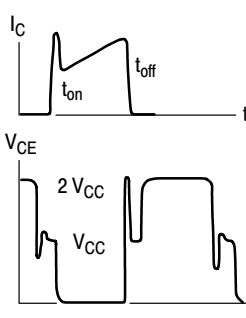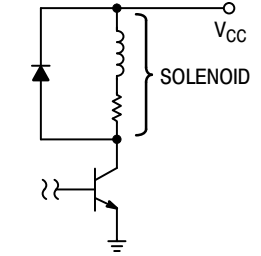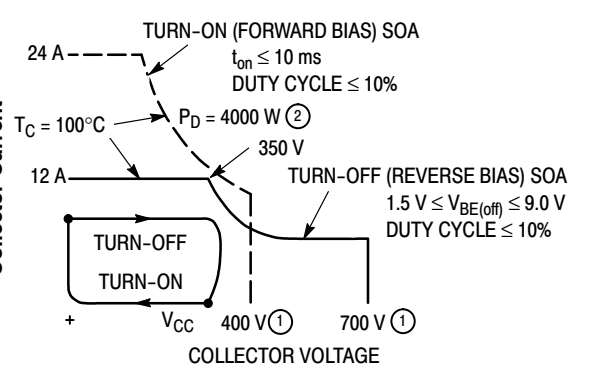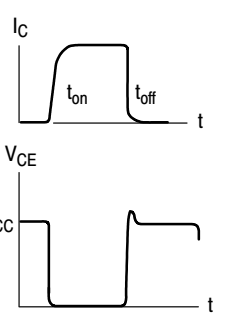
CIRCUIT	LOAD LINE DIAGRAMS	TIME DIAGRAMS
A **SERIES SWITCHING REGULATOR**		
B **RINGING CHOKE INVERTER**		
C **PUSH–PULL INVERTER/CONVERTER**		
D **SOLENOID DRIVER**		

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 switch-mode 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 AN222/D:

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

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 "switch-mode" transistor are the inductive switching speeds (t_c and t_{sv}) which are guaranteed at 100°C.

ADDITIONAL INFORMATION

TECHNICAL PUBLICATIONS:
Technical Library: www.onsemi.com/design/resources/technical–documentation
onsemi Website: www.onsemi.com

ONLINE SUPPORT: www.onsemi.com/support
For additional information, please contact your local Sales Representative at
www.onsemi.com/support/sales

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