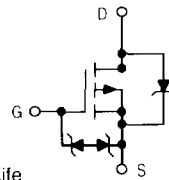


*Advance Information*

**Medium Power Surface Mount Products**  
**TMOS Single P-Channel with**  
**Monolithic Zener ESD**  
**Protected Gate**

EZFETs™ are an advanced series of power MOSFETs which utilize Motorola's High Cell Density TMOS process and contain monolithic back-to-back zener diodes. These zener diodes provide protection against ESD and unexpected transients. These miniature surface mount MOSFETs feature ultra low  $R_{DS(on)}$  and true logic level performance. They are capable of withstanding high energy in the avalanche and commutation modes and the drain-to-source diode has a very low reverse recovery time. EZFET devices are designed for use in low voltage, high speed switching applications where power efficiency is important. Typical applications are dc-dc converters, and power management in portable and battery powered products such as computers, printers, cellular and cordless phones. They can also be used for low voltage motor controls in mass storage products such as disk drives and tape drives.



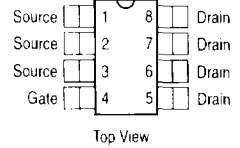
**MMSF4P01Z**

Motorola Preferred Device

**SINGLE TMOS**  
**POWER MOSFET**  
**4.0 AMPERES**  
**20 VOLTS**  
 $R_{DS(on)} = 0.070 \text{ OHM}$



**CASE 751-05, Style 12**  
**SO-8**



- Zener Protected Gates Provide Electrostatic Discharge Protection
- Ultra Low  $R_{DS(on)}$  Provides Higher Efficiency and Extends Battery Life
- Designed to withstand 200V Machine Model and 2000V Human Body Model
- Logic Level Gate Drive — Can Be Driven by Logic ICs
- Miniature SO-8 Surface Mount Package — Saves Board Space
- Diode Is Characterized for Use In Bridge Circuits
- Diode Exhibits High Speed, With Soft Recovery
- $I_{DSS}$  Specified at Elevated Temperature
- Mounting Information for SO-8 Package Provided

4

**MAXIMUM RATINGS** ( $T_J = 25 \text{ C}$  unless otherwise noted) \*

Rating	Symbol	Value	Unit
Drain-to-Source Voltage	$V_{DSS}$	20	Vdc
Drain-to-Gate Voltage ( $R_{GS} = 1.0 \text{ M}\Omega$ )	$V_{DGR}$	20	Vdc
Gate-to-Source Voltage - Continuous	$V_{GS}$	$\pm 8.0$	Vdc
Drain Current - Continuous @ $T_A = 25 \text{ C}$ (1)	$I_D$	5.7	Adc
- Continuous @ $T_A = 70 \text{ C}$ (1)	$I_D$	4.0	
- Pulsed Drain Current (3)	$I_{DM}$	46	Apk
Total Power Dissipation @ $T_A = 25 \text{ C}$ (1)	$P_D$	2.5	Watts
Linear Derating Factor (1)		20	mW/ C
Total Power Dissipation @ $T_A = 25 \text{ C}$ (2)	$P_D$	1.6	Watts
Linear Derating Factor (2)		12	mW/ C
Operating and Storage Temperature Range	$T_J, T_{stg}$	-55 to 150	C
Thermal Resistance - Junction to Ambient (1)	$R_{\theta JA}$	50	C/W
- Junction to Ambient (2)		80	

\* Negative sign for P-Channel omitted for clarity.

(1) When mounted on 1 inch square FR-4 or G-10 board ( $V_{GS} = 4.5 \text{ V}$ , @ 10 Seconds)

(2) When mounted on minimum recommended FR-4 or G-10 board ( $V_{GS} = 4.5 \text{ V}$ , @ Steady State)

(3) Repetitive rating, pulse width limited by maximum junction temperature.

**DEVICE MARKING**

**ORDERING INFORMATION**

S4P01Z	Device	Reel Size	Tape Width	Quantity
	MMSF4P01ZR2	13"	12 mm embossed tape	2500 units

This document contains information on a new product. Specifications and information are subject to change without notice.

Preferred devices are Motorola recommended choices for future use and best overall value.

REV 1

ELECTRICAL CHARACTERISTICS (T<sub>C</sub> = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
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OFF CHARACTERISTICS

Drain-to-Source Breakdown Voltage (V <sub>GS</sub> = 0 Vdc, I <sub>D</sub> = 250 μAdc) Temperature Coefficient (Positive)	(C <sub>pk</sub> ≥ 2.0) (1) (3) V <sub>(BR)DSS</sub>	20 —	— 16.6	— —	Vdc mV/°C
Zero Gate Voltage Drain Current (V <sub>DS</sub> = 12 Vdc, V <sub>GS</sub> = 0 Vdc) (V <sub>DS</sub> = 12 Vdc, V <sub>GS</sub> = 0 Vdc, T <sub>J</sub> = 125 C)	I <sub>DSS</sub>	— —	0.05 0.55	2.0 10	μAdc
Gate-Body Leakage Current (V <sub>GS</sub> = ± 8.0 Vdc, V <sub>DS</sub> = 0)	I <sub>GSS</sub>	—	0.15	5.0	μAdc

ON CHARACTERISTICS(1)

Gate Threshold Voltage (V <sub>DS</sub> = V <sub>GS</sub> , I <sub>D</sub> = 250 μAdc) Threshold Temperature Coefficient (Negative)	(C <sub>pk</sub> > 2.0) (1) (3) V <sub>GS(th)</sub>	0.7 —	0.85 2.5	1.1 —	Vdc mV/°C
Static Drain-to-Source On-Resistance (V <sub>GS</sub> = 4.5 Vdc, I <sub>D</sub> = 4.0 Adc) (V <sub>GS</sub> = 2.7 Vdc, I <sub>D</sub> = 2.0 Adc)	(C <sub>pk</sub> > 2.0) (1) (3) R <sub>DS(on)</sub>	— —	50 70	70 90	mΩ
Forward Transconductance (V <sub>DS</sub> = 3.0 Vdc, I <sub>D</sub> = 2.0 Adc)	(1) g <sub>FS</sub>	4.0	7.5	—	Mhos

DYNAMIC CHARACTERISTICS

Input Capacitance	(V <sub>DS</sub> = 10 Vdc, V <sub>GS</sub> = 0 Vdc, f = 1.0 MHz)	C <sub>iss</sub>	—	270	540	pF
Output Capacitance		C <sub>oss</sub>	—	825	1650	
Transfer Capacitance		C <sub>rss</sub>	—	100	200	

SWITCHING CHARACTERISTICS(2)

Turn-On Delay Time	(V <sub>DD</sub> = 6.0 Vdc, I <sub>D</sub> = 4.0 Adc, V <sub>GS</sub> = 4.5 Vdc, R <sub>G</sub> = 6.0 Ω) (1)	t <sub>d(on)</sub>	—	150	300	ns
Rise Time		t <sub>r</sub>	—	800	1600	
Turn-Off Delay Time		t <sub>d(off)</sub>	—	1420	2840	
Fall Time		t <sub>f</sub>	—	1830	3660	
Turn-On Delay Time	(V <sub>DD</sub> = 6.0 Vdc, I <sub>D</sub> = 4.0 Adc, V <sub>GS</sub> = 2.7 Vdc, R <sub>G</sub> = 6.0 Ω) (1)	t <sub>d(on)</sub>	—	260	520	ns
Rise Time		t <sub>r</sub>	—	1950	3900	
Turn-Off Delay Time		t <sub>d(off)</sub>	—	600	1200	
Fall Time		t <sub>f</sub>	—	1390	2780	
Gate Charge	(V <sub>DS</sub> = 10 Vdc, I <sub>D</sub> = 4.0 Adc, V <sub>GS</sub> = 4.5 Vdc) (1)	Q <sub>T</sub>	—	24	34	nC
		Q <sub>1</sub>	—	3.0	—	
		Q <sub>2</sub>	—	11	—	
		Q <sub>3</sub>	—	8.0	—	

SOURCE-DRAIN DIODE CHARACTERISTICS

Forward On-Voltage(1)	(I <sub>S</sub> = 4.0 Adc, V <sub>GS</sub> = 0 Vdc) (1) (I <sub>S</sub> = 4.0 Adc, V <sub>GS</sub> = 0 Vdc, T <sub>J</sub> = 125 C)	V <sub>SD</sub>	— —	1.1 0.75	1.8 —	Vdc
Reverse Recovery Time	(I <sub>S</sub> = 4.0 Adc, V <sub>GS</sub> = 0 Vdc, di/dt = 100 A/μs) (1)	t <sub>rr</sub>	—	373	—	ns
		t <sub>a</sub>	—	750	—	
		t <sub>b</sub>	—	1120	—	
Reverse Recovery Storage Charge		Q <sub>RR</sub>	—	9.0	—	μC

- (1) Pulse Test: Pulse Width ≤ 300 μs, Duty Cycle ≤ 2%.
- (2) Switching characteristics are independent of operating junction temperature.
- (3) Reflects typical values  

$$C_{pk} = \left| \frac{\text{Max limit} - \text{Typ}}{3 \times \text{SIGMA}} \right|$$

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TYPICAL ELECTRICAL CHARACTERISTICS

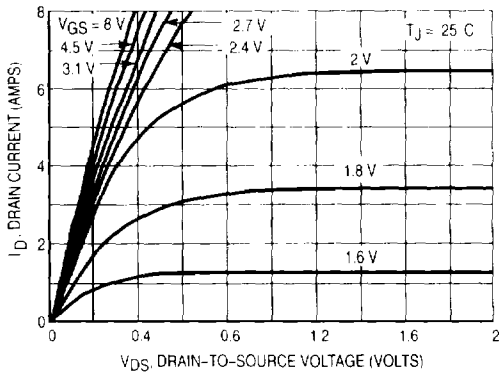


Figure 1. On-Region Characteristics

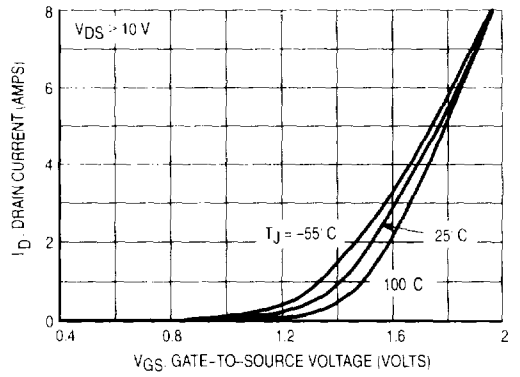


Figure 2. Transfer Characteristics

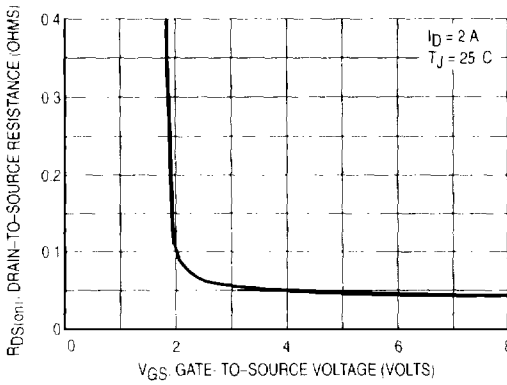


Figure 3. On-Resistance versus Gate-to-Source Voltage

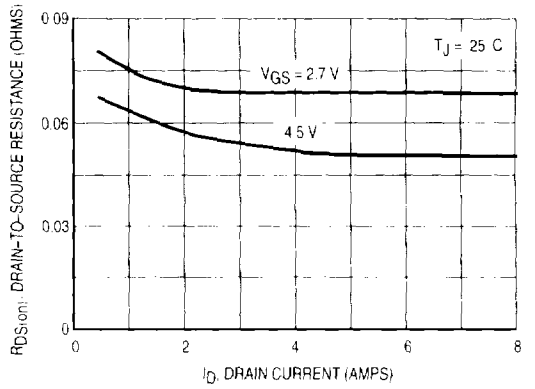


Figure 4. On-Resistance versus Drain Current and Gate Voltage

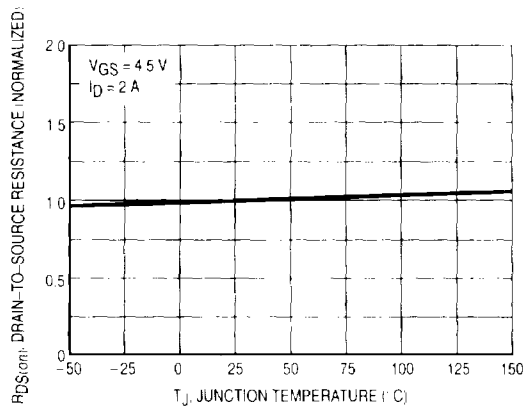


Figure 5. On-Resistance Variation with Temperature

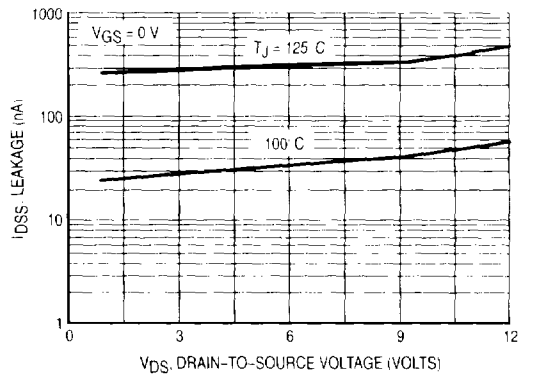


Figure 6. Drain-to-Source Leakage Current versus Voltage

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## POWER MOSFET SWITCHING

Switching behavior is most easily modeled and predicted by recognizing that the power MOSFET is charge controlled. The lengths of various switching intervals ( $\Delta t$ ) are determined by how fast the FET input capacitance can be charged by current from the generator.

The published capacitance data is difficult to use for calculating rise and fall because drain-gate capacitance varies greatly with applied voltage. Accordingly, gate charge data is used. In most cases, a satisfactory estimate of average input current ( $I_{G(AV)}$ ) can be made from a rudimentary analysis of the drive circuit so that

$$t = Q/I_{G(AV)}$$

During the rise and fall time interval when switching a resistive load,  $V_{GS}$  remains virtually constant at a level known as the plateau voltage,  $V_{GSP}$ . Therefore, rise and fall times may be approximated by the following:

$$t_r = Q_2 \times R_G / (V_{GG} - V_{GSP})$$

$$t_f = Q_2 \times R_G / V_{GSP}$$

where

$V_{GG}$  = the gate drive voltage, which varies from zero to  $V_{GG}$

$R_G$  = the gate drive resistance

and  $Q_2$  and  $V_{GSP}$  are read from the gate charge curve.

During the turn-on and turn-off delay times, gate current is not constant. The simplest calculation uses appropriate values from the capacitance curves in a standard equation for voltage change in an RC network. The equations are:

$$t_{d(on)} = R_G C_{iss} \ln [V_{GG}/(V_{GG} - V_{GSP})]$$

$$t_{d(off)} = R_G C_{iss} \ln (V_{GG}/V_{GSP})$$

The capacitance ( $C_{iss}$ ) is read from the capacitance curve at a voltage corresponding to the off-state condition when calculating  $t_{d(on)}$  and is read at a voltage corresponding to the on-state when calculating  $t_{d(off)}$ .

At high switching speeds, parasitic circuit elements complicate the analysis. The inductance of the MOSFET source lead, inside the package and in the circuit wiring which is common to both the drain and gate current paths, produces a voltage at the source which reduces the gate drive current. The voltage is determined by  $L di/dt$ , but since  $di/dt$  is a function of drain current, the mathematical solution is complex. The MOSFET output capacitance also complicates the mathematics. And finally, MOSFETs have finite internal gate resistance which effectively adds to the resistance of the driving source, but the internal resistance is difficult to measure and, consequently, is not specified.

The resistive switching time variation versus gate resistance (Figure 9) shows how typical switching performance is affected by the parasitic circuit elements. If the parasitics were not present, the slope of the curves would maintain a value of unity regardless of the switching speed. The circuit used to obtain the data is constructed to minimize common inductance in the drain and gate circuit loops and is believed readily achievable with board mounted components. Most power electronic loads are inductive; the data in the figure is taken with a resistive load, which approximates an optimally snubbed inductive load. Power MOSFETs may be safely operated into an inductive load; however, snubbing reduces switching losses.

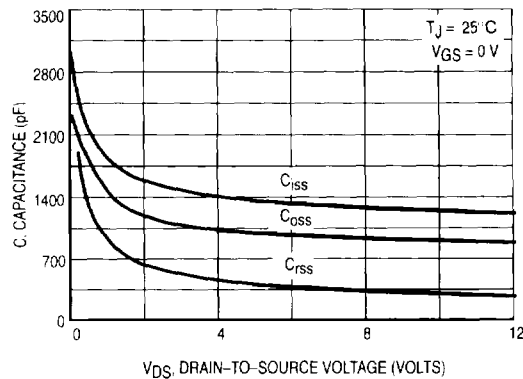
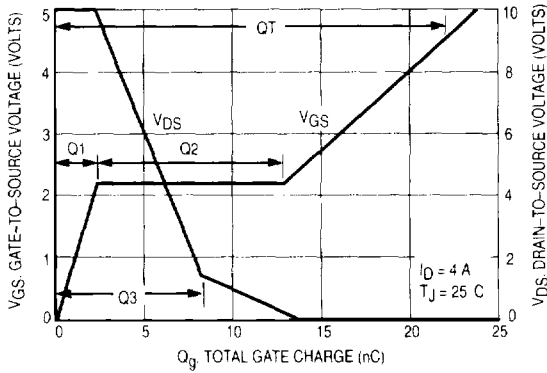
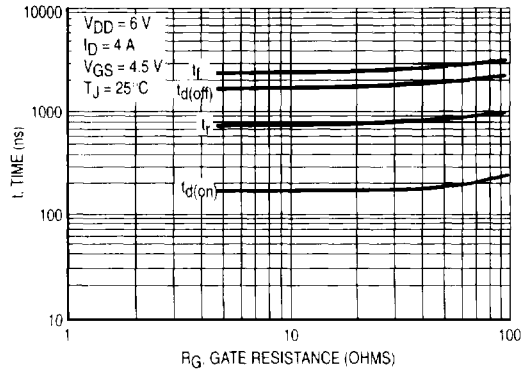


Figure 7. Capacitance Variation

**MMSF4P01Z**



**Figure 8. Gate-To-Source and Drain-To-Source Voltage versus Total Charge**



**Figure 9. Resistive Switching Time Variation versus Gate Resistance**

**DRAIN-TO-SOURCE DIODE CHARACTERISTICS**

The switching characteristics of a MOSFET body diode are very important in systems using it as a freewheeling or commutating diode. Of particular interest are the reverse recovery characteristics which play a major role in determining switching losses, radiated noise, EMI and RFI.

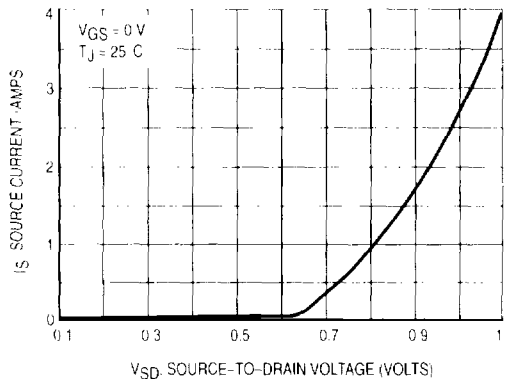
System switching losses are largely due to the nature of the body diode itself. The body diode is a minority carrier device, therefore it has a finite reverse recovery time,  $t_{rr}$ , due to the storage of minority carrier charge,  $Q_{RR}$ , as shown in the typical reverse recovery wave form of Figure 11. It is this stored charge that, when cleared from the diode, passes through a potential and defines an energy loss. Obviously, repeatedly forcing the diode through reverse recovery further increases switching losses. Therefore, one would like a diode with short  $t_{rr}$  and low  $Q_{RR}$  specifications to minimize these losses.

The abruptness of diode reverse recovery effects the amount of radiated noise, voltage spikes, and current ringing. The mechanisms at work are finite irremovable circuit parasitic inductances and capacitances acted upon by high

$di/dt$ s. The diode's negative  $di/dt$  during  $t_a$  is directly controlled by the device clearing the stored charge. However, the positive  $di/dt$  during  $t_b$  is an uncontrollable diode characteristic and is usually the culprit that induces current ringing. Therefore, when comparing diodes, the ratio of  $t_b/t_a$  serves as a good indicator of recovery abruptness and thus gives a comparative estimate of probable noise generated. A ratio of 1 is considered ideal and values less than 0.5 are considered snappy.

Compared to Motorola standard cell density low voltage MOSFETs, high cell density MOSFET diodes are faster (shorter  $t_{rr}$ ), have less stored charge and a softer reverse recovery characteristic. The softness advantage of the high cell density diode means they can be forced through reverse recovery at a higher  $di/dt$  than a standard cell MOSFET diode without increasing the current ringing or the noise generated. In addition, power dissipation incurred from switching the diode will be less due to the shorter recovery time and lower switching losses.

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**Figure 10. Diode Forward Voltage versus Current**

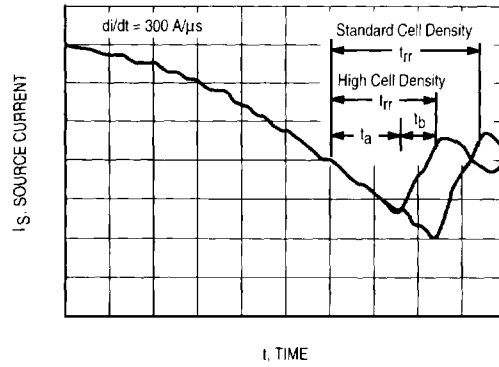


Figure 11. Reverse Recovery Time ( $t_{rr}$ )

**SAFE OPERATING AREA**

The Forward Biased Safe Operating Area curves define the maximum simultaneous drain-to-source voltage and drain current that a transistor can handle safely when it is forward biased. Curves are based upon maximum peak junction temperature and a case temperature ( $T_C$ ) of  $25^\circ\text{C}$ . Peak repetitive pulsed power limits are determined by using the thermal response data in conjunction with the procedures discussed in AN569, "Transient Thermal Resistance - General Data and Its Use."

Switching between the off-state and the on-state may traverse any load line provided neither rated peak current ( $I_{DM}$ ) nor rated voltage ( $V_{DSS}$ ) is exceeded, and that the transition time ( $t_r$ ,  $t_f$ ) does not exceed  $10 \mu\text{s}$ . In addition the total power averaged over a complete switching cycle must not exceed  $(T_{J(\text{MAX})} - T_C)/(R_{\theta\text{JC}})$ .

A power MOSFET designated E-FET can be safely used

in switching circuits with unclamped inductive loads. For reliable operation, the stored energy from circuit inductance dissipated in the transistor while in avalanche must be less than the rated limit and must be adjusted for operating conditions differing from those specified. Although industry practice is to rate in terms of energy, avalanche energy capability is not a constant. The energy rating decreases non-linearly with an increase of peak current in avalanche and peak junction temperature.

Although many E-FETs can withstand the stress of drain-to-source avalanche at currents up to rated pulsed current ( $I_{DM}$ ), the energy rating is specified for operating continuous current ( $I_D$ ), in accordance with industry custom. The energy rating must be derated for temperature. Maximum energy at currents below rated continuous  $I_D$  can safely be assumed to equal the values indicated.

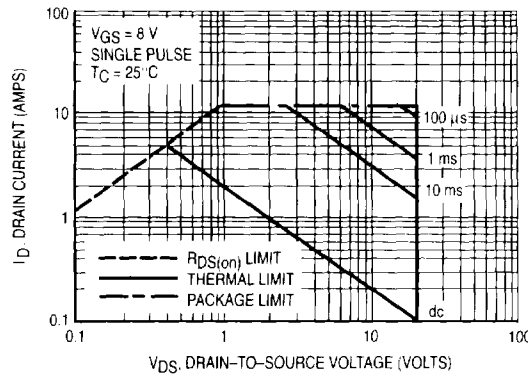


Figure 12. Maximum Rated Forward Biased Safe Operating Area

TYPICAL ELECTRICAL CHARACTERISTICS

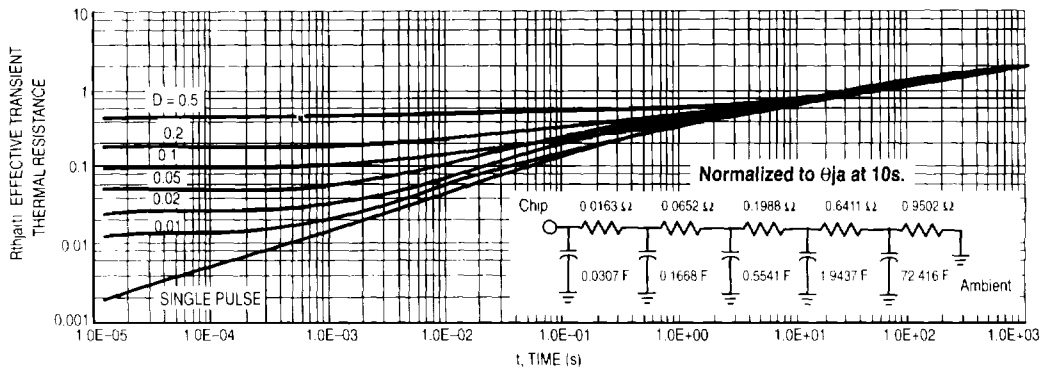


Figure 13. Thermal Response

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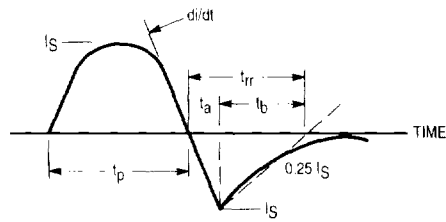


Figure 14. Diode Reverse Recovery Waveform