

INTERNATIONAL RECTIFIER



# INTELLIGENT HIGH-SIDE DMOS POWER SWITCH

# IR6000

## Avalanche Rated 60 Volts/100mΩ

### General Description

The IR6000 is a monolithic, fully self protected high side DMOS switch. Designed primarily for solenoid and inductive loads, the IR6000 provides a high clamp voltage ( $= V_{CC}$  minus the avalanche voltage of the output DMOS transistor body diode) to assure very rapid inductive current decay and a guaranteed avalanche energy rating for the diode.

The IR6000 has embedded output current limiting and thermal shutdown. In the event of an overload, the device goes into a pulse width modulated (PWM) current limiting mode to minimize power dissipation.

Open load detection is sensed when the output DMOS switch is in the off state by means of a resistor divider comprised of the load and an external resistor from  $V_{CC}$  to Output.

### Applications

- Relay Replacement
- DC Motor Drive
- Lamp Driver
- Solenoid Driver
- Valve Driver
- Contactor Driver

### Product Summary

$V_{CC}(\text{operation})$	5-35V
$I_{OUT(\text{MAX})}$	15A
$I_{OUT(\text{ISO})}$	3.5A
$V_{OUT(\text{CLAMP})}$	$V_{CC} - 72V$
$R_{DS(\text{ON})}$	100mΩ

### Features

- $(V_{CC} - 72V)$  output clamp voltage
- 100 mJ avalanche rating
- 175°C thermal shutdown
- 7A current limit for short circuit protection
- Open circuit detection in off state
- Diagnostic feedback
- LSTTL/CMOS compatible logic input

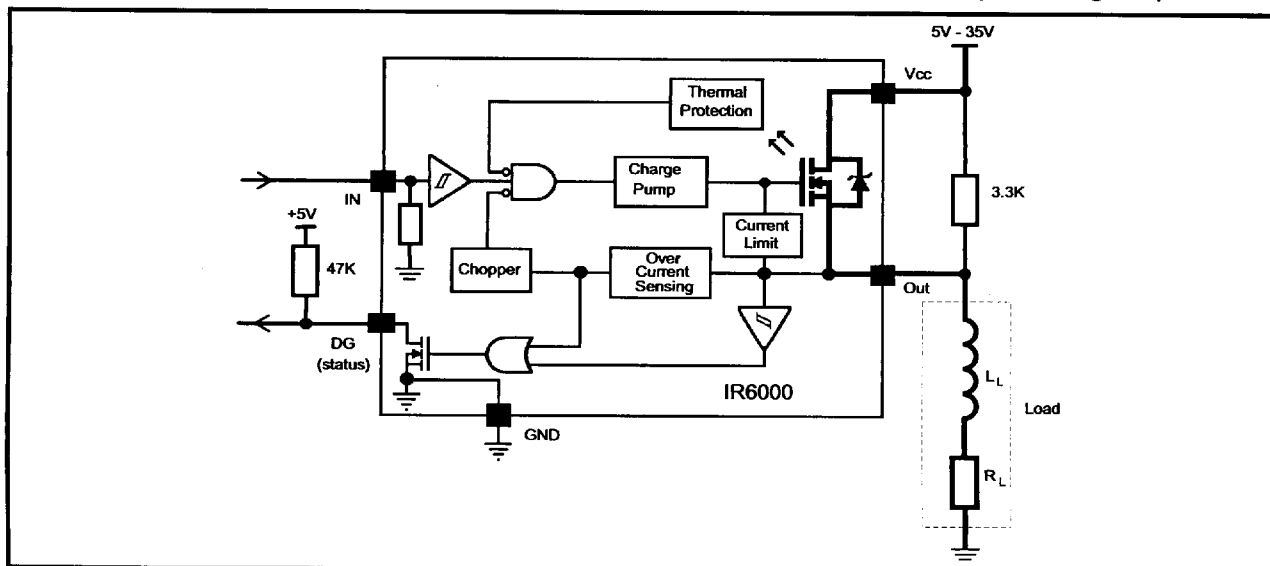


Fig. 1 — Block Diagram and Typical Connection

# IR6000

## Absolute Maximum Ratings ( $T_C = 25^\circ\text{C}$ unless otherwise noted)

Symbol	Parameter	Min	Max	Unit	Condition
$V_{CC}$	Supply Voltage	-0.3	60	V	
$V_{IN}$	Input Voltage	-0.3	30		$V_{CC} > 30\text{V}$
		-0.3	$V_{CC} + 0.3$		$V_{CC} \leq 30\text{V}$
$V_{OUT}$	Output Voltage	$V_{CC} - 60$	$V_{CC} + 0.3$		
$V_{DG}$	Diagnostic Voltage	-0.3	30	A	
$I_{OUT}$	Output Current		Self Limited		
$I_{AV}$	Output Avalanche Current ①		5	mJ	$I = 5\text{A}$
$E_{AV}$	Repetitive Avalanche Energy ②		100		
$I_{IN}$	Input Current		10	mA	
$I_{DG}$	Diagnostic Current		10		
$E_{SD1}$	Electrostatic Discharge Voltage - Human Body Model ③	4000		V	
$E_{SD2}$	Machine Model ④	1000			
$P_D$	Power Dissipation		40	W	$T_C = 25^\circ\text{C}$
$T_{JOP}$	Operating Junction Temperature Range	-40	150	$^\circ\text{C}$	
$T_{STG}$	Storage Temperature	-40	150		
	Soldering Temperature, for 10 sec.		300		1.6mm from case

## Electrical Characteristics ( $V_{CC} = 14\text{V}$ , $T_C = 25^\circ\text{C}$ , $R_L = 7\Omega$ unless specified otherwise)

Symbol	Parameter	Min	Typ	Max	Unit	Condition
$V_{CC(OP)}$	Operating Voltage Range	5	-	35	V	
$I_{CC(OFF)}$	Supply Current	-	2	5	mA	$V_{IN} = 0\text{V}$
$I_{CC(ON)}$		-	2.5	5		$V_{IN} = 5\text{V}$
$V_{IH}$	High Level Input Threshold	-	2.4	3.5	V	
$V_{IL}$	Low Level Input Threshold	1.5	2.3	-		
$I_{IH1}$	Input Current	50	150	300	$\mu\text{A}$	$V_{IN} = 5\text{V}$
$I_{IH2}$		-	1.5	5	mA	$V_{IN} = 30\text{V}$ $V_{CC} = 30\text{V}$
$V_{DGL}$	Diagnostic Output Low Level	-	0.3	0.6	V	$I_{DG} = 0.6\text{mA}$
$I_{DGH}$	Diagnostic Output Leakage	-	0	10	$\mu\text{A}$	$V_{DG} = 5\text{V}$
$I_{ISO}$	Output Current	-	3.5	-	A	ISO: $V_{DS(ON)} = 0.5\text{V}$ , $85^\circ\text{C}$
$R_{DS(ON)}$	"On State" Resistance	-	75	100	m $\Omega$	$V_{CC} = 14\text{V}$
		-	80	-		$V_{CC} = 8\text{V}$
		-	120	-		$V_{CC} = 5\text{V}$
$I_{OL}$	Output Leakage Current	-	0.001	0.4	mA	$V_{OUT} = 0\text{V}$
$I_{OH}$		-	-0.05	-2		$V_{OUT} = 14\text{V}$
$V_{open}$	Open Load Detection Threshold Voltage	2	3.3	4	V	
$I_{LIM1}$	Internal Current Limit	4	7	10	A	$V_{CC} = 14\text{V}$
$I_{LIM2}$		-	5	-		$V_{CC} = 8\text{V}$
$V_{PK}$	Current Limit $V_{DS}$ Threshold Voltage	-	2.8	-	V	
$I_{PK}$	Peak Output Current	-	30	-	A	
$t_{PK}$	Peak Current Duration	-	50	-	$\mu\text{s}$	
$f_C$	Over-Current Cycling Frequency	400	600	1000	Hz	
Dc	Over-Current Duty Cycle	5	15	25	%	
$t_{d(on)1}$	Turn-On Delay Time	-	40	200	$\mu\text{s}$	
$t_{r1}$	Rise Time	-	60	200		
$t_{d(off)1}$	Turn-Off Delay Time	-	100	200		
$t_{f1}$	Fall Time	-	40	200		
$V_{AV}$	Output Avalanche Voltage	60	72	-	V	$I_D = 2\text{A}$

## Thermal Characteristics

Symbol	Parameter	Min	Typ	Max	Unit
$T_{JSD}$	Over Temperature Shutdown Threshold	—	175	—	°C
$T_{HYS}$	Over Temperature Shutdown Hysteresis	—	5	—	
$R_{\theta JC}$	Thermal Resistance, Junction to Case	—	3	—	°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	—	50	—	

## Notes:

- ① Repetitive avalanche energy shall not be exceeded
- ② The maximum junction temperature  $T_{jop}$  shall not be exceeded
- ③  $C = 100\text{pF}$ ,  $R = 1500\Omega$
- ④  $C = 200\text{pF}$ ,  $R = 0\Omega$

## Truth Table

Condition	In	Out	DG
Normal	H	H	H
Normal	L	L	L
Open Load	H	H*	H
Open Load	L	H*	H
Shorted Output	H	Current Limiting	L
Shorted Output	L	L	L
Over-Temperature	H	L	L
Over-Temperature	L	L	L

\*With external pull-up resistor

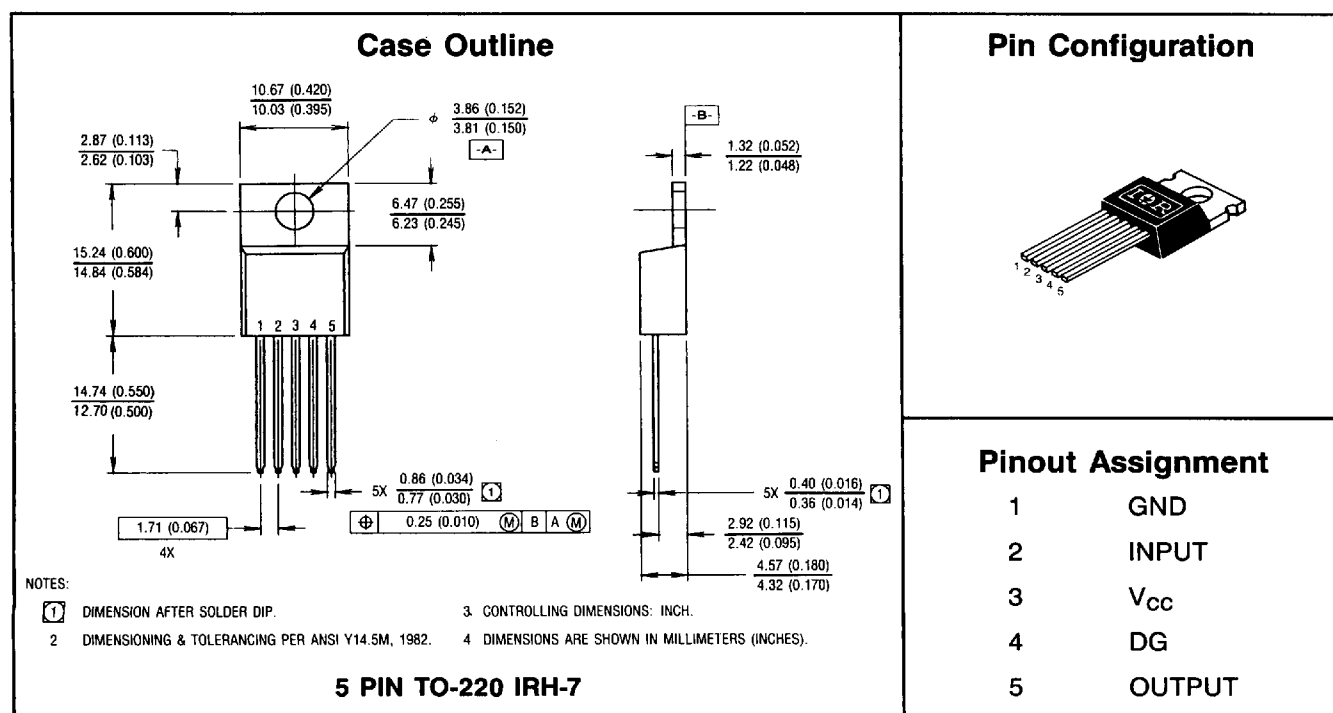


Fig. 2 - Package Information

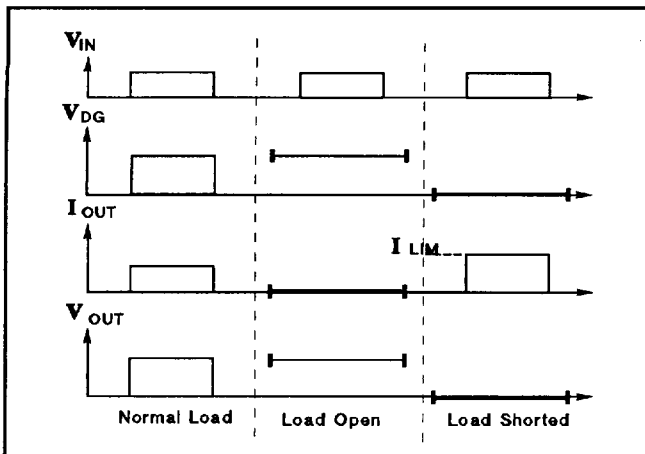


Fig. 3 - Typical Waveforms

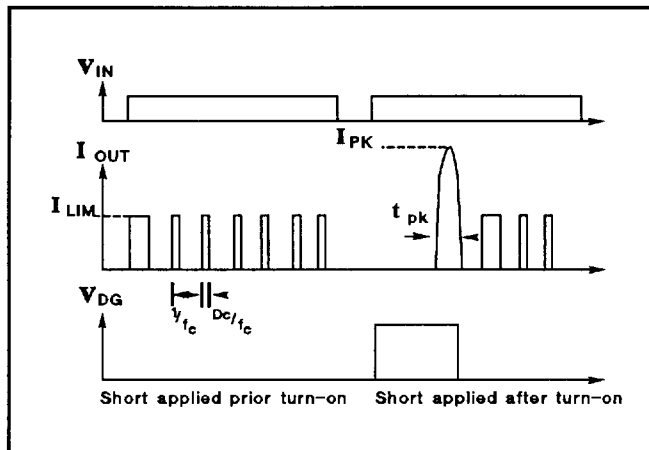


Fig. 4 - Detail of Short Circuit Operation

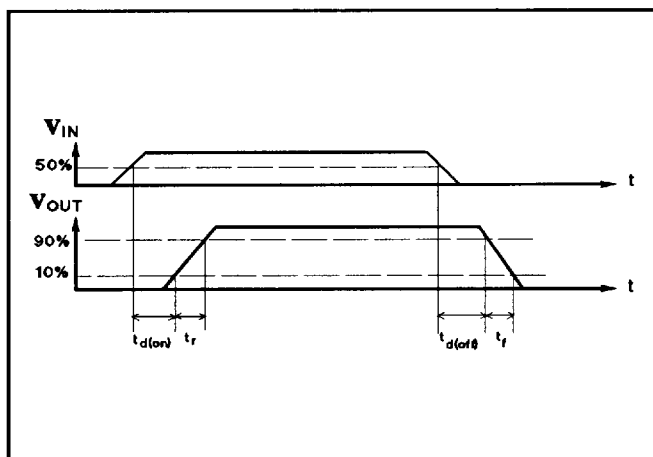


Fig. 5 - Switching Time Definition

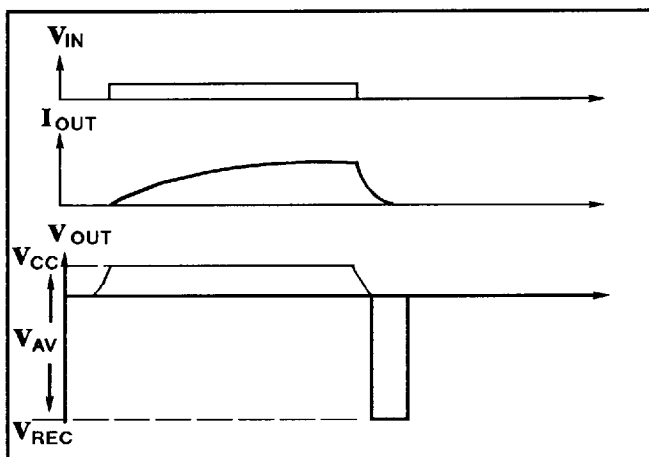


Fig. 6 - Inductive Load Switching

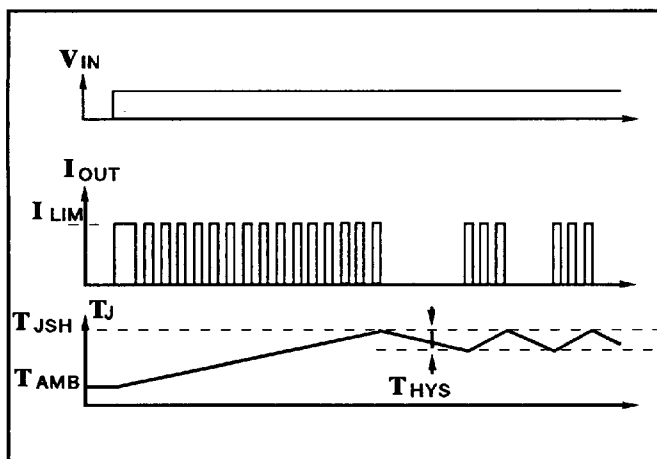


Fig. 7 - Thermal Cycling on a Permanent Short Circuit

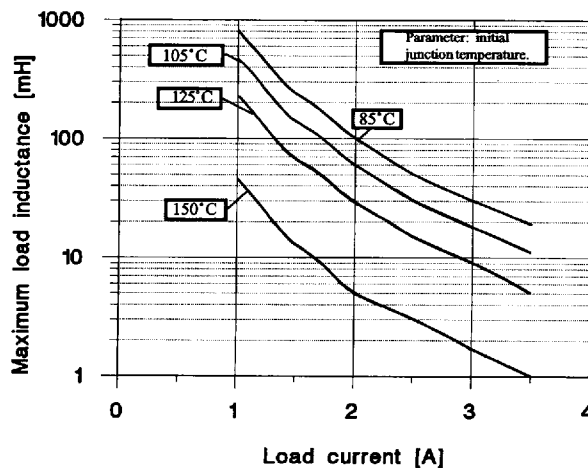


Fig. 8 - Maximum Output Current vs. Load Inductance for Single Pulse Avalanche Operation ( $V_{CC} = 14V$ )

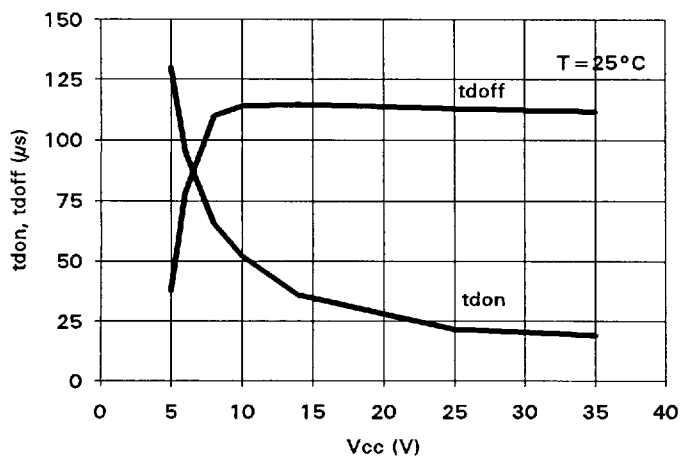


Fig. 9 - Delay Time vs.  $V_{cc}$

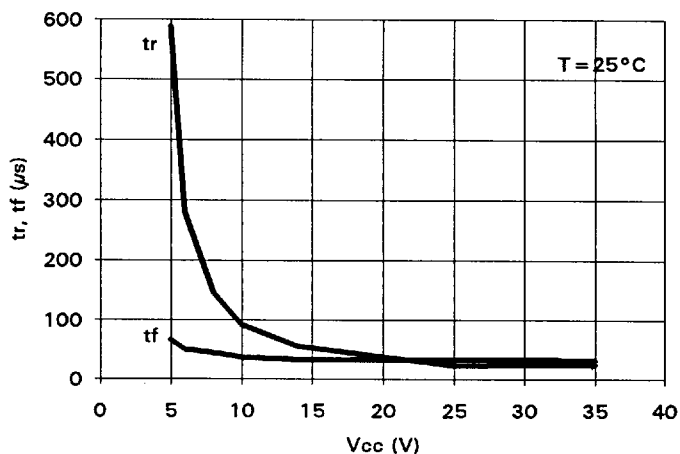


Fig. 10 - Switching Time vs.  $V_{cc}$

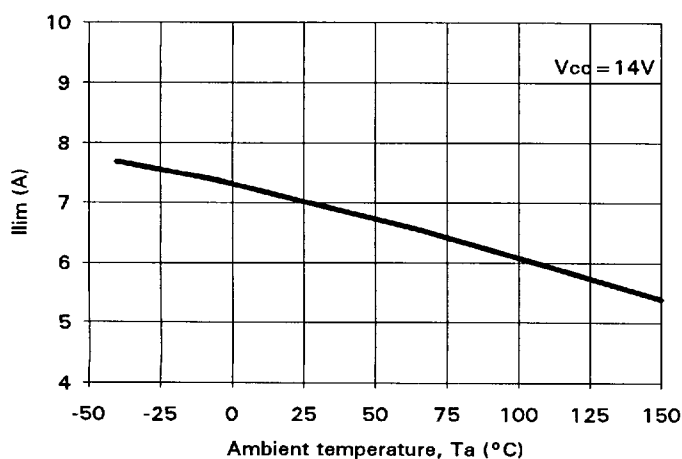


Fig. 11 -  $I_{LIM}$  vs. Temperature

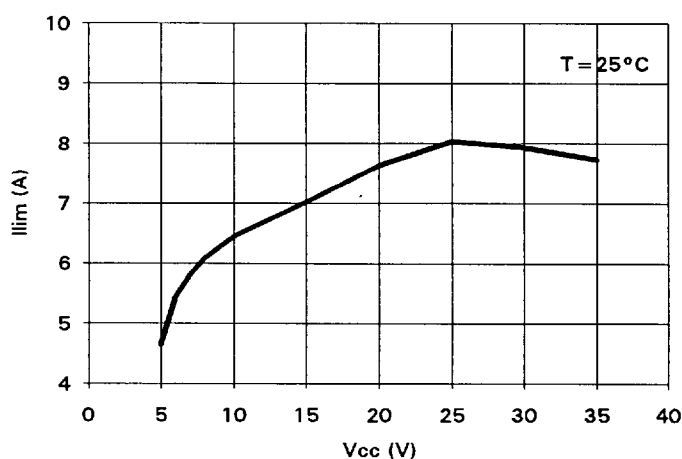


Fig. 12 -  $I_{LIM}$  vs.  $V_{cc}$

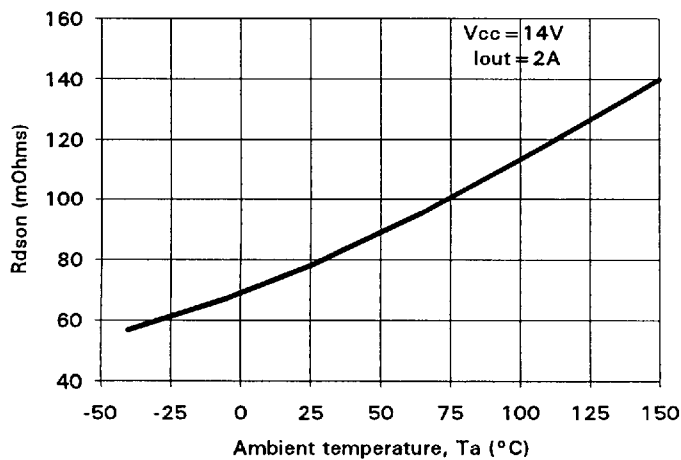


Fig. 13 -  $R_{DS(ON)}$  vs. Temperature

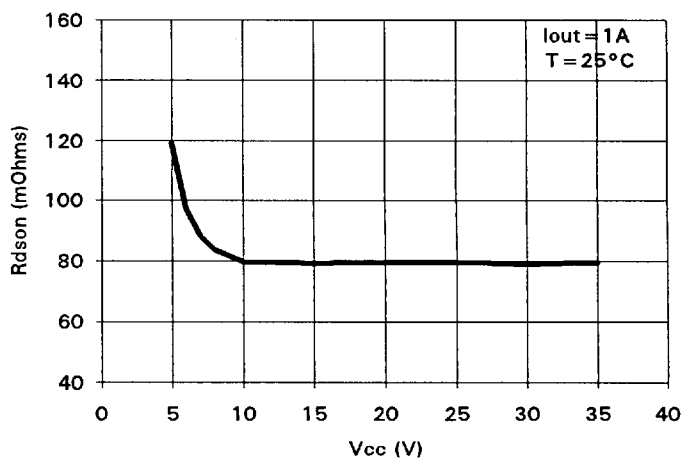


Fig. 14 -  $R_{DS(ON)}$  vs.  $V_{cc}$

## Application Information

### Introduction

High-side switches are commonly used in automotive and industrial applications. The high-side switch isolates the wiring and load from the positive terminal of the power supply or battery. If the wiring or load short circuits to the negative terminal of the power supply or battery (body of the car), the circuit can be protected from the effect of excessive current by turning off the high-side switch. This configuration also prevents the load being energized at ground short fault. The IR6000 contains all the protection circuitry required to build a fully protected circuit in a harsh industrial or automotive environment.

### General Description

The IR6000 is a fully protected, monolithic high-side switch with an  $75\text{m}\Omega$  DMOS output device, intended for industrial and automotive applications. The IR6000 is available in a 5-pin TO-220 plastic package with industry standard pin-out offering easy upgrade from other devices. Excellent ESD and fault condition circuitry protects the IR6000 during both installation and operation. Low on-resistance minimizes conduction loss, allowing free air operation in many applications. The 72V negative transient clamp capability provides fast turn-off of unclamped inductive loads like valves and fuel injectors. The slow switching speed minimizes conducted and radiated electromagnetic noise.

### Block Diagram

The block diagram of the IR6000 is shown in Figure 1 (front page). The input signal is received by a logic-level compatible CMOS schmitt trigger. A 20k pull down resistor between the input and ground keeps the input low if the input pin is not connected. During normal

operation, the output of the AND gate follows the output of the input buffer.

The charge pump starts generating gate voltage for the MOSFET at the output when logic "1" appears at the output of the AND gate. The output of the AND gate is also affected by output of the thermal protection and the chopper circuits. The thermal protection inhibits the operation of the IR6000 when the junction temperature exceeds the upper temperature threshold and restores operation when the junction temperature drops by  $5^{\circ}\text{C}$ , the temperature hysteresis.

The over-current limiting circuit turns the protection on when the drain-source voltage of the output device exceeds the predefined threshold level. During the overcurrent condition, the chopper periodically turns the MOSFET on, checking the conditions at the output. If the load current drops under the overcurrent threshold level, the IR6000 restores normal operation. The open drain diagnostic (DG) output requires an external pull-up resistor to the logic power. During normal operation, the DG output follows the input signal, and at fault condition it opposes the input (for details see truth table). The changing DG output makes possible continuous monitoring of the protection circuit and related wiring.

### Short Circuit Protection

The IR6000 protects itself against excessive load currents and hard shorts at the output. When the output is shorted to ground, the IR6000 sets the output MOSFET linear mode and limits the output current at 7A. To reduce the power dissipation the output is pulsed with 600Hz frequency and 20% duty cycle. With the removal of the short the IR6000 returns to normal operation. Typical waveforms are shown in Figure 15.

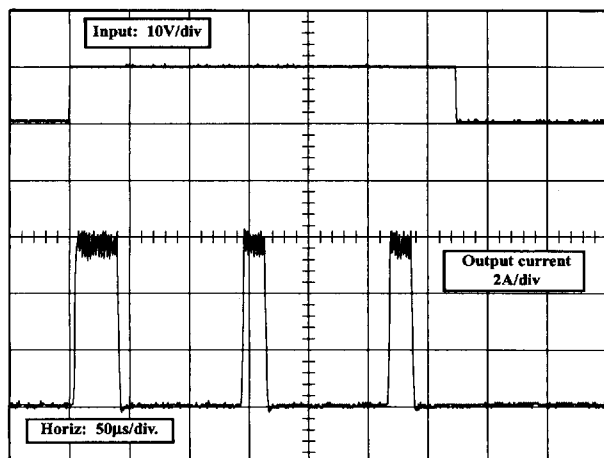


Fig. 15 – The IR6000 turns on into a short, and limits the output current and cycles the output to minimize the power dissipation.

When the output current increases slowly, typical for inductive loads the MOSFET does not go into linear mode, and the current threshold is set to

$$I_{\max} = 2.8V/R_{DS(ON)}$$

Where:  $R_{DS(ON)}$  is the on-resistance of the fully enhanced MOSFET at the junction temperature where the current limiting is activated.

Typical waveforms are shown in Figure 16. The current in the 0.8mH inductive load ramps up to 24A where the current limiting shuts down the output.

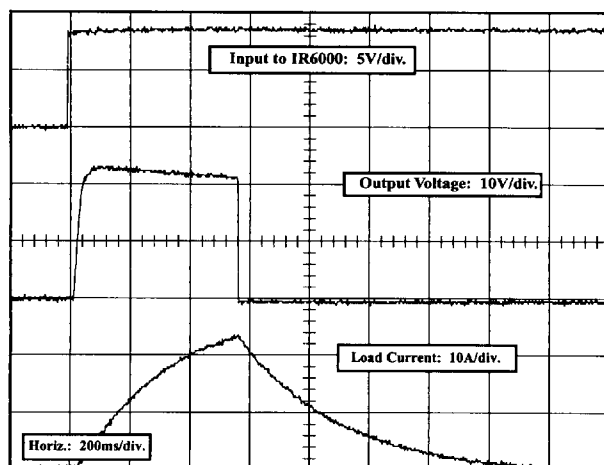


Fig. 16 – Limiting slow rising current. While the IR6000 drives a 0.8mH inductor, the current limiting turns the high-side switch off at 24A. The current threshold is set by an internal 2.8V reference and the on-resistance of the internal MOSFET.

## Thermal Protection

The IR6000 can be operated without a heatsink in many applications due to the low  $R_{DS(ON)}$  of the MOSFET. Handling extreme conditions, the thermal protection circuit continuously monitors the junction temperature and disables the output if the junction temperature exceeds 175°C. Normal operation will be restored when the junction temperature drops under 170°C. Figure 17 illustrates the operation of the overtemperature shut down circuit. For the test, the input of the IR6000 was held continuously high while the output was connected to ground via a 0.5Ω resistor. The heavily overloaded IR6000 was operating in overcurrent cycling mode until the junction temperature reached 175°C, where the overtemperature protection turned the output off. The output turned back on after 310ms, when the junction temperature dropped under 170°C.

## Avalanche Capability

The fully characterized avalanche capability of the IR6000 allows designing high speed circuits for inductive loads without the use of freewheeling diodes. Figure 18 shows the difference in switching speed between the freewheeling diode and by taking the MOSFET into avalanche. Utilizing the avalanche capability of the IR6000, this results in a turn-off delay of a NEMA size 4 contactor over the freewheeling diode circuit by a factor of three.

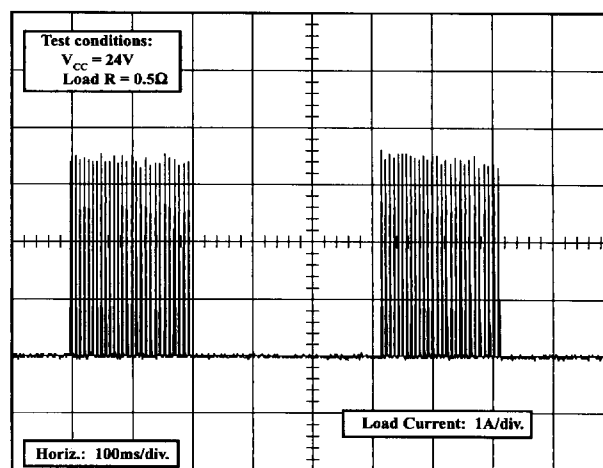


Fig. 17 – Thermal cycling. As the junction temperature of the heavily overloaded IR6000 reaches 175°C, the overtemperature protection turns off the output. After about 310ms the junction temperature falls under 170°C and the IR6000 returns to overcurrent cycling mode.

## IR6000

The speed improvement can significantly extend the lifetime of the contacts by reducing arcing. The higher speed can be utilized in other electro-mechanical systems as well such as ABS systems, fuel injectors, hydraulic, and pneumatic valves.

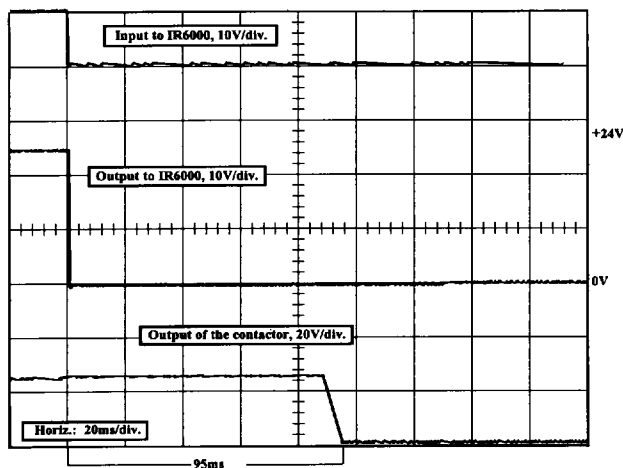
During avalanche, the voltage difference across the load is 48V, which can be calculated:

$$V_{REC} = V_{AV} - V_{CC}$$

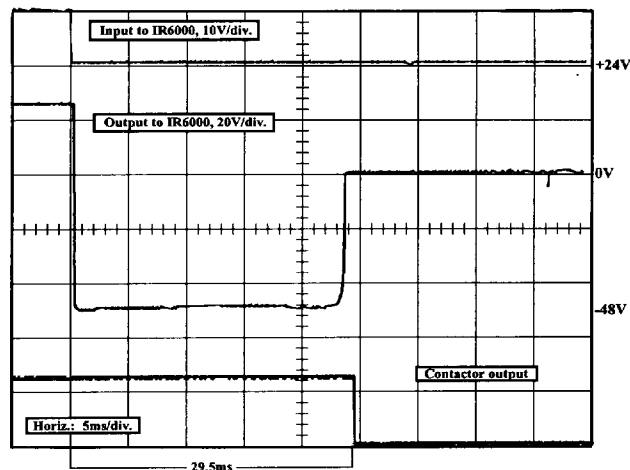
Where:  $V_{AV}$  is the avalanche voltage of the IR6000 between the  $V_{CC}$  and  $V_{OUT}$  pins. The typical value of  $V_{AV}$  is 72V.  $V_{CC} = 24V$ .

The maximum single pulse energy and the power dissipation due to repetitive avalanche operation are limited by the maximum junction temperature. The maximum avalanche current should not be exceeded.

Figures 18a and b indicate three times response time improvement at turn off of a NEMA size 4 contactor when the avalanche capability of the IR6000 is utilized.



**Fig. 18a** – Waveforms with freewheeling diode. The response time of the contactor is 95ms.



**Fig. 18b** – With utilizing the avalanche capability of the IR6000 the response time is 29.5ms.



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