

Application Note AN- 1122

Features of the high-side family IPS70xx-P3-75V

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Table of Contents

	Page
Introduction.....	2
Typical connection.....	2
Ground connection	2
Diagnostic.....	3
Open load detection when OFF	3
Short circuit detection when ON	3
Over temperature detection when ON	3
Protections	3
Current limitation-Temperature cycling.....	3
Ground loss protection	4
Active clamp	4
Reverse battery	6
Maximum voltage ratings.....	6
Recommended operating conditions	6
Driving the high side for reliability.....	6

Topics Covered

Inner Architecture

- Introduction
- Diagnostic
- Protections
- Active clamp and maximum inductive load
- Reverse battery

Typical Application

- Filament bulbs
- Solenoids
- Valves

Introduction

The new IPS70xx family of protected power MOSFETs consists of five terminal high side devices based on the latest IR proprietary vertical technology called P³ (Power Product Platform) with 75V voltage capability. IR protected MOSFETs are vertical power MOSFETs with integrated protection circuitry. The new IPS70XX family features a more efficient power MOSFET with active clamp and integrated protections for over-temperature, current limitation from over-current and active clamp.

IPS70xx family features a logic level input(IN), a logic ground pin(GND) isolated from power GND and a diagnostic pin (DG). An internal charge pump circuit allows the MOSFET to be driven in a high side configuration without the need of additional external components.

This application note explains the features of the high side family, helps the designer to understand how it works and provides suggestions on how to use these devices in the automotive environment.

Typical connection

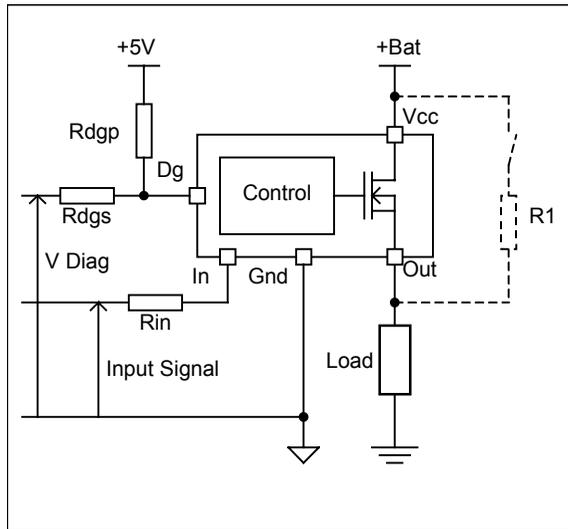
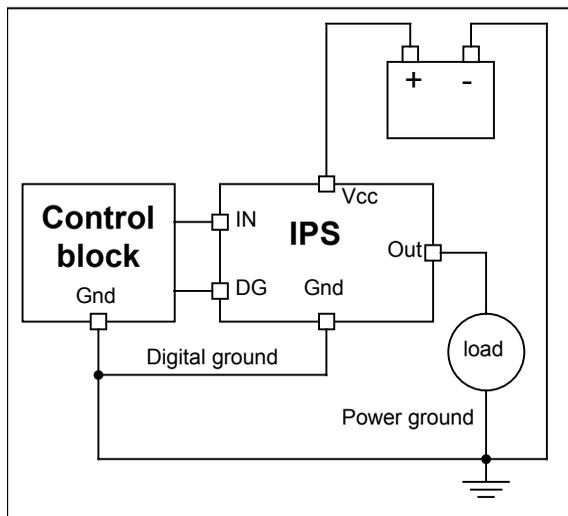


Figure 1 : Typical connection

Rin and Rdgs provide the protection for the controller during reverse battery and negative pulses on Vbat. R1 is required if the user want to use the open load detection.

Ground connection



The GND pin is the reference for the input and the DG pin and should be connected to the digital ground of the control block, so the load current does not flow into the

digital ground. If the GND pin is connected to the power ground, the load current will cause voltage difference in the ground path and could shift the input threshold.

Diagnostic

Diagnostic features are used to communicate the status of the IPS to the microcontroller. The IPS protects itself against different kind of faults, such as: over current, over temperature and open load. Once a fault condition is detected by the IPS, the diagnostic information is made available through a separate pin(DG). The truth table is shown in Table1.

Operating Conditions	IN	OUT	DG pin
Normal	H	H	H
Normal	L	L	L
Open Load	H	H	H
Open Load ⁽³⁾	L	H	H
Short circuit to Gnd	H	L(limiting)	L
Short circuit to Gnd	L	L	L
Over-temperature	H	L(cycling)	L
Over-temperature	L	L	L

Table 1. Diagnosis truth table

⁽³⁾ With a pull-up resistor connected between the output and Vcc.

Open load detection when OFF

There are cases in which the detection of an open-load is requested also when the load is OFF. In this case the micro-controller is aware of the open load as soon as it happens.

The IPS can detect this condition as well, but an external pull-up resistor is needed.

When the power MOSFET is OFF the open load condition is detected by comparing the OUT voltage to the GND. In the normal condition, the load is connected to GND and no current (beside the output leakage) flows into the load. The Source voltage will be almost zero. If the load is disconnected, an external resistor pulls-up the output so that the open load condition is detected by an integrated comparator.

Short circuit detection when ON

When the part is on, the diagnostic detects a short circuit because Vbat - Vout is higher than the short circuit detection voltage(Vsc in the datasheet).

Over temperature detection when ON

The over temperature condition is detected when the input is high by a thermal sensor.

Protections

The IPS70xx family features protections in order to prevent device failures during short circuit or over temperature. After a fault condition is removed, the part restarts automatically. During active clamp and reverse battery there is no protection.

Current limitation-Temperature cycling

When the output is shorted to ground, the device limits the current by driving the MOSFET into linear mode. The power dissipation is high in this mode, so the temperature protection will stop the device. The device will restart when the junction temperature cools down by 7°C.

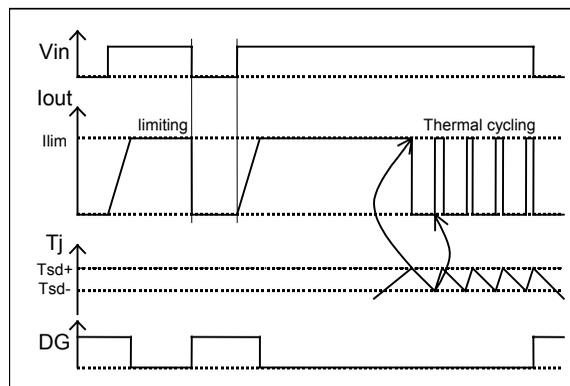


Figure 2: Protections timing diagram

The current limitation and the over-temperature must only be used for protection. In normal mode, these protections must not be triggered, otherwise the reliability of the device will be affected. For example, the inrush current of the load must be lower than the current limit.

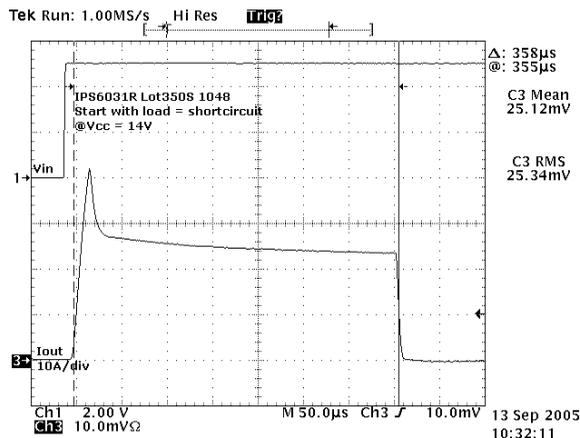


Figure 3 : Turn on a short circuit
 CH1: Input, CH3 : I load 10A/div

Ground loss protection

When the ground is disconnected, the device is automatically switched off in order to prevent any failure. The two parasitic bipolars between input and drain pins and diagnostic and drain pins may turn on and current will flow from the drain to the microcontroller. Rdgs and Rin limit the current in order to protect the IPS and the microcontroller.

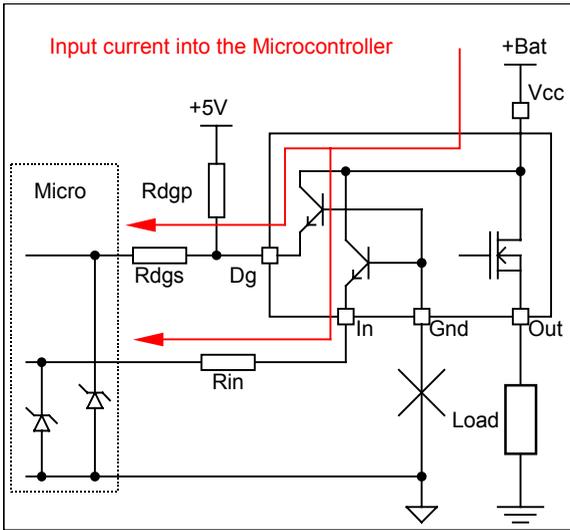


Figure 4 : Ground loss protection

Active clamp

During active clamp, the current is controlled by the load. So no protection (temperature or current) is active during this mode. The designer must check such that in the worst condition of current and temperature, the power dissipated during the turn off is within the SOA of the IPS.

Purpose of the active clamp

When switched OFF, an inductive load generates a voltage across its terminal whose amplitude depends on the current slope and the inductance value. In a high side configuration the over voltage across the inductance will make the drain-to-source voltage rise above the battery voltage. This would cause the body diode to go into avalanche, if no external zener clamps or freewheeling diodes are used, as shown in figure 5.

The purpose of the active clamp is to limit the voltage across the MOSFET to a value below the body diode break down voltage to reduce the amount of stress on the device during switching.

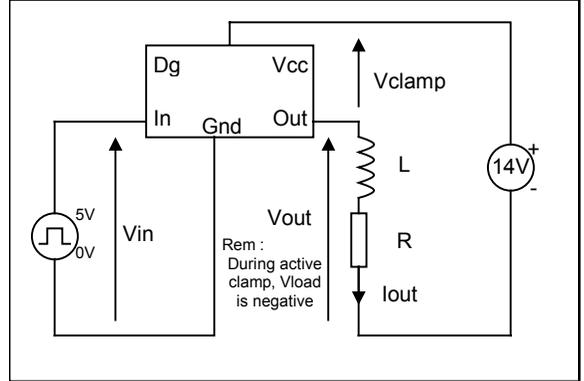


Figure 5 : Active clamp circuitry

Active clamp methodology

One way to control the V_{DS} of a MOSFET is by driving it in the linear region. A feedback loop inside the IPS, allows regulation of V_{DS} to the targeted active clamp voltage by adjusting the output MOSFET gate voltage independently of the load current. The internal circuitry consists of a zener diode connected between drain and gate and a resistor from gate to ground. Note that during active clamp the output MOSFET is driven in the linear region and the power dissipation does not depend on the R_{DSON} .

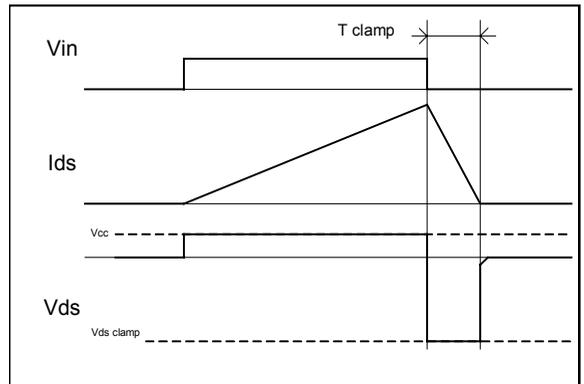


Figure 6 : Active clamp waveforms

Energy consideration when using active clamp

Active clamp allows faster recirculation compared to free wheeling techniques, and it does not require the use of external devices. The drawback of the active clamp technique is that the energy is dissipated by the IPS. The energy must be evaluated to ensure safe operation of the IPS. Energy dissipation calculations are shown in the following section:

Energy dissipated by the IPS:

$$E_{IPS} = \frac{1}{2} \cdot L \cdot I^2 \cdot \frac{V_{CLAMP}}{V_{CLAMP} - V_{BATT}}$$

Energy dissipated by the load:

$$\frac{1}{2} \cdot L \cdot I^2$$

Since V_{CLAMP} must be higher than V_{BATT} the IPS dissipates more energy than the load. This is due to the fact that during active clamp some energy is taken from the battery.

In order to minimize the energy dissipation on the IPS the V_{CLAMP} must be as high as possible, compatibly with the breakdown voltage of the technology. The IPS70XX family has a typical active clamp voltage of 70V.

The energy dissipated by the IPS is proportional to the load inductance and the square of the load current.

Curves similar to figure 7 are given in the data sheet. They allow the estimation of the maximum load inductance vs. the load current, based on the amount of energy that can be dissipated by the IPS.

Note that the load 'parasitic resistance' provides a limitation to the load current. Maximum load current must be calculated in the worst possible supply conditions. For example with a 100uH load, the curve shows a maximum load = 12A. If the worst-case $V_{BATTERY}$ is 18V, the inductor minimum series resistance must be $18V/12A = 1.5 \text{ Ohm}$, according to figure 7.

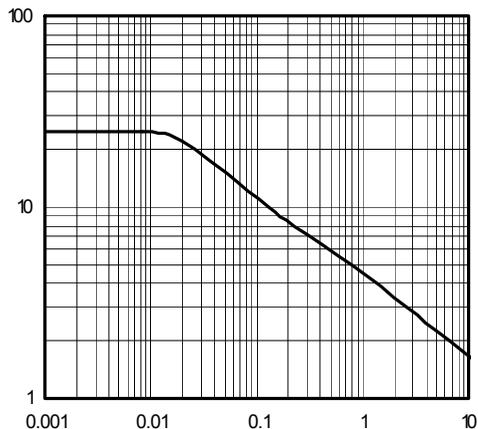


Figure 7 : Max. Output current (A) vs. inductive load (mH)

Temperature increase during active clamp

The energy dissipation during active clamp will cause the junction temperature to increase.

The temperature increase during active clamp can be estimated as follows:

$$\Delta T_J = P_{CL} \cdot Z_{TH}(t_{CLAMP})$$

Where: $Z_{TH}(t_{CLAMP})$ is the thermal impedance at t_{CLAMP} and can be read from the thermal impedance curves given in the data sheets.

$P_{CL} = V_{CL} \cdot I_{CLavg}$: Power dissipation during active clamp

$V_{CL} = 70V$: Typical V_{CLAMP} value for the IPS70xx

$I_{CLavg} = \frac{I_{CL}}{2}$: Average current during active clamp

$t_{CL} = \frac{I_{CL}}{\left| \frac{di}{dt} \right|}$: Active clamp duration

$\frac{di}{dt} = \frac{V_{Battery} - V_{CL}}{L}$: Demagnetization current

The temperature increase during active clamp must be limited by design to avoid damaging the IPS.

Reverse battery

In the reverse battery condition, the designer should be aware that no other protection is available. So in the worst case condition of temperature and voltage, the over temperature threshold should not be reached. The current will flow from In, Dg, Gnd and Out pin to Vcc pin.

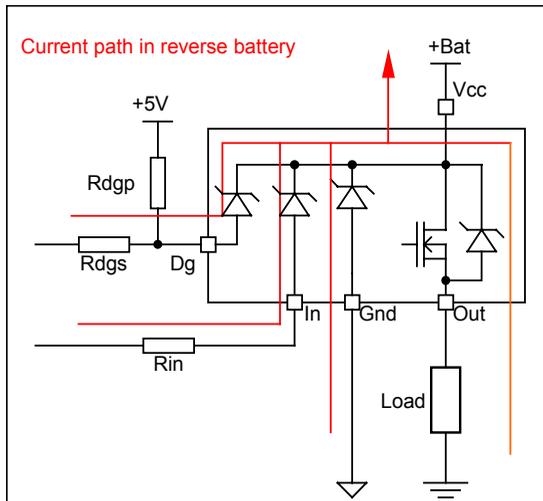


Figure 8: Current paths in reverse battery conditions

Current through the output pin

The current would normally flow through the load into the body diode of the MOSFET during reverse battery. The power dissipation in the IPS can be estimated as

$$Pd_{IPS} = V_f \cdot \frac{V_{BATT}}{R_{LOAD}}$$

where V_f is the forward voltage drop of the MOSFET body diode (typical 0.7V).

Current through In and Diag

Resistors in series with the terminals (In and Diag) will limit the current in the IPS. A typical value for these resistors is 7.5K Ω .

Current through GND

Current through the GND terminal can be very high since no external components can be placed on this terminal. A schottky diode should be inserted in the positive Vcc line.

Maximum voltage ratings

Maximum Vcc voltage

This is the maximum voltage before the breakdown of IC process.

Maximum continuous Vcc voltage

This is the voltage used during the qualification.

Recommended operating conditions

These are the operating conditions for the key specifications, under which the device is recommended to be operated. Typically, the recommended operating conditions define limits for device operation under steady state conditions. The absolute maximum rating provide the limits for worst case conditions, such as transient.

Driving the high side for reliability

The reliability rules for the IPS are the same as for a MOSFET. A high variation of junction temperature decreases the life expectancy. During thermal cycling, the variation of the junction temperature is 7°C. But if the system switches off the device for a long time before restarting it, the junction temperature variation will be higher.

If autorestart is required, the controller should maintain the device in thermal cycling. If the controller must switch off, the number of retries must be limited to guarantee a high level of reliability.