International Rectifier

APPLICATION NOTE

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Features of the high-side family IPS60xx

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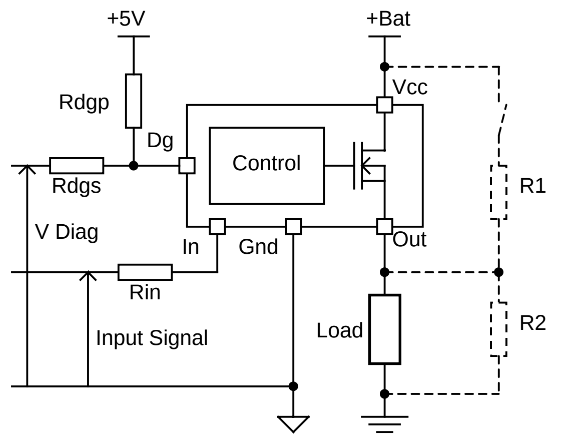
Introduction

The new IPS60xx family of protected power MOSFETs consists of five terminal high side devices based on the latest IR proprietary vertical technology called P^3 (Power Product Platform). IR protected MOSFETs are vertical power MOSFETs with integrated protection circuitry. The new IPS60XX family features a more efficient power MOSFET with active clamp and integrated protections for over-temperature, current limitation from over-current and reverse battery.

IPS60xx 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.

The new P3 technology enables monolithic designs to be implemented in monolithic for R_{DSON} Values as low as 14mΩ. 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

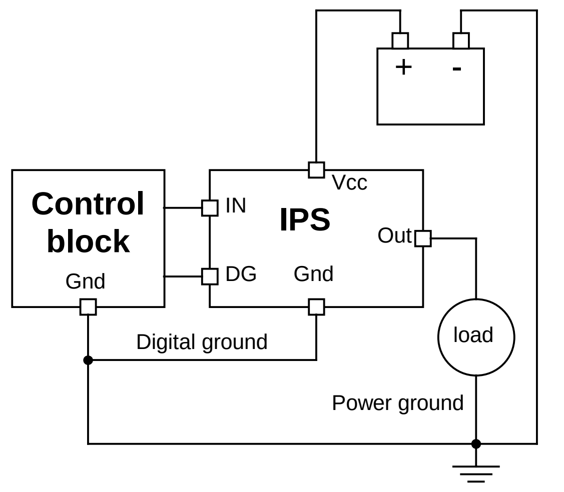


R1 and R2 are required for open load off and short cicuit to Vbat detection

Figure 1 : Typical connection

Rin and Rdgs provide the protection for the controller during reverse battery and negative pulses on Vbat. R1 and R2 are required if the user must distinguish the failure mode between open load and short circuit to Vbat.

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
Normal	H	H	H
Normal	L	L	H
Open Load	H	H	L
Open Load (1)	L	H	L
Short circuit to Gnd	H	L	L
Short circuit to Gnd	L	L	H
Short circuit to Vcc	H	H	L
Short circuit to Vcc (2)	L	H	L
Over-temperature	H	L	L
Over-temperature	L	L	H

Table 1. Diagnosis truth table

(1) With a pull-up connected between the output and VCC

(2) Without pull-up connected between the output and VCC

Open load detection when ON

The IPS60XX family offers open load detection during the ON state. The open load condition when the load is ON is detected by reading the VDS of the power MOSFET. An internal comparator with a 20mV reference is placed between Drain and Source of the Power MOSFET. If VDS < 20mV when the load is turned ON, the open load condition is detected. This corresponds to a load current of less than 2A in the load for IPS6011.

Open load detection of 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 and without the need to turn ON the load.

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 source 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.

The internal reference needs to be fixed at a lower value than the minimum battery voltage (6V). The IPS60xx family uses a 3V reference for the open load detection.

Diagnostic during turn on

During turn on, the diagnostic is fast enough to detect a short circuit because Vbat - Vout is higher than the short circuit detection voltage(Vsc in the datasheet). See figure 2.

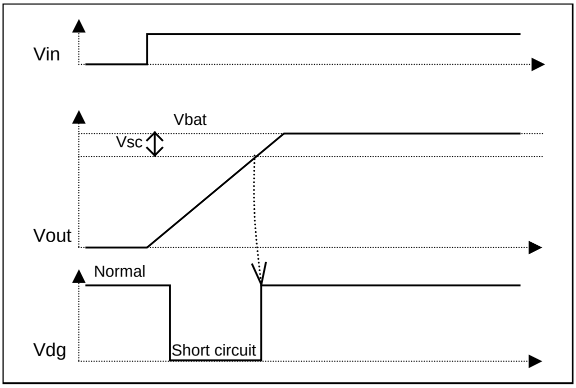


Figure 2 : Diagnostic during turn on

Diagnostic during turn off

During turn off, the diagnostic is fast enough to detect an open load because Vout is higher than the open load off detection voltage(V OL Off in the datasheet). See figure 3.

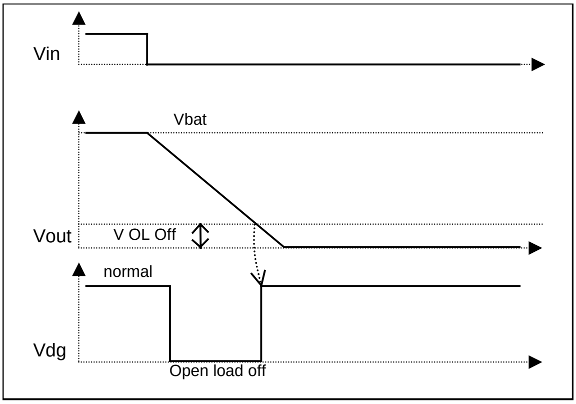


Figure 3 : Diagnostic during turn off

How the diagnostic can detect each failure mode

The truth table shows that the diagnostic is not able to distinguish between open load and short circuit to Vbat when ON because in both cases the output is high and there is no current flowing in the device. When the device is off, the

diagnostic is low if the output voltage is lower than V OL off. Disconnecting the pull up resistor on the output (R1 in figure 1) allows these 2 modes to be differentiated. The output will be high and the diagnostic low during short circuit to Vbat. During open load, the output will be low and the diagnostic high. For open load detection, an internal resistor of 500k between the output and the ground will pull down the output lower than V OL off. If the environmental condition requires lower impedance a pull down resistance must be added.

R2 pulls the output lower than V OL off. So for the minimum value of Vbat, R2 can be chosen as :

$$R2\ Min. = \frac{V\ OL\ off \times R1}{Vbat\ min. - V\ OL\ off}$$

When the device is on, the system can switch off the load to distinguish between open load and short circuit to Vbat.

The algorithm can be found in annex 1.

Protections

The IPS60xx 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.

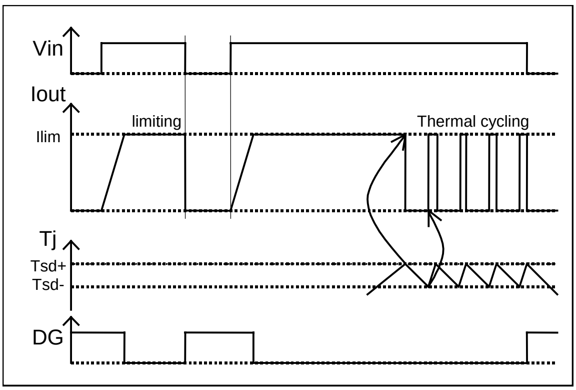


Figure 4: Protections timing diagram

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.

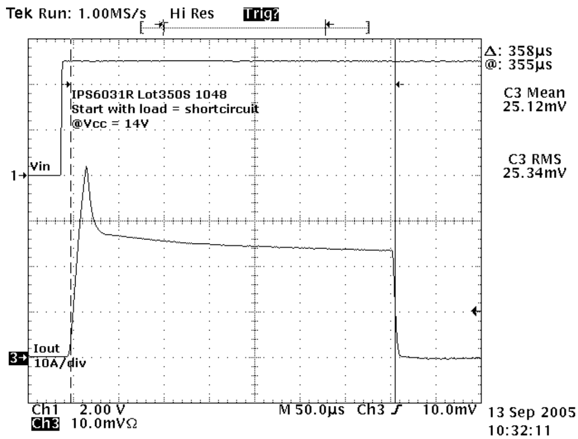


Figure 5 : Turn on a short circuit
CH1: Input, CH3 : I load 10A/div

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 microcontroller.

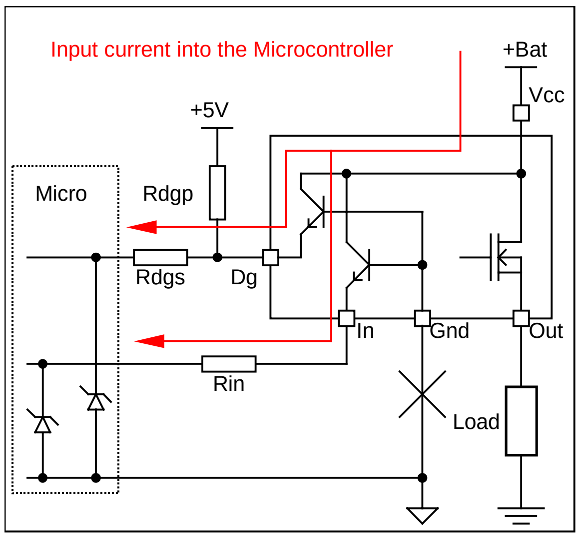


Figure 6 : Ground loss protection

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 7.

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.

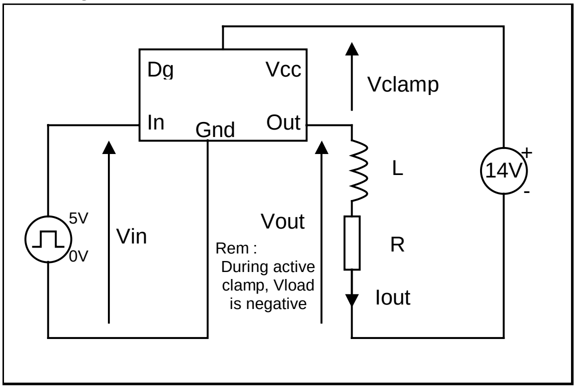


Figure 7 : Active clamp circuitry

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}.

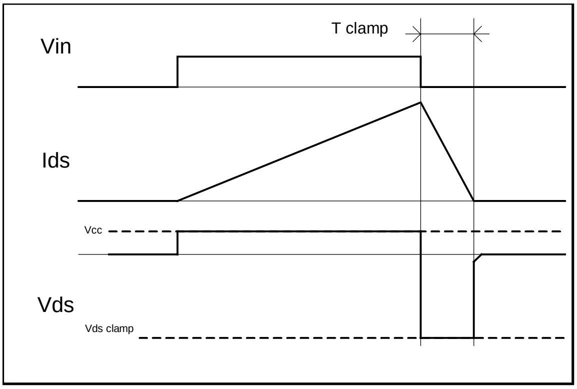


Figure 8 : Active clamp waveforms

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 IPS60XX family has a typical active clamp voltage of 39V.

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

Curves similar to figure 9 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 Iload = 12A. If the worst-case $V_{BATTERY}$ is 18V, the inductor minimum series resistance must be 18V/12A= 1.5 Ohm, according to figure 9.

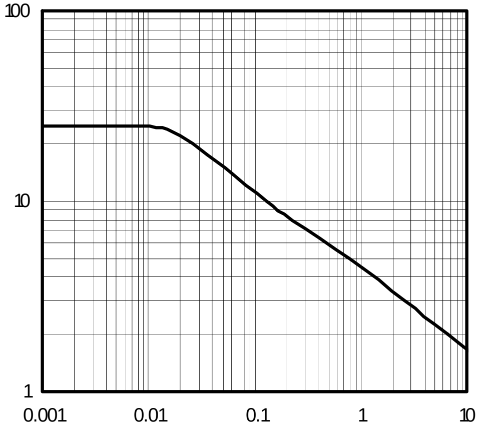


Figure 9 : Max. Output current (A) vs. inductive load (mH)

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:

$$\Delta_{Tj} = P_{CL} \cdot Z_{TH}(t_{CLAMP})$$

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

$V_{CL} = 39V$: Typical V_{CLAMP} value for the IPS60xx

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

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

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

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

Reverse battery

The reverse battery protection of the IPS60xx family relies on 2 circuitries : switching ON the power MOSFET and disconnecting the ground.

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. As the maximum battery voltage is higher in normal mode than in reverse battery, if the over temperature protection is not triggered in normal mode, it will not be in reverse battery.

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

$$Pd_{IPS} = V_f \cdot \frac{V_{BATT}}{R_{LOAD}} \qquad (1)$$

where Vf is the forward voltage drop of the MOSFET body diode (typical 0.7V). In order to protect the IPS, a circuit turns ON the MOSFET when reverse battery is detected, allowing the channel of the Mosfet to carry the current instead of the body diode. The power dissipation in this case can be estimated as shown in (2).

$$Pd_{IPS} = R_{DSON} \cdot \left(\frac{V_{BATT}}{R_{LOAD}}\right)^2 \qquad (2)$$

Due to the value of the Rdson, the power dissipation will be lower when using the MOSFET instead of the body diode. For a 25mΩ IPS with a 2A load current, the power dissipation during reverse battery can be lowered from 1.5W (body diode) to 100mW (MOSFET's channel). This limits the junction temperature during reverse battery thus improving the reliability of the device.

Current through In and Diag

Resistors in series with the terminals (In and Diag) will limit the current in the IPS.

Current through GND

Current through the GND terminal can be very high since no external components can be placed on this terminal.

The IPS60xx family features a GND disconnect circuitry, which opens the path for the current through GND, when the reverse battery condition is detected.

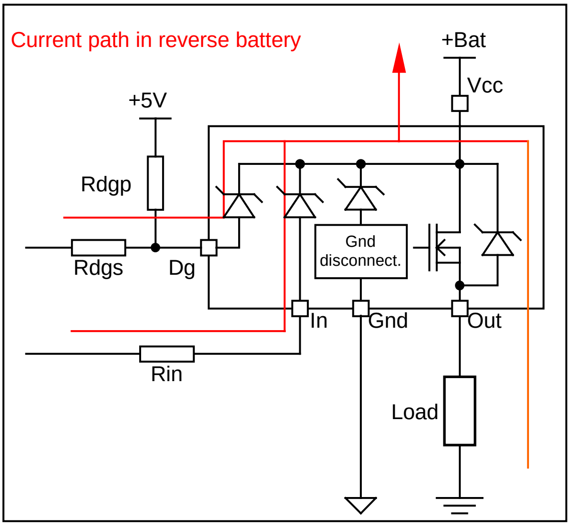


Figure 10: Current paths in reverse battery conditions

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 for the qualification.

Maximum Vcc voltage with full short circuit protection

This is the maximum voltage on the Vcc pin with a safe short circuit protection on the ouput.

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.

Annex 1 : Diagnostic algorithm for IPS60xx high side switch