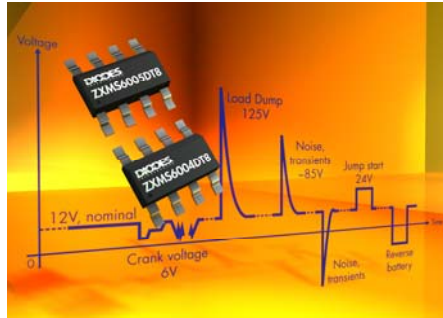


Know How Guide

IntelliFET - low side self-protected MOSFET



Features	Benefits
<ul style="list-style-type: none"> • Load dump protection 	<ul style="list-style-type: none"> • Designed for harsh operating environments without the need for extra clamps.
<ul style="list-style-type: none"> • Thermal shutdown (non-latching auto restart) 	<ul style="list-style-type: none"> • Self-protecting when in high current/high temperature applications – increasing reliability
<ul style="list-style-type: none"> • Short circuit protection 	<ul style="list-style-type: none"> • Device protects both itself and the load from over current conditions
<ul style="list-style-type: none"> • Over voltage protection 	<ul style="list-style-type: none"> • Particularly important when driving inductive loads, to protect against over-voltage breakdown
<ul style="list-style-type: none"> • Input protection (ESD) 	<ul style="list-style-type: none"> • No external ESD protection required
<ul style="list-style-type: none"> • 3.3V and μC compatible inputs 	<ul style="list-style-type: none"> • No gate drivers or level shifters required
<ul style="list-style-type: none"> • Status flag pin with three voltage levels (ZXMS6002G, ZXMS6003G only) 	<ul style="list-style-type: none"> • Provides feedback on the condition of the MOSFET, thereby providing feedback on the condition of the load

Applications

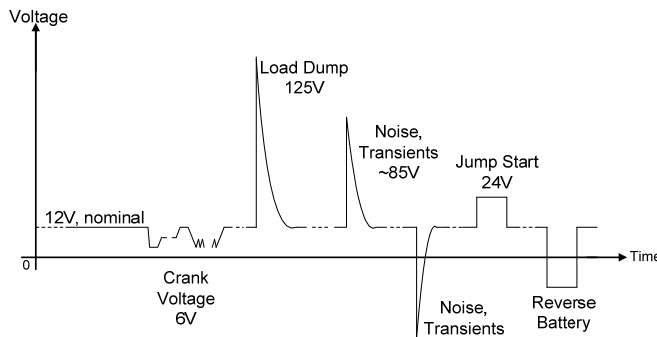
- Lamp driver
- Motor driver
- Solenoid driver
- Compatible with a wide variety of resistive, capacitive and inductive loads
- 5V microcontroller compatible low side switch

IntelliFET - low side self-protected IntelliFET family

The need for self-protected MOSFETs

While it's been said many times before, the automotive electrical environment is tough! It is a lot tougher than consumer electronics' for example. Figure 1 provides the classic illustration: the nominal 12V DC battery voltage of a vehicle swinging from a negative 12V (due to a reversed battery) through to a positive 125V DC (due to load dump transients and inductive field decay).

Figure1



Apart from routine events such as these, there are considerations as to what happens if:

- The wrong load, an overload (e.g. wrong type of bulb), is connected.
- The load is stalled or develops a short circuit or partial short circuit.
- A foreign object (a screwdriver) short circuits the load.
- Module cooling proves insufficient in extreme (fault) circumstances and devices overheat.

Similarly, Self protected MOSFETs are ideally suited to use in harsh industrial environments where there is a need for immunity from radiated and conducted emissions. Consequently, self-protected MOSFETs have proliferated into a number of non automotive applications that include:

- Remote I/O controller outputs (Programmable Logic Controllers)
- Distributed I/O Modules
- Relay driving
- Lamp driving
- Proximity switches
- Alarm system
- GPS system
- Relay driving in HVAC applications

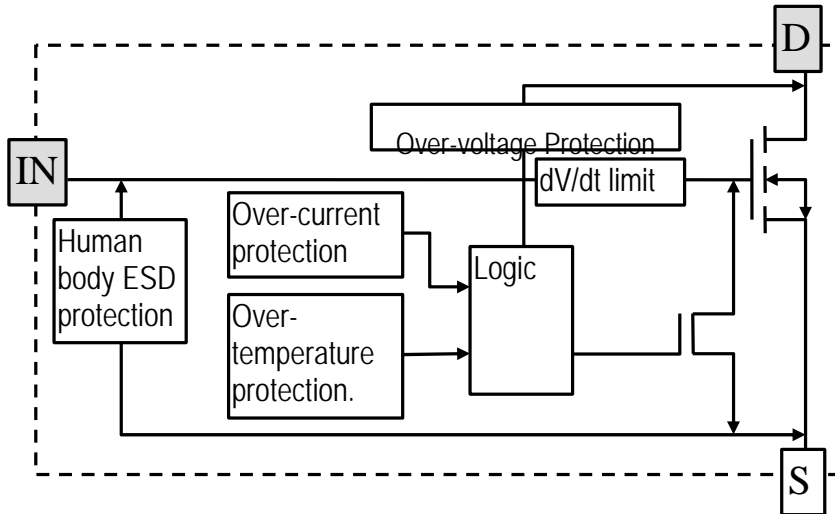
When solid state electronics were first deployed in automotive applications supporting electric windows for example, system designers either relied on the inherent ruggedness of large MOSFETs to absorb the energy from transient load dumps or used discrete voltage clamp circuits. Such approaches only served to increase both complexity and cost. The self-protected MOSFET was therefore developed to address such limitations and improve overall circuit reliability.

Introducing the Diodes Inc IntelliFET portfolio of self-protected MOSFETs

Self-protected MOSFETs integrate a power MOSFET with a complete array of protection circuits that guard against ESD, over-current, over-voltage, and over-temperature conditions. A typical block diagram of a low-side protected MOSFET is shown in Fig. 2

Figure 2 – Block Diagram Lowside self-protected MOSFET

IntelliFET - low side self-protected IntelliFET family



When an 'intelligent' MOSFET senses the presence of any one of these potentially catastrophic conditions, it protects both itself and the load connected to it. The integration of these protection functions therefore improves overall system reliability. The addition of features such as status flags also helps improve overall system performance by providing a diagnostics capability that can aid the isolation and rectification of faults within a vehicle.

Self-protected MOSFETs can be categorised as either low side devices, where the load is switched with reference to ground, or high side devices, where the load is switched with reference to a floating point. This know-how guide outlines the function, operation and competitive environment of the Diodes Inc low-side portfolio.

IntelliFET - low side self-protected IntelliFET family

Overview of the IntelliFET low side family

ZXMS6004/5DT8 – dual devices that provide customers with a thermally efficient alternative to SO8.

ZXMS6004/5DG – drain connected to the tab (improved power handling capability). Released for those customers who do not need the benefit of ZXMS6004FF's features.

ZXMS6004/5SG – source connected to the tab – matches the pin-out of BSP75N.

ZXMS6004FFTA – provides the performance of a BSP75 but occupies 85% less board space

BSP75N - matches the pin-out (SOURCE connected to TAB) of the industry standard BSP75N.

BSP75G - has DRAIN connected to TAB, offering improved thermal impedance (and hence power handling capability) over the Zetex BSP75N, but with different pin-out.

ZXMS6001G – has the drain connected to TAB as in the BSP75G but has a 500uA input current and is able to operate down to 4V input.

ZXMS6002G – has DRAIN connected to TAB as in the BSP75G, plus a fourth 'STATUS' pin providing a voltage-level indicative of the internal gate status.

ZXMS6003G - has DRAIN connected to TAB as in the BSP75G, plus a fourth 'PROGRAM/STATUS' pin requiring an external resistor to be connected between itself and Vin Adjustments to the value of this resistor provide for adjustment of the operational current-limit.

With the external resistor in place, the 'PROGRAM/STATUS' pin also provides a voltage-level indicative of the internal gate status, in similar fashion to the ZXMS600

ZXMS6003G - has DRAIN connected to TAB as in the BSP75G, plus a fourth 'PROGRAM/STATUS' pin requiring an external resistor to be connected between itself and Vin Adjustments to the value of this resistor provide for adjustment of the operational current-limit.

With the external resistor in place, the 'PROGRAM/STATUS' pin also provides a voltage-level indicative of the internal gate status, in similar fashion to the ZXMS6002G

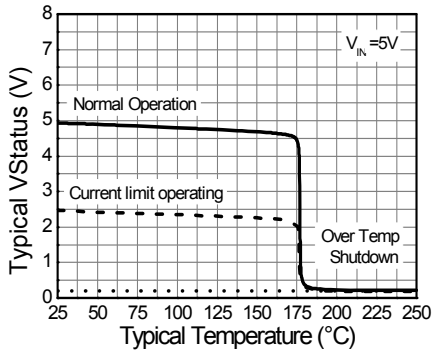
Part Number	TAB	BV _{DSS} (V)	ID(A) VIN = 5V	PD (W)	RDS (on) Max(Ω) @VIN =			VDS(S/C) VIN = 5V	EAS (mJ)	Package Outlines
					3V	5V	10V			
BSP75G	Drain	60	1.4	2.5	-	0.675	0.55	36	550	SOT223
BSP75N	Source	60	1.2	1.5	-	0.675	0.55	36	550	SOT223
ZXMS6001N3	Source	60	1.1	1.5	2	0.675	-	36	550	SOT223
ZXMS6002G	Drain	60	1.4	2.5	-	0.675	0.55	36	550	SOT223
ZXMS6003G	Drain	60	1.4	2.5	-	0.675	0.55	36	550	SOT223
ZXMS6004DG	Drain	60	1.3	3	0.6	0.5	-	36	490	SOT223
ZXMS6004FF	N/A	60	1.3	1.5	0.6	0.5	-	36	90	SOT23F
ZXMS6004SG	Source	60	1.3	1.6	0.6	0.5	-	36	480	SOT223
ZXMS6004DT8		60	1.2	2.3	0.6	0.5	-	36	210	SM8
ZXMS6005DG	Drain	60	2	1.6	0.25	0.2	-	36	490	SOT223
ZXMS6005SG	Source	60	2	1.6	0.25	0.2	-	36	490	SOT223
ZXMS6005DT8		60	1.8	1.6	0.25	0.2	-	36	210	SM8

IntelliFET - low side self-protected IntelliFET family

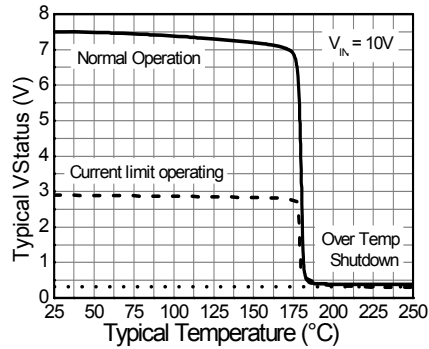
Relevant to ZXMS6002G, ZXMS6003G only:

Both of these devices feature a STATUS pin, the voltage on which is identical to that being applied internally to the MOSFET gate. This pin can therefore be used to indicate the mode of device operation (normal, over-current-shutdown or over-temperature shutdown) as shown below:

Current Limiting and Over Temp Shutdown Status Indication at Vin=5V



Current Limiting and Over Temp Shutdown Status Indication at Vin=10V



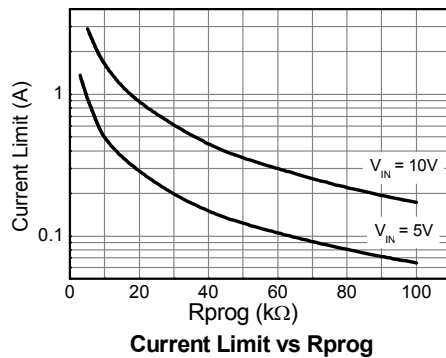
The behaviour shown is typical of that observed on the ZXMS6002G, and also typical of that observed on the ZXMS6003G device with Rprog = 24kΩ connected between Vin and STATUS pins.

Relevant to ZXMS6003G only:

Unlike all other devices within this family, the ZXMS6003G requires connection of an external resistor (Rprog) in order to function. Rprog is connected between the Vin and STATUS pins, and its value determines the operational current-limit as shown below.

The customer may use this trimming capability in order to provide a desirable level of start-up current limitation, when driving loads which generate high initial current surges (e.g. lamps, motors).

This feature may also be used to adjust the degree of IV protection which will apply under load-dump conditions.

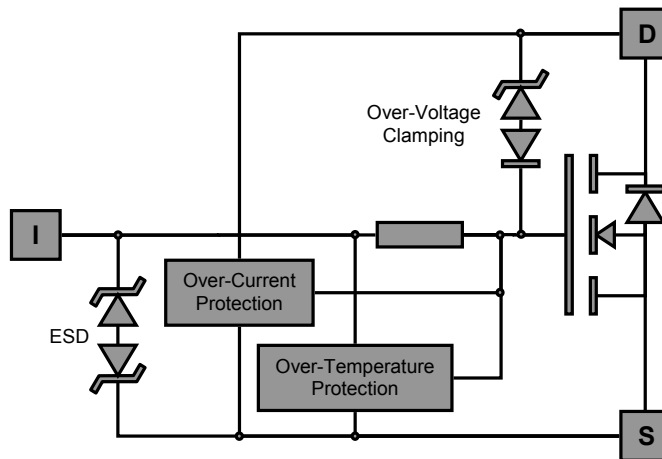


IntelliFET - low side self-protected IntelliFET family

Function and operation of Diodes' Low Side IntelliFET portfolio

The protection circuitry described in the following paragraphs is based on the Diodes Inc ZXMS6xxx series of low side self-protected MOSFET (IntelliFET). These devices have a V_{DS} of 60V and a typical $R_{DS(ON)}$ of between 50m Ω and 0.5 Ω ; They operates in circuit in much the same way as a standard unprotected MOSFET. The device is turned on by a logic high (5V) however unlike a standard MOSFET a small current of the order 100 μ A is drawn by the input to power the on board protection circuitry. Similarly, the device is turned off by a logic low of <0.7V. Figure 3 illustrates this point.

Figure 3 – Function of a low-side self protected MOSFET

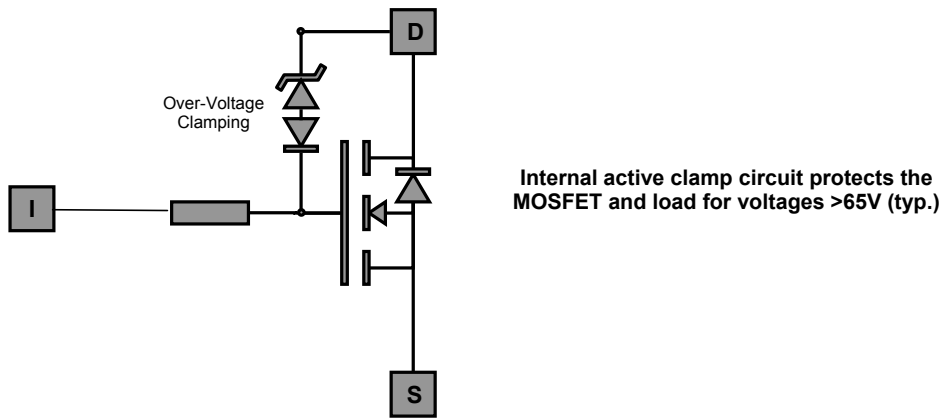


The IntelliFET portfolio features an ESD rating of 4kV based on the lectrostatic discharge model. ESD protection is provided on the input by clamp diodes to protect both the internal gate and the protection circuitry and across the Drain-Source is protected by its built-in Miller capacitance, active clamping, and reverse (body-drain) diode.

Over-voltage protection is implemented via a Zener diode stack operating as an active clamp that turns the gate on when the V_{DS} exceeds 65V. Active clamping ensures that the whole of the MOSFET is turned on and the voltage energy dissipated across the entire area of the MOSFET. For example, when a relay deactivates, any generated transient would be clamped at 65V for the duration of the transient and the energy dissipated. Once the transient's energy has been dissipated the device would revert to its normal off state.

IntelliFET - low side self-protected IntelliFET family

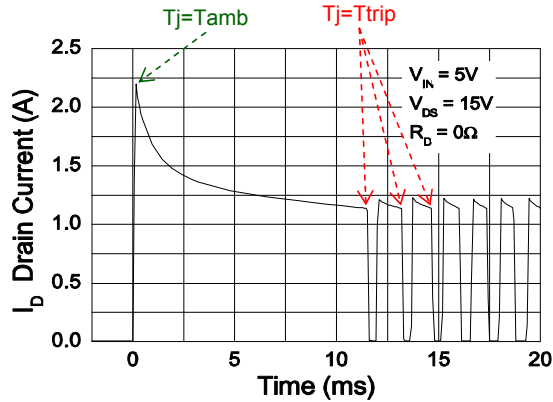
Figure 4 – Overvoltage protection – active clamping



Over-temperature protection is provided by a temperature sensor and a hysteresis circuit. This over temperature thermal shutdown circuit is active whenever the input is logic high (usually 5V) and constantly monitors the junction temperature. It does this completely independently of over-current, clamping etc. Once the temperature of the MOSFET device reaches the threshold temperature of typically 175 °C the thermal shutdown circuit turns the internal gate off and interrupts the dissipation. The hysteresis of this circuit ensures that the output of the device will turn back on again once the device has cooled by around 10°C. This behavior is illustrated in Fig. 5. Note that during over-temperature hysteresis cycling, on the right of the chart, the over-current protection levels never return to the initial (25°C) values.

IntelliFET - low side self-protected IntelliFET family

Figure 5 – Over-temperature protection – thermal shutdown with hysteresis

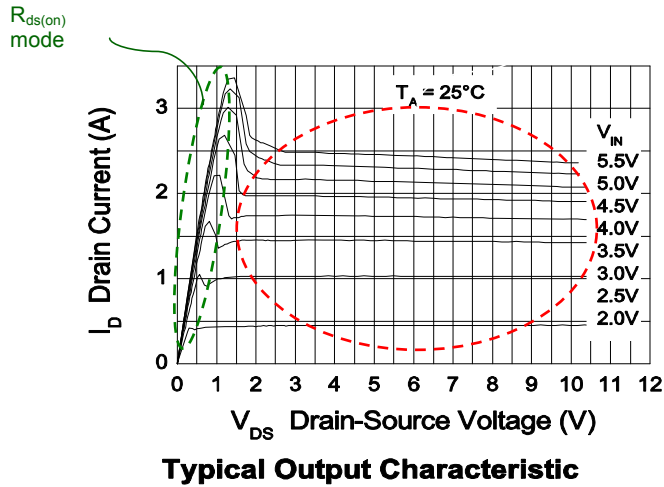


Typical Short Circuit Protection

Over-current protection is effected through a current limit circuit. During normal operation the full input voltage (5V) is delivered to the internal gate as long as the V_{DS} is small and low dissipation is assured. However, if the load current rises sufficiently to generate a substantial V_{DS} , then the device reacts by reducing the internal gate drive and restricting the drain current (I_D). This functionality is illustrated in Figure 6.

IntelliFET - low side self-protected IntelliFET family

Figure 6 – current limiting – typical output characteristics.



For example, at turn on an incandescent lamp has a low resistance that increases as the lamp heats up. If the lamp is being driven by a self-protected MOSFET the inrush current associated with this low resistance will be limited by the over-current protection circuit, protecting the MOSFET and prolonging the life of the lamp.

The over-current and over-temperature protections are completely independent functions. In a cool ambient environment the over-current regulation may operate for substantial periods before temperatures approach the threshold of the over-temperature thermal shutdown circuit. In a hot enough ambient environment the over-temperature will turn-off the output even if there is little or no dissipation in the device.

Normally though, the two functions work together. The normal protection sequence is that an excessive load condition causes the over-current circuit to reduce the gate drive and self-regulate the current. Then, if the condition persists for long enough, the device temperature rises until over-temperature cycling begins. Over-temperature cycling will continue until the Input voltage or overload conditions are removed.

IntelliFET - low side self-protected IntelliFET family

Competitive Environment

- The IntelliFET market is valued at approximately 400 to 500m€.
- Low side market is approx 30%.
- High side market is approx 70%.
- Two distinct requirements
 - Single/dual low-side and high-side switches for lamp, solenoid, motor apps
 - Integrated power modules for specific applications – customer/application specific

Competitors

There are four major suppliers of self-protected MOSFETs. These are:

Infineon - Market leader, with high market share. Developed and released the first self-protected MOSFET in mid 1990's. Broad portfolio of low side and high side devices.

ST – strong number two – Broad rang of lowside and highside devices

NXP - Strong presence in a few key customers. Innovation is primarily focused on the development of integrated power modules such as DISD. No further development of lowside/highside portfolio

On Semi – relative new entrant. Lowside portfolio but no high side

IntelliFET - low side self-protected IntelliFET family

Cross Reference to Infineon

Competitor Part	Basic specification of competitor part			Diodes Near Equivalent	Comment
	V _{DS clamp} (V)	R _{DSON} (mOhm)	Package		
BSP75G	60	500	SOT223	ZXMS6004DG	
BSP75N	60	500	SOT223	ZXMS6004SG	
BSP76	42	200	SOT223	ZXMS6005DG	
BTS3410G	42	200	SO8 (dual)	ZXMS6005DT8	Provides, same performance in smaller package
BTS3118N	42	100	SOT223	ZXMS6006DG	Scheduled for release Q3
BTS3118D	42	100	DPak	ZXMS6006K	Scheduled for release Q3
BSP77	42	100	SOT223	ZXMS6005DG	Scheduled for release Q3
BSP78	42	50	SOT223	ZXMS6008DG	Scheduled for release Q3

Cross Reference to ST

Competitor Part	Basic specification of competitor part			Diodes Near Equivalent	Comment
	V _{DS clamp} (V)	R _{DSON} (mOhm)	Package		
VNS1NV04D	42	250	SO8 (dual)	ZXMS6005DT8	Provides, same performance in smaller package
VNS3NV04D	42	120	SO8 (dual)	ZXMS6006DT8	Provides, same performance in smaller package
VNN7NV04P	42	60	SOT223	ZXXMS6008DG	Scheduled for Q3 release
VNS7NV04P	42	60	SO8	ZXMS6008N8	Scheduled for Q3 release
VNLS160N3	42	160	SOT223	ZXMS6007DG	Scheduled for Q3 release
VNLS160N5	42	160	DPak	ZXMS6007K	Scheduled for Q3 release
VNN7NV04P	42	60	SOT223	ZXMS6008DG	Scheduled for Q3 release
VNS7NV04P	42	60	SO8	ZXMS6008N8	Scheduled for Q3 release
VND7NV04P	42	60	DPak	ZXMS6008K	Scheduled for Q3 release
VNN3NV04	42	120	SOT223	ZXMS6007DG	Scheduled for Q3 release
VNS3NV04D	42	120	SO8	ZXMS6007N8	Scheduled for Q3 release
VND3NV04	42	120	DPak	ZXMS6007K	Scheduled for Q3 release
VNN1NV04	42	250	SOT223	ZXMS6005DG	Scheduled for Q3 release
VNS1NV04D	42	250	SO8	ZXMS6005N8	Scheduled for Q3 release
VND1NV04	42	250	DPak	ZXMS6006K	Scheduled for Q3 release

IntelliFET - low side self-protected IntelliFET family

Cross reference to NXP

Competitor Part	Basic specification of competitor part			Diodes Near Equivalent	Comment
	$V_{DS\ clamp}$ (V)	$R_{DS(on)}$ (mOhm)	Package		
BUK127-50DL	50	200	SOT223	ZXMS6005DG	
BUK127-50GT	50	200	SOT223	ZXMS6005DG	
BUK117-50DL	50	100	SOT223	ZXMS6006DG	scheduled for Q3 release

Comment [BK1]:

Target Customers

- Automotive electronics manufacturers – see list below
- Industrial/security peripheral driving applications
- Motor control design and manufacturers

Target Markets

- Automotive electronics manufacturers – see list below
- Industrial/security peripheral driving applications
- Motor control design and manufacturers
- **Automotive electronics manufacturers include:**
- Delphi – Hella – Valeo – Johnson Controls – Motorola AIEG – Bosch – Siemens VDO – Lear – TRW – AB Automotive

IntelliFET - low side self-protected IntelliFET family

Supporting information

- Samples – available now
- Datasheets available online
www.diodes.com
- To download selected data sheet, enter p/n in our website Product Data Sheet search.

Solderability, Reliability and Environmental Highlights

- Qualified to rigorous AEC-Q101 (automotive) standards for high reliability
- Compliant with RoHS environmental standards and lead free design
- Pb-Free, 100% Matte-Tin Plating
- Withstands 260°C Solder Reflow
- Meets Moisture Sensitivity Level (MSL)

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