# Diodes for Bootstrap and Desaturation Functions

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## INTRODUCTION

This application note describes the basic operating principles of bootstrap and desaturation circuits — commonly used with high voltage IC drivers — and provides a general guideline for pairing the IC driver with the right component that allows it to work properly and safely.

Driving a half-bridge based on n-channel MOSFETs or IGBTs requires providing the proper gate signal to the switch. The high side switch requires a gate voltage higher than the main supply, and the low side should not be influenced by the load current. Without the proper supply driver, this cannot be done correctly. In addition, a driver includes protection, the desaturation function should protect the active switch without creating an unwanted error.

In the past, the rules for choosing a diode for bootstrap applications were quite simple. It was enough to choose a fast recovery diode with a reverse recovery time smaller than 100 ns and a breakdown voltage of 600 V / 1200 V. This approach works for low frequencies (lower than 70 kHz), but at higher frequencies more attention is required when selecting a device. Today's SiC devices and faster silicon IGBTs or MOSFETs require a different approach.

The new devices are very fast and can work at higher and higher frequencies, so a new generation of IC drivers has been developed that allows them to switch with dV/dt up to 100 kV/μs. In addition, at the buffer function, new gate driver ICs implement insulation, desaturation protection, soft turn-off, active clamping, and many other features that require an auxiliary diode. To reduce the bill of material, using a single device that works well for all of these functions is the best solution; however, it is not easy to satisfy so many different requirements with a single device.

Vishay Intertechnology suggest a solution with its Fred Pt® Gen 7 hyperfast family of rectifiers, which are specifically designed to be used as diodes for bootstrap circuits, desaturation, and high frequency rectification. All the functions that a diode should perform in a gate driver circuit are completed in the best way with this new generation of devices.

## TYPICAL GATE DRIVER CIRCUIT

The typical driver circuit for a high voltage application usually has the following architecture:

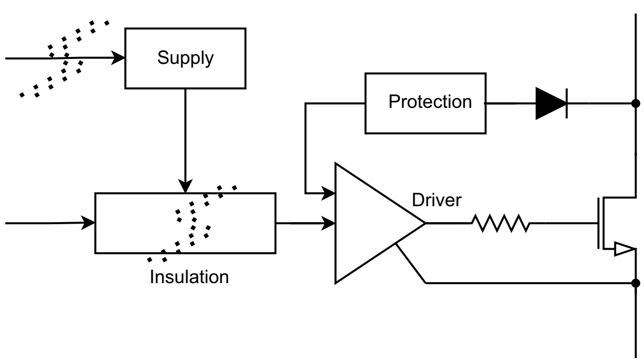



Fig. 1 - High Voltage Driver

In the past, only the high side was isolated for functional reasons, and the low side had no insulation or minimum capability to avoid issues related to stray inductance.

Today, there is often insulation for both the high and low sides. The reasons are the high di/dt and current that can be present; which can induce a significant voltage between the reference of the driver input and the reference of the active switch due to stray inductance (see Fig. 2).

# Diodes for Bootstrap and Desaturation Functions

Usually there are separate supplies for the two sections of the driver — input and output — because the output voltage level for the gate is much higher than the voltage present at the logic input. In the past, IGBTs sometimes required +15 V / -15 V. This means that a 30 V auxiliary power supply with -15 V is no longer necessary today, because an active Miller clamp helps to avoid spurious turn-on. The SiC MOSFET could require 15 V to 20 V for the positive gate and -3 V to -5 V for the negative gate, which requires 18 V to 25 V of auxiliary power. High voltage MOSFETs can work with a 10 V positive gate and a few volts — or no volts — of negative voltage, and in most cases do not require an active Miller clamp. However, to reduce $R_{DS(on)}$, MOSFETs are often driven with a 15 V positive gate voltage, so the supply for the driver should be 15 V or more.

The insulation section guarantees the capability of the driver circuit connected to the active switch to follow the reference pin of the active switch, so all voltages (gate and collector / drain) are correctly defined.

Sometimes internal and software-programmable, sometimes realized with an external resistor and diode or connected with two separate driver outputs, the gate resistor is necessary to control the di/dt and dv/dt of the active switch and dump the gate mesh. An external resistor not only controls the turn-on and turn-off of the active switch, but it helps the driver to reduce its losses. The gate is a capacitor, charged from another capacitor (the decoupling capacitor).

The energy associated at all the variations of the gate voltage, required from the turn-on and turn-off the active switch, induces losses in the circuit that charge and discharge the gate capacitance.

The energy losses are equal to the energy stored or discharged from the gate. A resistor is a better device for dissipating energy.

Today, many drivers implement a protection circuit to protect the active switch from improper working conditions, like incorrect voltage levels at the gate that could bring the active switch to quick thermal failure, desaturation protection to avoid overcurrent in the circuit, or soft switch-off to avoid overvoltage due to overcurrent turn-off. An active Miller clamp also protects against the improper turn-on of the active switch induced by dv/dt related to the turn-on of the complementary switch.

A half-bridge is the typical structure for the driver and is the basic circuit for DC/DC converters and 3-phase inverters.

The simple circuit with two switches and two drivers is different from the basic schematic, and with the growth of di/dt shows more and more of these differences.

A simple real-world model is shown in Fig.2

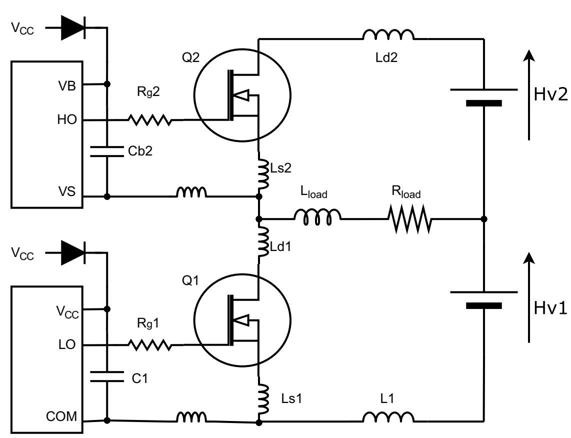



Fig. 2 - Half-Bridge

The high side Q2 has its reference (source or emitter) that follows the output load voltage. So, for functional reasons, it is normal that the high side driver should have a float supply, because compared with the COM reference, it could reach the level of the high voltage source or higher. In addition, the low side reference that seems connected to the COM of the circuit's power reference could show a voltage level very different from the circuit reference, where the DC bus capacitor — Hv1 Hv2— is connected. During normal circuit operation, and often during start-up or overload, the reference of the low side could be very different from the reference of the circuit, which could induce the failure of the active switch or driver.

For this reason, the low side often includes an isolation driver that requires a floating supply to follow the variations of the active switch reference (source or emitter) from the input driver circuit reference.

# Diodes for Bootstrap and Desaturation Functions

## THE SUPPLY CIRCUITS

To take advantage of the isolated driver's characteristics, there should be an isolated supply for each driven gate.

There are many ways to create this isolation or floating supply to meet circuit requirements. For the low side switch, the common mode voltage is limited to a small portion of the high power voltage, but in the event of a fault could be several tens of volts. For the high side, the common mode voltage could be higher than the DC bus voltage.

The two most common solutions for making isolated driver supplies are a bootstrap circuit or an isolated power supply.

Other solutions with a charge pump or carrier driver are not suggested for high voltage, high frequency circuits.

The two solutions have pros and cons.
The bootstrap circuit is a very simple solution.

The pros are:

- Requires only a diode, resistor, and capacitor for each driver
- The parasitic capacitance between the two sides of the supply is only the junction capacitance of the diode
- It is not expensive and requires a very small area on the PCB
- Noise is only present during the output transition

The cons are:

- To charge the high side supply, the low side switch should be closed
- The high side has a limited on-time because the energy stored in the bootstrap capacitor is enough to supply the circuit for a limited time
- The driver could be supplied by a bootstrap capacitor for a long time, compared with the switching period, but not infinitely.

For an isolated power supply made with a flyback circuit or square wave transformer, the pros are:

- Guarantees a supply in any condition
- The control of the gate is complete, with no limit on duty cycles or time

The cons are:

- Is expensive and requires more space on the PCB
- Transformers should have very small parasitic capacitance between the primary winding and secondary winding
- Could generate noise related to the switching of the circuit that is not synchronized with the power stage transition

## THE BOOTSTRAP CIRCUIT

The simplest circuit for creating a floating voltage for the high side — and sometimes the low side — is the bootstrap. The circuit requires only three components: one diode, one capacitor, and one resistor.

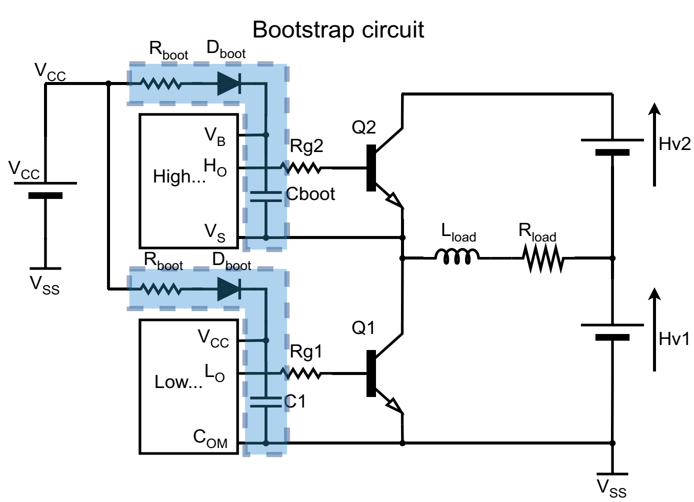



Fig. 3 - Bootstrap Circuit

# Diodes for Bootstrap and Desaturation Functions

The working principle is easy, but the right parts are required for proper operation.

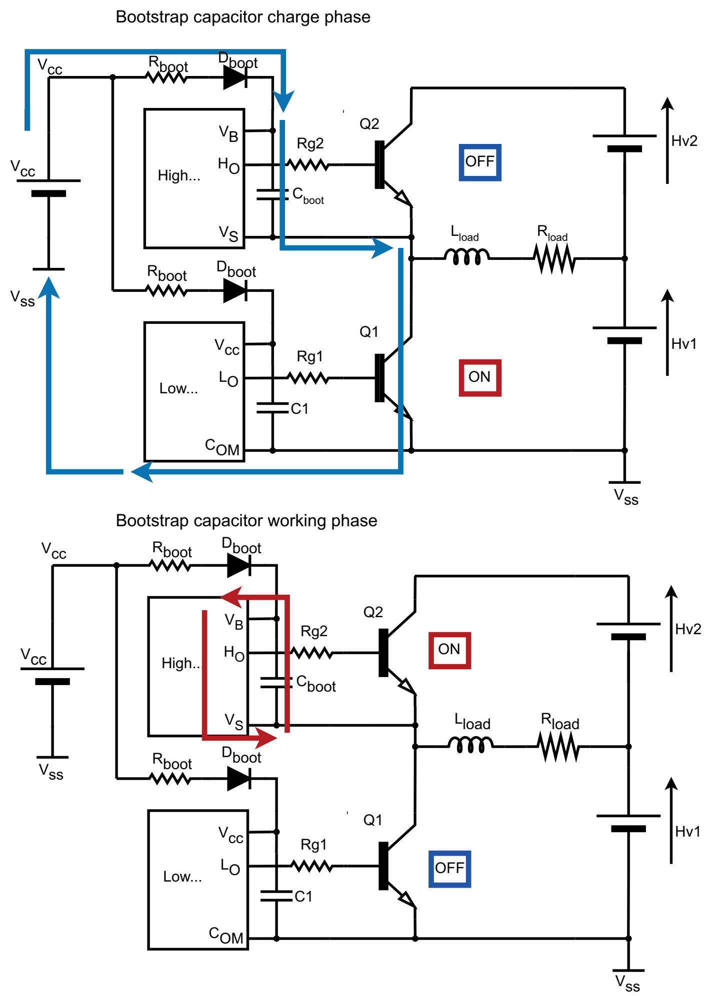



Fig. 4 - Bootstrap Operation

Turning on the low side switch, the bootstrap capacitor $C_{boot}$ is charged through the diode $D_{boot}$ and resistor $R_{boot}$ from a low voltage source $V_{CC}$, as shown in Fig. 4.

When the low side switch is open, charging is stopped, and the high side driver is supplied from the bootstrap capacitor $C_{boot}$. When the high side switch is turned on, the supply for the driver and charge required from the gate is taken from the $C_{boot}$ capacitor, which is the battery of the system. When closing the high side switch, its reference terminal goes to a high voltage potential, moving the supply battery $C_{boot}$ to the other reference. The voltage across the capacitor does not change, but the common voltage does. This is allowed because the bootstrap diode becomes an open circuit. $D_{boot}$ goes in reverse mode due the positive voltage on its cathode connected to the $C_{boot}$ capacitor (actually VS node is the high side reference).

Now $C_{boot}$ is floating with its reference connected to the output of the half-bridge and the driver is supplied by the capacitor itself.

The driver is able to respond at the command and it works correctly until the voltage across $C_{boot}$ is high enough —usually the driver has an undervoltage lockout and under this level the driver output is in high impedance.

When the input of the driver goes to zero, the active switch is turned off and usually the current in the load moves the output voltage to a low value until the antiparallel diode of the low side switch goes into conduction.

# Diodes for Bootstrap and Desaturation Functions

During this phase the diode $D_{boot}$ could recharge the $C_{boot}$ capacitor, and the current is limited by the $R_{boot}$ resistor to avoid a current peak that is typically too high due to the low impedance of the mesh.

Fred Pt Gen 7 hyperfast devices can manage very high repetitive peak current, so in theory the $R_{boot}$ resistor is not needed and it is possible to reduce the charge time of $C_{boot}$. In reality, the fast peak current (high and short) in a long path (the current return is through the low side switch) could create noise in the circuit. Usually, this noise is not visible because it's present at the same time as the output voltage transition and is not dominant in respect to the noise present in the power circuit. Another important function of $R_{boot}$ is to limit the charge of the bootstrap capacitor in case of a fault.

After a short circuit or overload on the output, the free-wheeling diode could carry a very large current with high di/dt because the active switch is opening a large current.

Should the low switch open in an over-current condition, the drain / collector of the low side has a voltage lower than the reference $V_{ss}$; this means that $C_{boot}$ could be charged with voltage higher than the $V_{CC}$. To prevent overcharge, a Zener diode could be put in parallel at $C_{boot}$, but to work properly $R_{boot}$ must have the right value. The value of $R_{boot}$ must be chosen as a function of how a drain / collector becomes negative and the maximum limit of the Zener diode, considering that in any case the driver IC has a maximum operating voltage.

If the switch that opens over the current is low side, the stray inductance (L1, Figure 2) could push the COM voltage much lower than $V_{SS}$.

When an isolated driver is used this is not an issue, but C1 should be protected from overcharge by $R_{boot}$ and the appropriate Zener diode.

The bootstrap diode and capacitor are the only components strictly required for a bootstrap circuit. The local capacitor on the supply line and decoupling of the IC are already used in practice.

In order to compensate for stray inductance, good design practice imposes the use of capacitors on the supply line and parallel to the IC.

The bootstrap capacitance value is determined by the following constraints:

1. Gate charge needed to turn on the active switch
2. Quiescent current of the driver when it is idling
3. Charge loss occuring at the voltage transition of the level shifter or insulator circuit
4. Gate source leakage (mainly to the pull-down resistor, as actual oxide leakage is negligible)
5. Bootstrap diode leakage current, reverse recovery, and $C_J$
6. Bootstrap capacitor leakage current

Point 6 is only relevant if the bootstrap capacitor is an electrolytic capacitor and can be ignored if other types of capacitors are used. Usually, electrolytic capacitors are used only in a very low frequency circuit of a few kHz. In all other applications ceramic capacitors are suitable.

In addition, point 5 is not an issue because Fred Pt Gen 7 hyperfast devices have low leakage at high temperatures; for example, 2 μA typical at 800 V and 125 °C (as shown in Fig. 5). That is negligible compared to the quiescent current of the driver that is in the order of magnitude of mA.

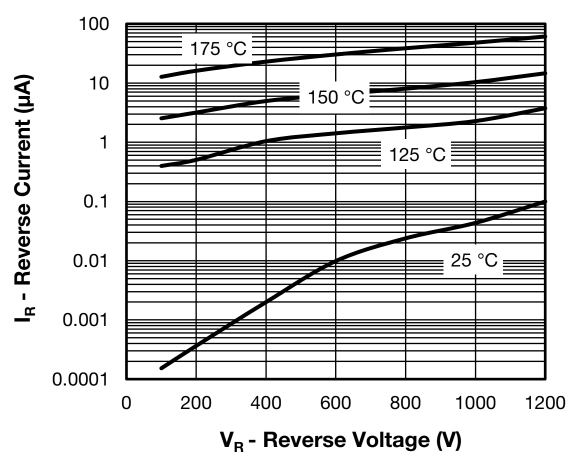



Fig. 5 - Typical Value of Reverse Current vs. Reverse Voltage

# Diodes for Bootstrap and Desaturation Functions

The equivalent $C_J$ for a charge from 0 V to 800 V is about 4.7 pF, as shown in Fig. 6.

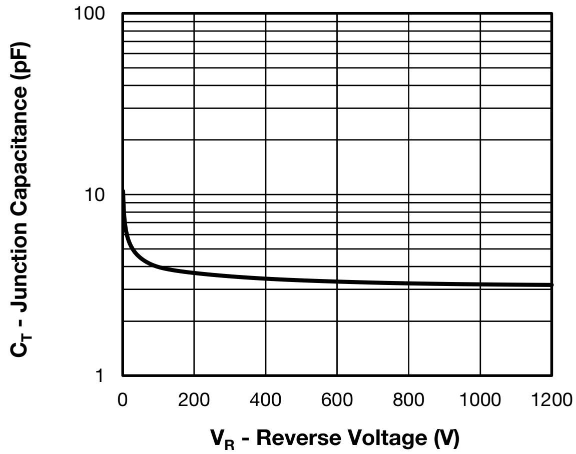



Fig. 6 - Junction Capacitance as a Function of Reverse Voltage

Reverse recovery charge $Q_{rr}$ is a function of di/dt and forward current. Usually, the reverse recovery current is very low if the layout stray inductance is not too large or the high side off-time is not very short.

$Q_{rr}$ at 1 A, 800 V as a function of di/dt is available in the datasheet. Gen 7 devices have quite a constant $Q_{rr}$ as a function of di/dt. Equation 1 gives a simple model for estimating the $Q_{rr}$ of Gen 7 devices as a function of forward current

Eq.1

$$Q_{rr} = (Q_{rr}(T_j) \text{ at } I_{f0}) \times \sqrt{I_f / I_{f0}}$$

Point 4 is up to the designer; however, it is a good practice to place a resistor between the gate and source in power electronics to guarantee that switches are open when the control circuit is unpowered. This not only applies to bootstrap circuits, but also in general because at system power-off, the DC-Link capacitor is not completely discharged, and all drivers are in high impedance. Typical values for resistors between the gate and source are in the range of 1 kΩ to 10 kΩ, which means leakage current between 10 mA to 1 mA when the gate to source voltage is 10 V.

The minimum bootstrap capacitor value can be calculated using Equation 2.

Eq.2

$$C \geq \frac{Q_g + Q_{is} + Q_{rr} + \frac{I_{bias}}{f} + \frac{I_{lk}}{f}}{V_{CC} - V_f - V_{LS} - V_{UL}}$$

Where:

- $Q_g$ is the gate charge needed for the gate voltage transition
- $Q_{is}$ is in the charge needed for the voltage transition of the insulation section (typically 5 nC for 600 V and 20 nC for 1200 V capacitor insulators; 3.5 nC for magnetic couplers; and a few nC for optocouplers)
- $Q_{rr}$ is the charge needed by the diode to perform, and is usually only present at very short duty cycles
- $\frac{I_{bias}}{f}$ is the charge required to keep the active insulated section of the driver when it is isolated from the low voltage supply. In this case duty cycle 1 is assumed, and it could be present in a certain motor drive application for a few cycles
- $\frac{I_{lk}}{f}$ is the charge required from the pull-down resistor when the gate level is high, and in this case the duty cycle is considered 1.

  f is the carrier frequency if it is used without a complementary switching scheme or other modulation. When the active switch is closed for a time longer than 1 cycle of the carrier frequency, use the longer time to evaluate the required charge
- $V_{CC}$ is the low voltage supply
- $V_{UL}$ is the undervoltage lock to maintain the minimum required voltage for the driver (usually the UVL circuit in the driver has two thresholds. One is the higher threshold that is the minimum voltage that turns on the driver. The other is lower, and under this value the driver is switched off until $V_{CC}$ becomes higher. Refer to the driver datasheet and use the highest value to evaluate the value of the bootstrap capacitor)

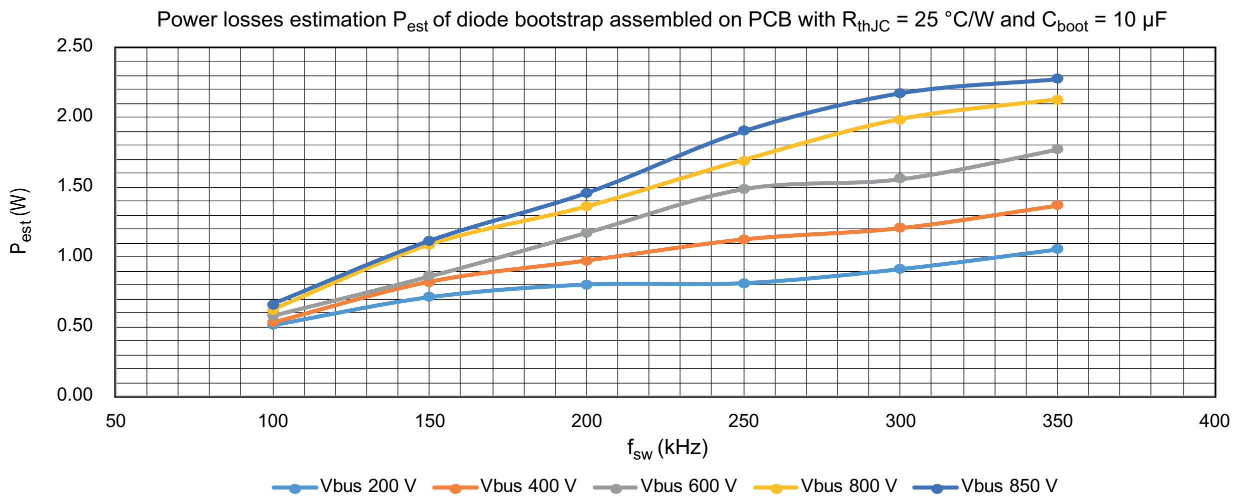
- $V_{LS}$ is the voltage drop across the low side switch that reduces the available voltage to charge the bootstrap capacitor
- $V_f$ is the voltage drop across the bootstrap diode. For Fred Pt Gen 7 hyperfast devices, it is a function of the current and temperature. Usually, it is considered 0.8 V and should be added as a contribution to $R_{boot}$. For more detail, refer to (1)

The average current through the diode is determined using Equation 3.

Eq.3

$$I_D = \left(Q_g + Q_{is} + Q_{rr} + \frac{I_{bias}}{f} + \frac{I_{lk}}{f}\right) \times f$$

The current limit is a thermal limit, so the amount of switching losses induced from the $E_{rec}$ of the diode must be considered. For reference, in a common condition (duty cycle of 50 %) the graph in Fig. 7 gives the losses of VS-E7MH0112-M3 as a function of frequency and thermal management.



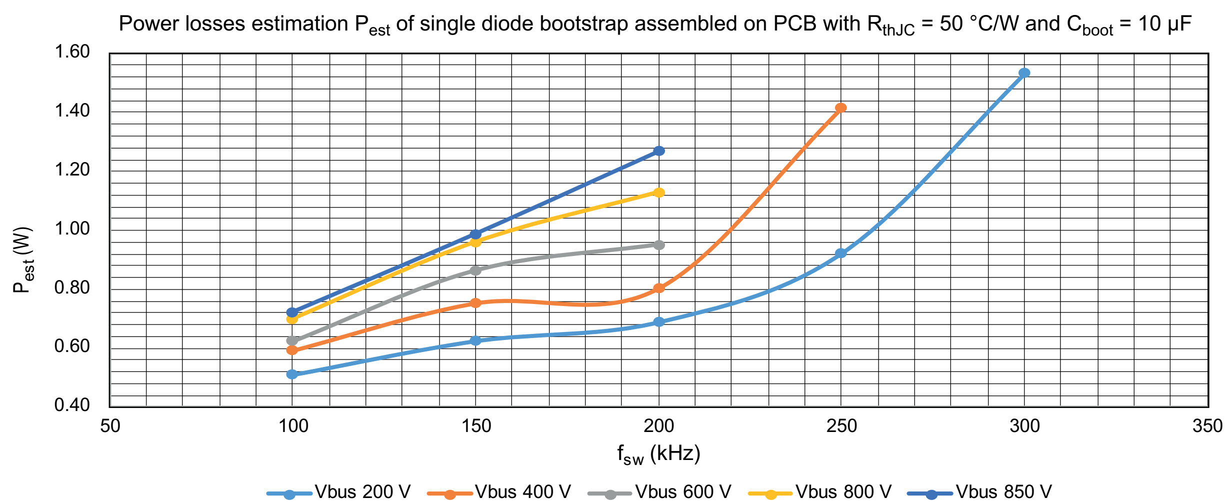




Fig. 7 - Losses vs. Frequency for the VS-E7MH0112-M3

The losses are a function of switching frequency and the bootstrap voltage, which can be evaluated from the $Q_{rr}$. However, the thermal resistance junction to air also plays an important role in losses because $Q_{rr}$ / $E_{rec}$ is a function of junction temperature. Different junction temperatures mean different $E_{rec}$ during switching, so thermal management has a certain influence on the losses of diodes, which are not negligible at high voltages and frequencies.

# Diodes for Bootstrap and Desaturation Functions

## THE ISOLATED POWER SUPPLY CIRCUIT

The independent and isolated supply solution is necessary when full control over time of the driver output is required. Moreover, it is mandatory when specific diagnostic controls have to be implemented before any switch activation.

Based on driver power consumption and circuit requirements (diagnostic specs, duty cycle range…), various solutions can be used.

Utilizing multiple output flybacks (as shown in Fig. 8) is a good choice for a simple and cost effective solution, but a coupled inductor should have low capacitance between different windings.

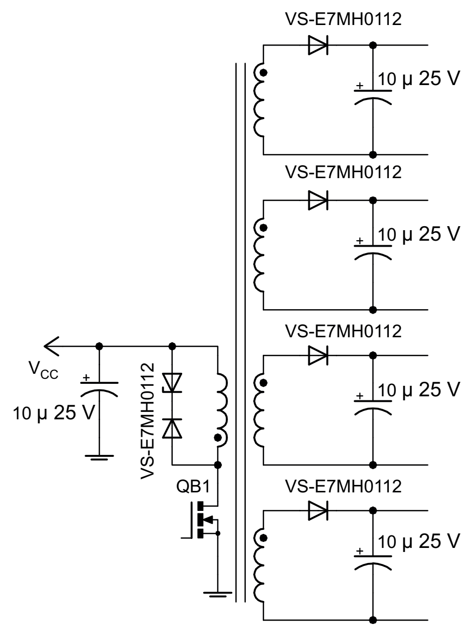



Fig. 8 - Multiple Output Flyback

In addition, the supply distribution on the PCB is not easy because the high side supply has a common mode voltage swing equal to the DC bus and dV/dt that could be very high. The multiple output flyback solution is suitable for small circuits, where the length of PCB tracks is short.

A slightly more complex solution is to use an independent flyback supply for each section, as shown in Fig. 9.

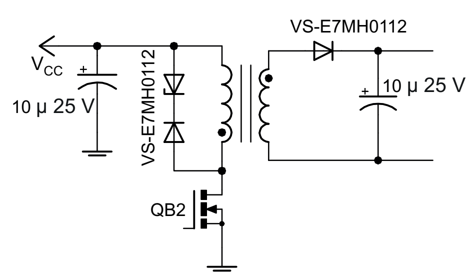



Fig. 9 - Single Output Flyback

This solution requires one IC and one choke for each supply. The choke is much easier to build and could be placed very near the driver-avoiding a critical long track with high dv/dt. In addition, each channel has proper feedback, and, in the case of a fault, all other drivers can be opened safely.

If a large amount of power and a dual supply is required, a push-pull circuit (as shown in Fig.10) is a solution.

## Diodes for Bootstrap and Desaturation Functions

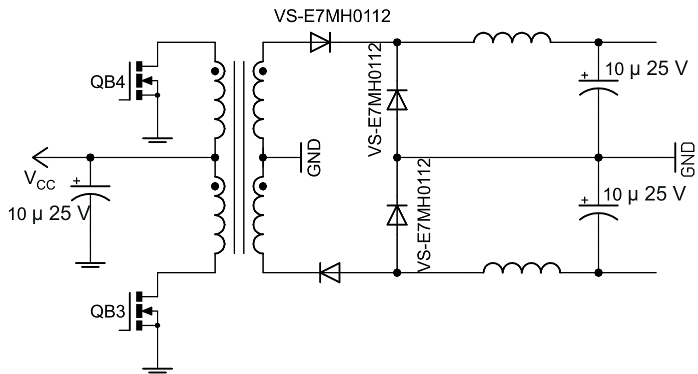



Fig. 10 - Push-Pull Power Supply

This circuit guarantees a stable dual supply, but requires more parts. A push-pull transformer is simple and could be built with a small capacitance between the primary and secondary windings, but needs an output rectifier requiring two diodes and two inductors. It is justified when large power modules are being driven at high frequencies. In all these cases, a Fred Pt® Gen 7 diode could be used. For low voltage circuits, a Schottky diode is the preferred solution because it offers a very low voltage drop that assures high efficiency. However, the good switching characteristics and low forward voltage of Fred Pt Gen 7 devices allow them to reduce the part count in the bill of material without significantly reducing efficiency.

### THE DESATURATION CIRCUIT

The desaturation circuit protects the active switch from overcurrent. This protection is based on the output characteristics of the active switch, which shows a rapidly growing forward voltage, especially when the current exceeds the normal working value.

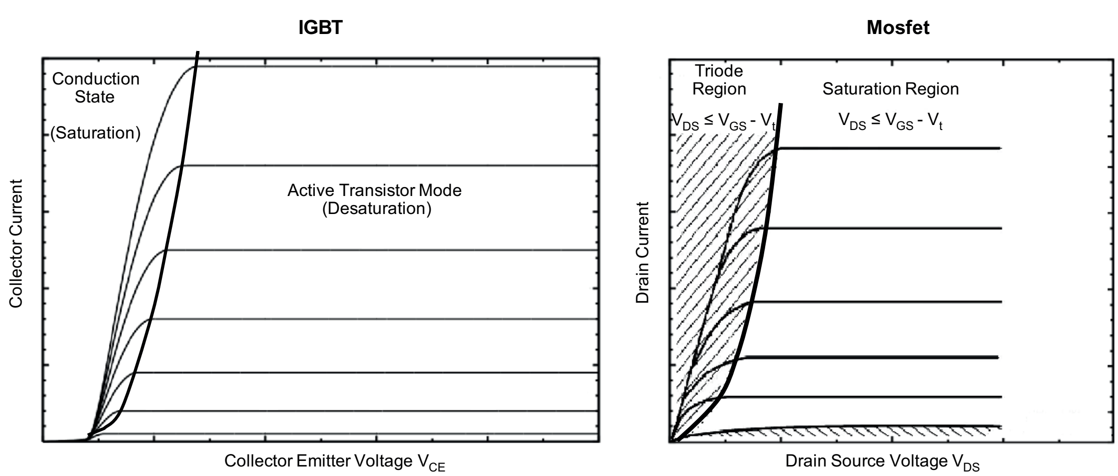



Fig. 11 - Output Characteristics for an IGBT and MOSFET

The active switch usually has an output characteristic as shown in Fig. 11. If it is an IGBT, the output voltage curve starts from a low voltage (there is a threshold voltage), and it starts from zero (curve is like a resistor) if the active switch is a MOSFET. The operating area of the device as a switch is shown in Fig. 12. The green circle is the region where the active switch works correctly and shows the lowest forward voltage.

# Diodes for Bootstrap and Desaturation Functions

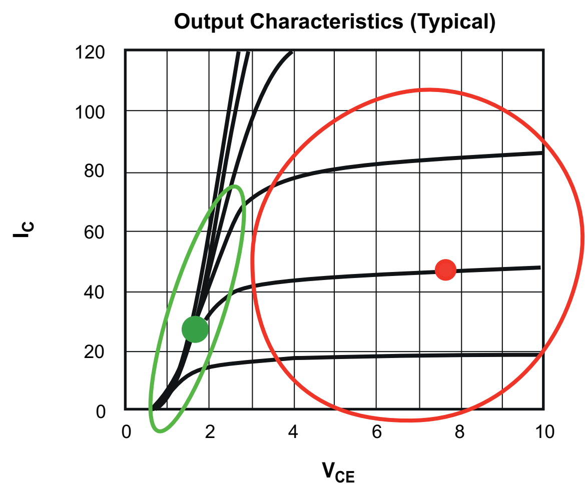



Fig. 12 - Working Area

During normal operation, the voltage across the active switch is a few volts as a function of the type of active switch, current, and temperature; like the green point in Fig. 12. When the load changes, the operating point is expected to be inside the green area too. This is because with a certain gate voltage and current, the active switch should ideally be a short circuit, and current that flows into the device is a function of the external circuit not being proportional at the gate voltage. If current through the device increases, the effect is that the active switch becomes a current generator controlled by the gate voltage. In this condition, the operating point moves inside the red area (the saturation zone) where the current is proportional to the gate voltage level. In this condition, the voltage across the device becomes higher because the active switch is operating like an amplifier and the voltage across the $V_{CE}/V_{DS}$ is much higher. This higher voltage is used to detect if something is not going as designed in the circuit. With a fixed gate voltage, over a certain current, the voltage across the active switch grows very quickly, so it is simple to detect that the active switch is working in the saturation region and dissipating a significant amount of power. When it comes to nomenclature, unfortunately there is ambiguity about the saturation region between a MOSFET and IGBT. Fig. 11 clarifies the meaning in both cases where two opposite areas have the same name: the saturation region for the MOSFET is the desaturation region for the IGBT. Usually, the most common nomenclature used is the one referring to the IGBT. For this reason, the circuit is named desaturation, because for IGBTs we detect when the device goes out of the saturation region.

With a simple comparator, it is easy to detect that the device is not working properly. But in the circuit, there is a time when the voltage across the active switch is quite high.

# Diodes for Bootstrap and Desaturation Functions

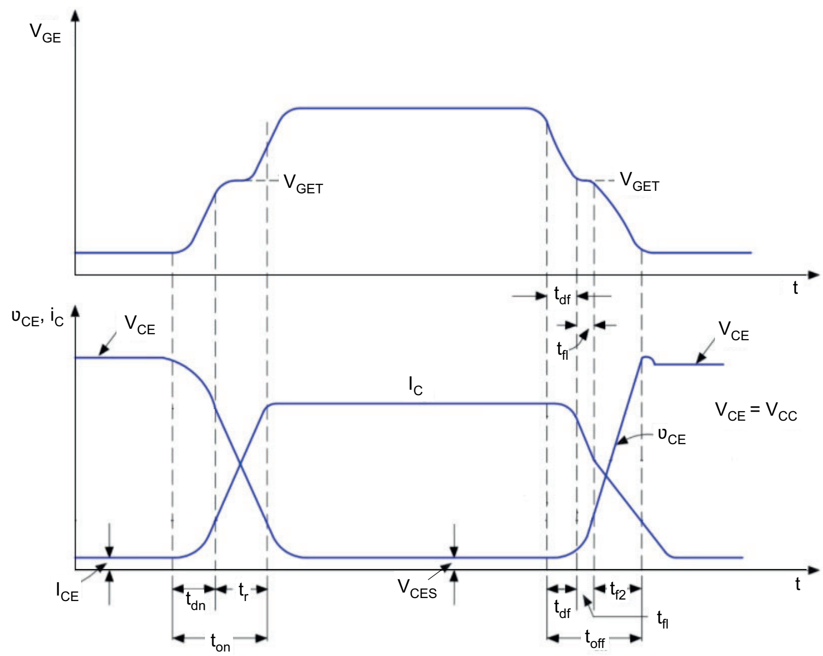



Fig. 13 - Behavior of $V_{CE}$ for IGBT During Normal Operation

Fig. 13 shows the $V_{CEsat}$ when the active switch is closed and $V_{CE}$ when the switch is open. These two voltages can be very different. $V_{CEsat}$ is a few volts, while $V_{CE}$ in high voltage applications is a few hundred volts.

The comparator input that measures the voltage drop across the active switch is the input of the IC circuit. Usually, the maximum allowed voltage for this kind of input does not exceed 10 V to 30 V (every IC has its limit, but due to the technology of the IC the level of voltage cannot be a hundred volts), so it is necessary to isolate the input of the comparator from the high voltage section of the circuit. The simplest and most reliable way to do this is to use a diode.

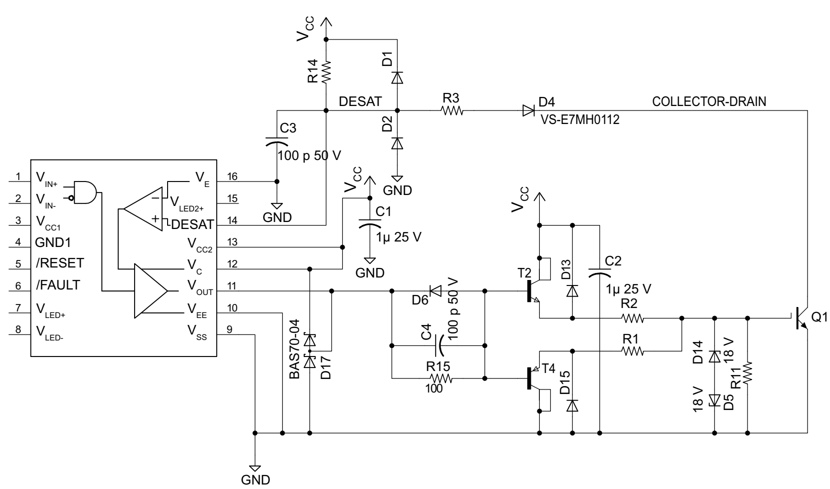



Fig. 14 - Example of Desaturation Circuit

During turn-on, IGBT Q1 has a $V_{CE}$ of a few volts, and the cathode of diode D4 is connected to the collector that pulls down, through R3, the input of the desaturation comparator of the driver IC. The voltage of the comparator input is pulled up from resistor R14 and / or the current source inside the driver IC (usually hundreds of µA or few mA).

# Diodes for Bootstrap and Desaturation Functions

The value of this voltage is:

Eq.4
$$V_{DESAT} = V_{CEsat} + V_{D4} + R_3 \left(I_{OUTIC} + \frac{(V_{CC} - V_{DESAT})}{R_{14}}\right)$$

From Equation 4, we can see that the variation of the desaturation input voltage is mainly a function of $V_{CEsat}$.

$V_D$, the forward voltage of the diode, is quite constant. Fred Pt Gen 7 diodes are designed to minimize their forward voltage variation with temperature, so $V_D$ could be considered a constant term. In addition, the contribution from the resistive drop is quite constant (if the current source inside the $I_C$ is stable), which means that until diode D4 is in the forward condition, the voltage on the desaturation pin is strictly related to the collector voltage of the active switch.

When the active switch is closed, the collector voltage is low and diode D4 is in the forward condition — Equation 4 is valid — and the IC measures $V_{CE}$ across the active switch.

When the active switch is open, the collector voltage is higher than the IC supply voltage, so diode D3 goes in reverse condition and the voltage on the desaturation pin is controlled from the IC circuit. In this condition, the active switch is opened and does not control the voltage on the desaturation input. Sometimes the result of the comparator has a logic blanking. Very often, the input is shorted to ground with a MOSFET inside the IC driver. It is just a function of the technology used in the driver. In any case, the input of the desaturation comparator is protected with a small capacitor or clamping diode. This is related to the large voltage swing present on the active switch with often large dv/dt. The desaturation diode, as all diodes, has a junction capacitance with large dv/dt.

The current that the diode could inject is $i_d = C_j^{d\upsilon_d}/dt$

Fred Pt Gen 7 diodes have a small junction capacitance $C_J$ that allows for the use of a minimum C3 capacitor to filter and protect the IC input. The use of C3 also helps to filter the desaturation input during turn-on and turn-off events, but introduces a delay in the case of a fault. For this reason, its value should be as low as possible without inducing overstress and noise in the driver IC. Usually using a Fred Pt Gen 7 diode, the desaturation circuit does not need clamping with a diode. The common value of C3 necessary to avoid a false trigger during normal operation is enough to protect the IC driver without adding a large clamping diode. This is important when the circuit is used to protect MOSFETs, or IGBTs that are not rated for short circuits, to reduce the current stress on the devices.

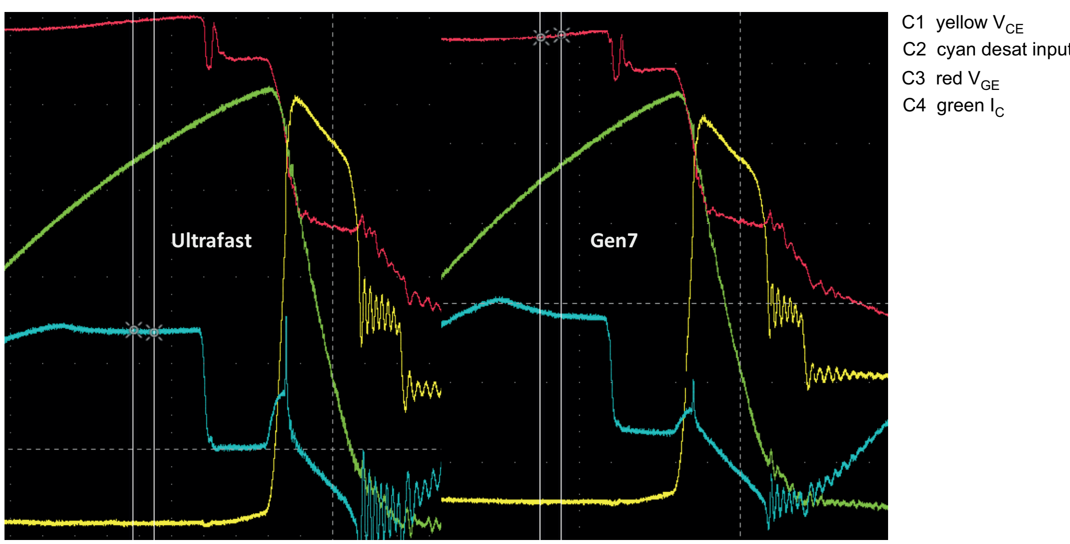



Fig. 15 - Comparison Between Voltage on Desaturation Input Pin on Driver IC

Fig. 15 shows the voltage on the $I_C$ desaturation input. A normal ultrafast diode with standard junction capacitance is shown on the left side. Despite the pull-down provided by the internal MOSFET, an overvoltage that does not exceed the $V_{CC}$ of the chip is present during normal operation. However, this is very similar to voltage levels that trigger faults during normal operation. The same circuit with a Fred Pt Gen 7 diode shows a much lower overvoltage thanks to the lower junction capacitance, which moves the ratio of the capacitor divider between C3 and diode $C_J$ to a lower value.

# Diodes for Bootstrap and Desaturation Functions

This is normal behavior during turn-on and turn-off of the active switch. Each cycle has this behavior, and it is repeated at switching frequencies. During a failure event, it is important not to stress the input of the desaturation comparator for long term reliability purposes.

When the active switch fails, the voltage drop across the active switch could increase significantly.

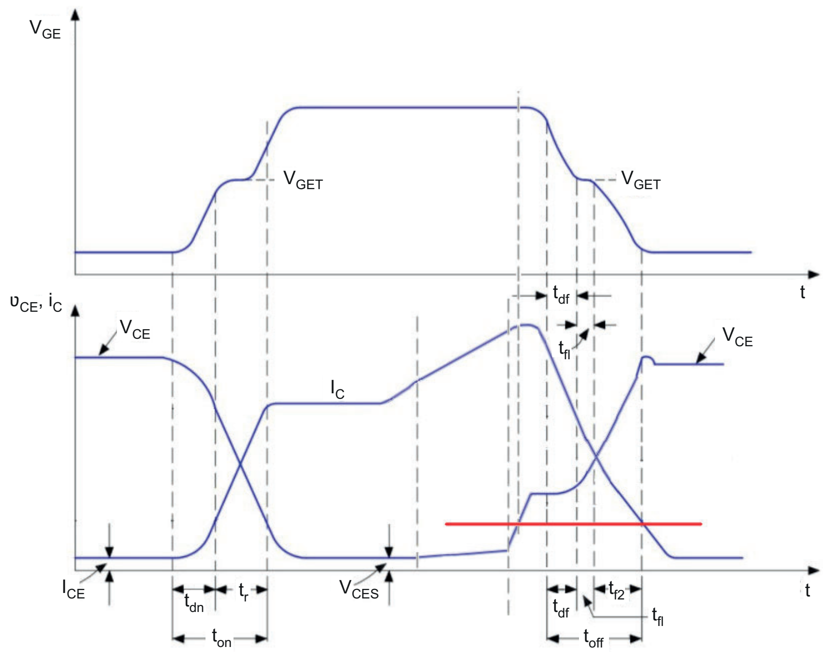



Fig. 16 - Behavior of $V_{CE}$ for an IGBT During Overcurrent Operation

If the active switch is an IGBT, its voltage drop during a short circuit could be very high (hundreds of volts). In this condition, detecting the failure is easy and the characteristics of the insulation network (diode, resistor, capacitor) are not critical. The diode switches off because the voltage on the cathode becomes much higher than the voltage on the anode. This is true for IGBTs that are short circuit rated (like in Fig. 16), where limited transconductance brings the device into the red working area (like in Fig. 12) quickly.

For IGBTs and MOSFETs that are not short circuit rated, the detection of overcurrent should be considered more carefully, because the active switch could reach the red zone working point at a current level too high for a safe turn-off.

In fact, the detection of overcurrent is not based on a high voltage (that puts the diode in reverse), but on the voltage present at the desaturation pin as long as the desaturation comparator is triggered. The main difference is that the detection of the voltage drop of the active switch is done with a diode operating in forward mode. In this sense, it is important that the forward voltage drop of the diode is stable with junction temperature. The margin between the desaturation trigger level and normal operation level must be designed above a specific level (compatible with the maximum current required from the load) to avoid false triggers.

# Diodes for Bootstrap and Desaturation Functions

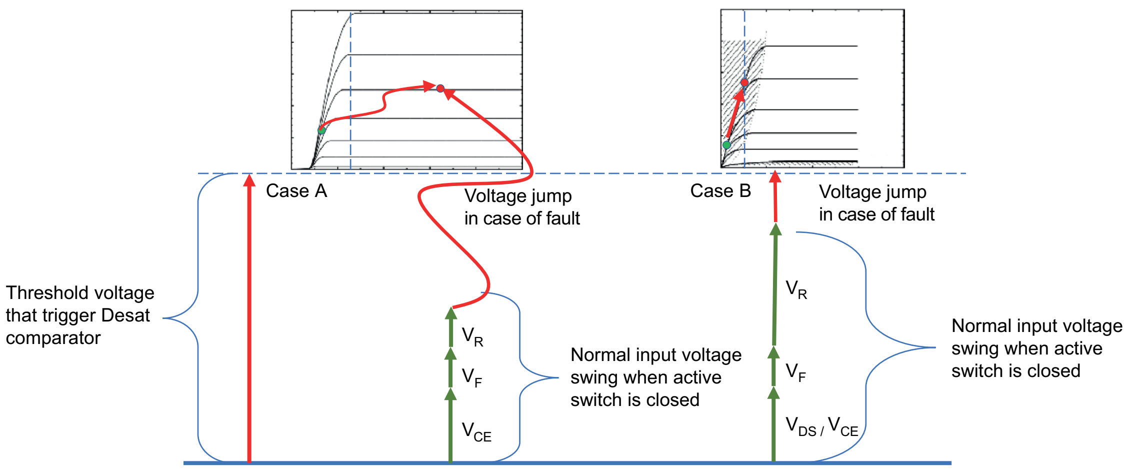



Fig. 17 - Comparison Between the Voltage Input and Voltage Threshold of the Desaturation Comparator

Fig. 17 shows how the voltage on the desaturation input is composed in different cases. Case A on the left is the typical protection for a short circuit rated IGBT. It is not important how the normal voltage level is near to the trigger voltage. In the case of an overcurrent, the voltage drop on the active switch becomes so high that, in any case, the desaturation comparator is triggered, and the level of fault current is not a function of the threshold voltage; it is defined by device transconductance gm and $V_{GE}$. In this condition, a wide margin between the normal operating voltage and desaturation threshold will avoid a false trigger, allowing for simple and safe protection of the active switch.

Case B on the right is an example of operating with a MOSFET or an IGBT that is not short circuit rated. Here, it is necessary to tune the margin between the normal operating voltage and the trigger level of the desaturation comparator to assure that current in the active switch is not too high, and also to provide reasonable immunity against noise.

To change the offset of the comparator input (the threshold is usually fixed inside the IC), it's best to use resistor R3. Resistors are stable with temperature, accurate, and cheaper. The higher the value of the R3 resistor, the lower the allowed rise of the active switch forward voltage and the lower the current level in case of a fault. Other circuit configurations, like more diodes in series, are mainly used to obtain the right clearance creepage distances to be compliant with application relative standards.

In theory, a circuit built with Zener diodes or NTCs in series to compensate for the variations in the forward voltage characteristic of the active switch with temperature is possible. In practice this does not give good results. This is because sensitive devices (Zener diodes or NTCs) on the driver do not feel the real junction temperature of the active switch, so compensation in general is not good because there is no real thermal feedback from the power section.

In addition, if R14 is present, it could be used to fine tune the trigger level of desaturation. In Fig. 14 it is connected to $V_{CC}$ and reduces the noise margin and operation time of protection. On the contrary, if R14 is connected to the reference GND, the effect is specular with increasing noise margin and active switch current levels for triggering, and the delay of protection. Usually, a current source is already present inside the IC, which is enough in 80 % of cases, so it is possible to avoid the use of a resistor. R14 could be useful when a high C3 value is required, there is high noise, and the IC driver's internal source is too small to have the right response to trigger protection.

1 AN-1123 International Rectifier Bootstrap Network Analysis: Focusing on the Integrated Bootstrap Functionality By Andrea Merello