Driving IGBTs with unipolar gate voltage

Introduction

Infineon recommends the use of negative gate voltage to safely turn-off and block IGBT modules. In areas with nominal currents less than 100 A the negative gate voltage is often omitted for cost reasons. The following paper describes special considerations for a unipolar drive of IGBT modules.

Turn-off to 0 V

The latest Infineon IGBT chip generations have several advantages. Some highlights especially are a wider dynamic range, faster switching, less switching losses and lower conduction losses.
When switching to 0 V two effects may come into play:

- parasitic turn-on via the Miller capacitance
- parasitic turn-on via stray inductances

Turn-on via the Miller capacitance

When turning on the lower IGBT in a half-bridge a voltage change $\mathrm{d}v_{\mathrm{CE}}/\mathrm{d}t$ occurs across the upper IGBT / diode. This causes an approach current $i_{\mathrm{CG}} = C_{\mathrm{CG}} \frac{\mathrm{d}v_{\mathrm{CE}}}{\mathrm{d}t}$ to flow which charges the parasitic capacitance C_{CG} of the upper IGBT. The capacitances C_{CG} and C_{GE} form a capacitive voltage divider. Figure 1 depicts the current path via the Miller capacitance of the upper IGBT.

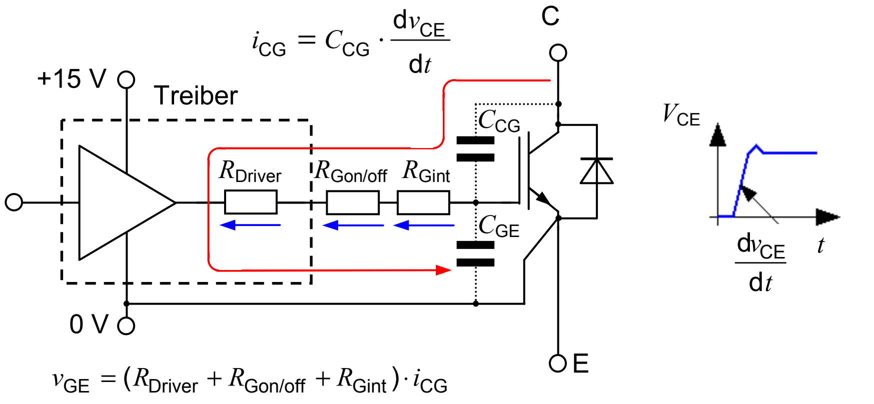

Figure 1: Current via the Miller capacitance of the upper IGBT

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The current i_{CG} flows via the Miller capacitance, the serial resistors, C_{GE} and the DC-bus.
If the voltage drop across the gate resistor exceeds the threshold voltage of the IGBT, a parasitic turn-on occurs.
With rising chip temperature the threshold voltage drops by several mV / K.
When the upper IGBT switches, a current flows via the Miller capacitance of the lower IGBT and may lead to parasitic turn-on here as well.

Turn-on via stray inductances

When turning off the load current a voltage $v_{\sigma E2} = L_{\sigma E2}\frac{di_{C2}}{dt}$ is induced across the emitter stray inductance.

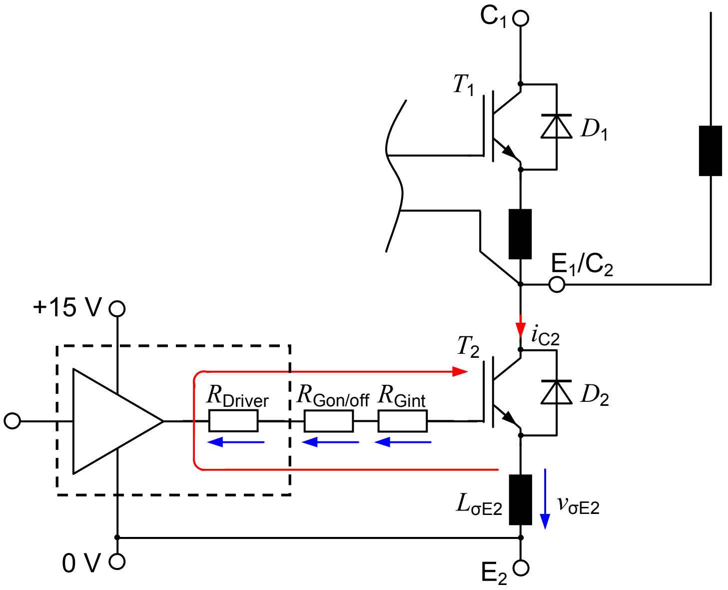

Figure 2: Induced voltage across the emitter inductance

When switching the IGBT T_1 on the main current will commutate from the free wheeling diode D_2 to the IGBT. The di_{C2}/dt produced from decay of the reverse recovery of the diode, induces a voltage on $L_{\sigma E2}$ and shifts the emitter potential of T_2 to the negative.
If the induced voltage produced through a high di_C/dt is higher than the threshold voltage of the IGBT this will result in a parasitic turn-on of T_2.

Parasitic turn-on in modules with common auxiliary emitter

In modules where the auxiliary emitter connections of several IGBTs are joined to a common emitter connection, very fast switching may result in an induced voltage across stray inductances of the emitter.

The equivalent circuit diagram is depicted in figure 3:

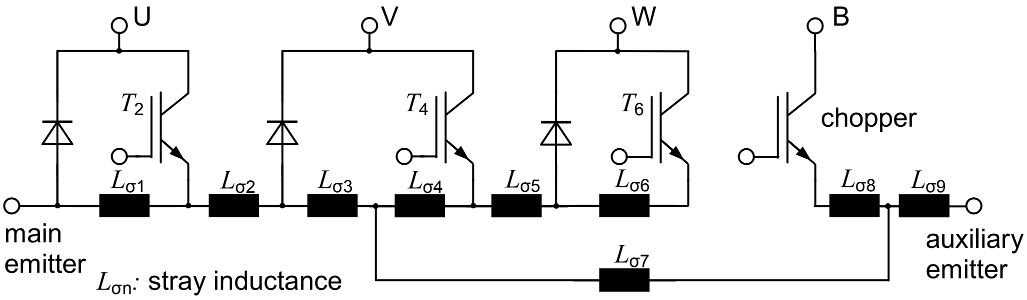

Figure 3: Parasitic turn-on via the common emitter inductance

The parasitic inductances in the module are here numbered $L_{\sigma 1}$ to $L_{\sigma 9}$. When turning on IGBT T_6 an induced voltage across $L_{\sigma 2}$ to $L_{\sigma 3}$ results, which affects T_2. The emitter potential of IGBT T_2 is thus shifted resulting in parasitic turn-on of IGBT T_2 when the voltage change exceeds the threshold voltage.

Proving parasitic switching

To prove parasitic turn-on, it is necessary to insert a current sensor in the bridge arm of the module. Two measurements may lead to the definite proof.

1. Double-pulsing the lower IGBT while blocking the upper IGBT with a negative voltage.
2. Double-pulsing the lower IGBT while the upper IGBT is shut off as done later in the application.

It is recommended to make two measurements with different current between $\frac{1}{10} \cdot I_{\text{Cnom}}$ to $2 \cdot I_{\text{Cnom}}$.

Parasitic turn-on has been proven when the two current curves differ considerably. To be noted here especially is a higher current peak, a wider reverse current peak and/or an additional current pulse. Means to suppress the inadvertent turn-on are described in details in the chapter “Suggestions for Solutions”.

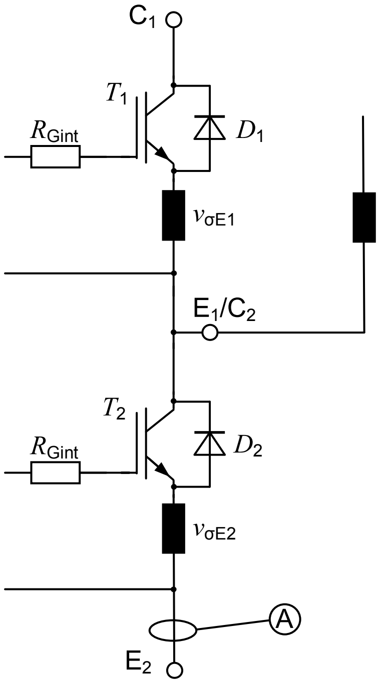

Figure 4: Bridge arm with current sensor

In applications with screw terminal power connections it is often possible to use a Rogowski coil for measurements. In most cases, however, it is not possible to measure directly in one arm. In smaller modules the load current is often brought to the PCB via solder pins. Here it is recommended to measure in the DC-bus e.g. with a Rogowski coil or a shunt resistor.

Suggestions for solutions

Variation of the gate resistor

The voltage change -dv_{CE}/dt and the current change di_C/dt during the turn-on process may be influenced by varying the gate resistor R_{Gon}. Increasing the gate resistor reduces the voltage and current changes. The IGBT switches slower; see also table 1.
The capacitive parasitic turn-on may be obviated by reducing the R_{Goff} value. The inductive parasitic turn-on, however, is prevented by increasing the R_{Goff} value.

Separate gate resistors to achieve non-critical turn-on and turn-off

In many applications a non-critical switching characteristics may be achieved when separate turn-on and turn-off resistors are used.

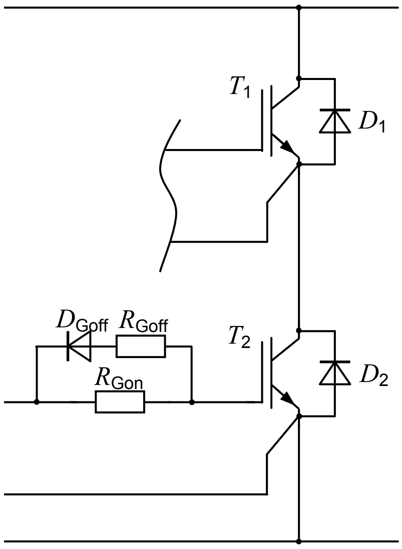

Figure 5: Separate turn-on and turn-off resistors

Choosing R_{Goff} < R_{Gon} prevents a capacitive turn-on via the Miller capacitance; s. paragraph “Turn-on via the Miller capacitance”.

Additional gate emitter capacitor to shunt the Miller current

The switching behaviour may be influenced with an additional capacitor C_G between gate and emitter. The capacitor is to take up additional charge originating from the Miller capacitance. Due to the fact that the total input capacitance of the IGBT is $C_G||C_{GE}$, the gate charge necessary to reach the threshold voltage is increased.

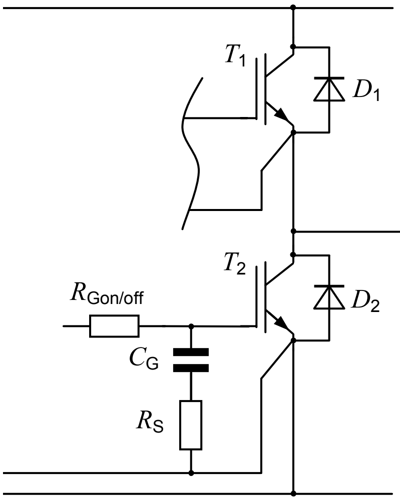

Fig. 6: Additional capacitor between gate and emitter

In applications where the IGBT module does not have an internal gate resistor it is recommended to place an additional resistor R_S in series with the capacitor, to prevent oscillation. The recommended value for R_S is: $R_S \approx \frac{1}{20} \cdot R_{\text{Gon/off}}$. These are values derived from experience.

The capacitance recommended for the additional capacitor is also derived from experience and is calculated by:

$$C_G \approx \frac{Q_{ge}}{3 \cdot 30V} .$$

Due to the additional capacitor the required driver power is increased and the IGBT shows higher switching losses depending on how the $R_{\text{Gon/off}}$ where modified.

Transistor to shunt the Miller current (active Miller clamping)

An additional measure to prevent the unwanted turn-on is shorting the gate to emitter path.
This can be achieved by an additional transistor between gate and emitter.
This “switch” shorts the gate-emitter region after a time delay, as long as the driver shows a 0V signal at its output. The Schottky diode prevents a current flow coming from the Miller capacitance back through the gate resistor.

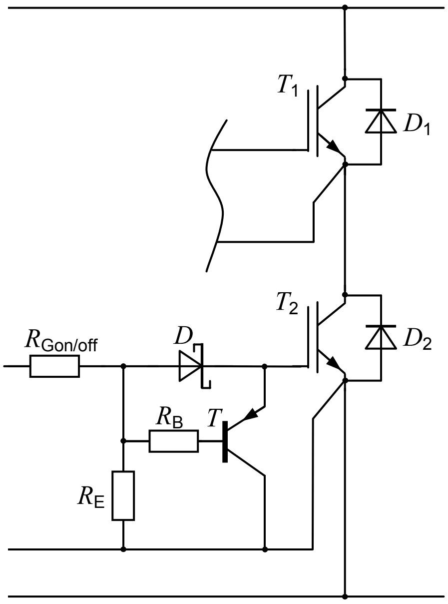

Fig. 7: Possible set-up with additional transistor

The occurring currents across the Miller capacitance are shunted by the transistor in a controlled manner. This guaranties safe switching.

Conclusion

Table 1 gives an overview of the measures discussed above with their advantages and disadvantages accordingly. R_{Gon} is used to turn the IGBT on; R_{Goff} is used to block and to turn off the IGBT.
$R_{\text{Gon/off}}$ is the common resistor for turn-on and turn-off the IGBT.

Effect Measure	Turn-on due to the Miller capacitance	Turn-on due to the stray inductance	Switching losses
Reducing $R_{\mathrm{Gon/off}}$	+	-	↓
Increasing $R_{\mathrm{Gon/off}}$	-	+	↑
Additional C_{G}	+	-	↑
Reducing R_{Goff}	+	o	↓
Reducing R_{Gon}	-	-	↓
Increasing R_{Goff}	-	+	↑
Increasing R_{Gon}	+	+	↑
Additional transistor	++	-	↓

Table 1: Effectiveness of different measures

++: Very good results

+: Improvement

- : Deterioration

o: no change

↑: increase

↓: decrease