EiceDRIVER™

High voltage gate drive IC

External Booster for Driver IC

Application Note

Application Note

AN2013-10

Revision 1.6, 2014-08-05

Industrial Power Control

Edition 2014-08-05

Published by

Infineon Technologies AG

81726 Munich, Germany

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Revision History: 2013-09 Rev.1.0	
Page or Item	**Subjects (major changes since last revision)**
Previous Version: 1.0	

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1 Introduction

An external booster is used to extend the operating range of the driver IC to current levels beyond maximum rating. To achieve this purpose, additional components will be necessary. For instance, the Infineon 1ED020I12-F2 driver IC has a 2A driving capability, but to reach a higher than 2A driving capability used for driving larger IGBTs or parallel driving, an external booster will be the most popular solution. In this configuration the driver IC is used as a controller and an external booster transistor is employed to handle the higher current and heat dissipation [1]. At the first glance, the external booster is not a complicated circuit. But often in real applications questions rise up when considering the device selection (bipolar transistor or MOSFET) and also the influence of the driver IC features (e.g. Clamping, DESAT, etc…). This application note will give the hints and recommendations with focus on the above mentioned items.

Although 1ED020I12-F2 driver IC is mainly used in the examples, this application note can also be applied to the most of the Infineon EiceDRIVER™ driver IC family (1ED, 2ED and 6ED) with exception of 1ED-SRC.

2 External booster basics

A typical external booster circuit can normally be built with a discrete NPN/PNP complimentary output stage which is added to the output of a driver IC. One possible implementation is shown in Figure 1. The NPN and PNP booster transistors should be fast switching and have sufficient current gain to deliver the desired peak output current. The circuit, seen in Figure 1, depicts the output external booster being used with an Infineon 1ED020I12-F2 driver IC.

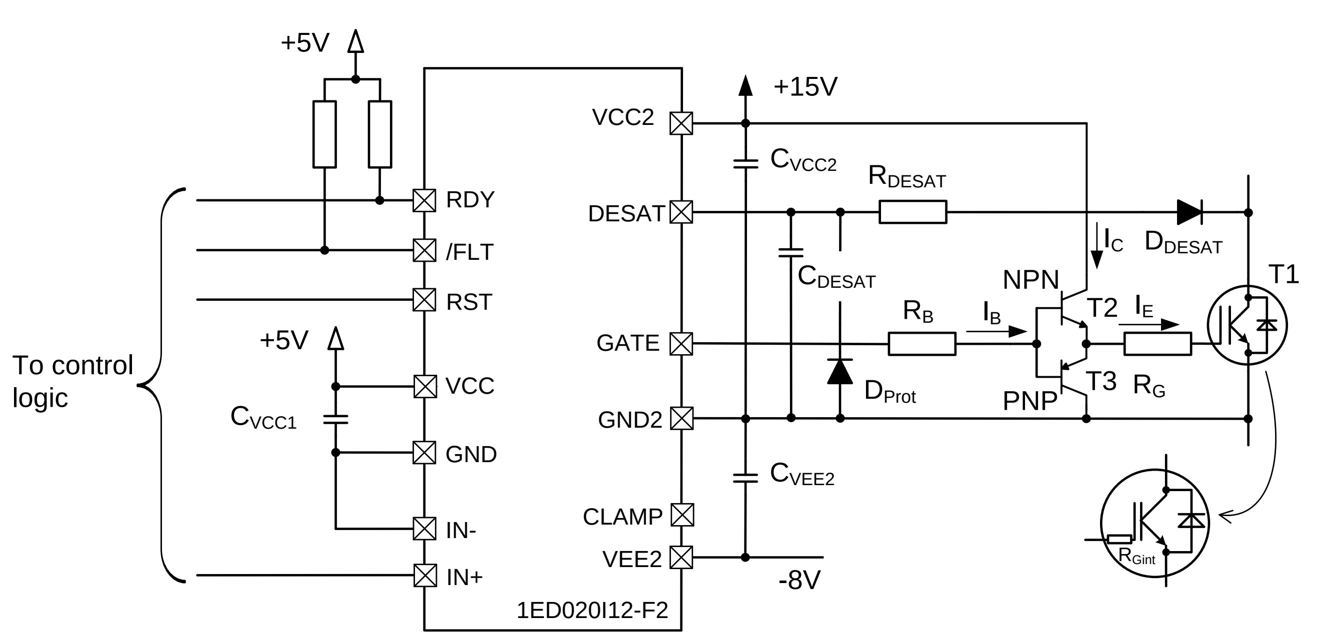

Figure 1 Example circuit for driving large IGBT modules (bipolar supply for driver IC)

Here, the NPN transistor T2 is responsible for turning on the load T1 (IGBT or IGBT module) and PNP transistor T3 is responsible for turning it off.

The basic concept is simple: the 1ED020I12-F2 driver IC feeds its output current into the base terminal of the external NPN booster transistor during turning on. The booster transistor then multiplies this base current I_B by the DC current gain (h_{FE}) of the boost transistor, with a much higher current I_C at the collector. Equation (1) and (2) provide a method to derive I_C and I_E from I_B:

$$I_C = h_{FE} \cdot I_B \tag{1}$$

$$I_E = I_C + I_B = (1 + h_{FE}) \cdot I_B \tag{2}$$

Finally, the emitter current I_E will drive the load T1 (IGBT or IGBT module). Normally I_C is far larger than I_B ($I_C >> I_B$) when driving the load, so I_C will be used instead of I_E in this application note. During turning off the PNP transistor will work in the same way.

With the external booster, the required output current from the driver IC is reduced by the factor of DC current gain of the booster's transistor. Most of the power dissipation burden is now placed upon the booster's transistor, instead of on the driver IC.

A proper gate resistor R_G can be sized according to the power device and application requirement, and the base resistor R_B can be sized to provide the required base current according to the gain of the booster transistors. These resistors need to have a suitable rating for repetitive pulse power to avoid degradation. In some applications, it might be required to separate the turning on and turning off resistance for R_G and R_B. To focus more on the selected topics, single R_G and R_B will be used in this application note.

3 Device selection

As a rule of thumb, the booster transistors T2 and T3 are dimensioned to provide enough peak collector current I_{Cpk} to drive the load T1. This peak current can be calculated with the following simplified equation:

$$I_{Cpk} = \frac{\Delta V_{out}}{R_{Gint} + R_G} \quad (3)$$

$$I_{CM} > I_{Cpk} \quad (4)$$

In this equation, ΔV_{out} is the voltage drop along the charging/discharging path. Normally with unipolar supply it is V_{CC2} and with bipolar supply it is V_{CC2}-V_{EE2}. R_{Gint} is the internal gate resistance of the IGBT, R_G is the gate resistance between the external booster and the IGBT, and I_{CM} is the maximum allowed peak pulse current.

In reality, the upper limit on output current for the external booster circuit is often limited by the maximum power dissipation and junction temperature of the booster transistor (T2 or T3). So, the power dissipation and maximum ratings of the booster transistors must be checked and verified for each individual circuit design. To simplify the calculation for a transient behavior basing on non-constant gate current, the following equation (5) can be used to do a quick power dissipation check with normalized application parameters:

$$P_D = \frac{1}{2}\Delta V_{out} \cdot f_S \cdot Q_G - (R_{Gint} + R_G) \cdot (f_S \cdot Q_G)^2 \quad (5)$$

Here P_D is the power dissipation of the bipolar transistor, f_S is the switching frequency, and Q_G is the gate charge of the IGBT. The first portion of this equation is the whole power which is consumed along the path from power supply to the gate of IGBT. The second portion is the power which is consumed by the gate resistors, so that the difference is the power which is consumed by the booster's transistor.

Now with the calculated P_D, the junction temperature of the booster's transistor can be derived as given in equation (6) and (7):

$$T_J = T_A + R_{THJA} \cdot P_D \quad (6)$$

$$T_J < T_{Jmax} \quad (7)$$

T_A is the ambient temperature, R_{THJA} is the thermal resistance between the junction and ambient, and T_{Jmax} is the maximum allowed junction temperature for the selected bipolar transistor. The calculated junction temperature T_J of the booster transistor must be lower than T_{Jmax}, otherwise the external booster will be damaged.

This is just a simply approach to describe the thermal behavoir. More detail about the thermal modeling for SMD components on PCB which dissipates significant power, please refer to the reference such as [2].

To allow the output of the external booster to track close to the driver IC output at low current (to preserve the rail-to-rail capability), it may become necessary to add resistor (R_E) from base to emitter on the booster transistors as shown in Figure 2. The recommended value range is between 50Ω and 100Ω. Sometimes, when very high gain transistors need to be used in the external booster, this R_E could also be helpful to avoid oscillations in the output stage with careful exercise.

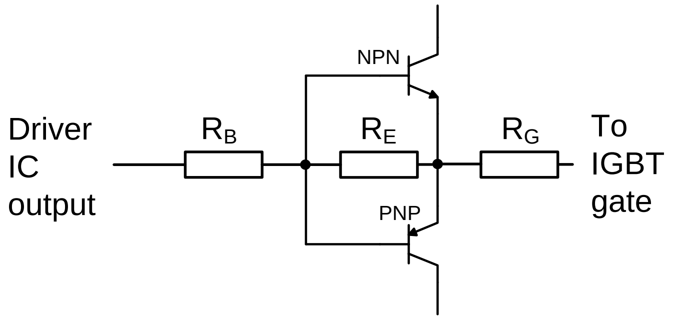

Figure 2 Alternative booster stage configuration

Intrinsically, MOSFETs can also be used for an external booster, and the polarity issue can be solved by adding an additional inverter (theoretically it can also be solved by using the inverting input pin from the driver IC side, but then the DESAT and Active Miller Clamp feature can not be used when designing gate drives with 1ED020I12-F2) as shown in Figure 3. In this case several points may be considered when comparing the difference between bipolar transistors and MOSFETs:

1) Voltage loss at output $V_{CE(sat)}$ for bipolar solution meanwhile MOSFET solution almost has a rail-to-rail output.
2) Breakdown voltage limitation for MOSFET (~20V for V_{GS}), which could be a problem when using a bipolar power supply.
3) The booster with MOSFETs is prone to shoot through especially when supply voltage is beyond 15V. Also, MOSFETs have negative temperature coefficient for threshold voltage Vth, this will make the shoot through worse at higher temperature. This should be paid attention and carefully considered when the MOSFETs are used for external booster.
4) Switching speed: bipolar transistors are normally switching slower than MOSFETs in an external booster circuit.
5) Robustness of the booster’s input stage towards ESD and voltage surge: gate oxide vs PN junction.
6) Last but not least, the cost.

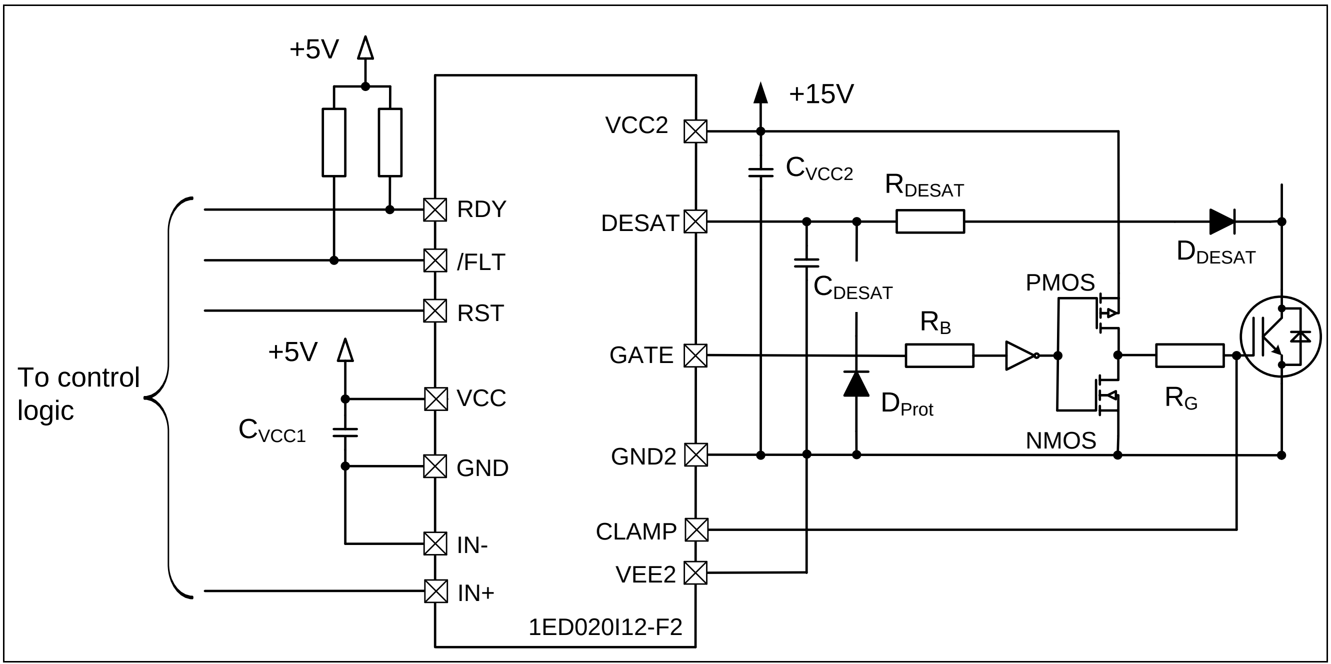

Figure 3 Example circuit for external booster with MOSFET (unipolar supply for driver IC)

4 Design considerations

When applying the external booster, there will be some influence to the application circuit and also to the features of the driver IC, so some hints are noted here for design considerations:

1) The Active Miller Clamp feature of the 1ED020I12-F2 family can be used together with external booster (mainly in the unipolar supply case). When the Miller current is larger than the maximum clamping capability of driver IC (2A for 1ED020I12-F2), an additional sinking path will be needed along the clamping path (between gate of IGBT and CLAMP pin). The booster transistor itself also has sinking capability, but due to the exist of the gate resistor (R_G), this sinking capability is probably not enough. Figure 4 gives an example about how to implement this additional sinking path. Here the PNP_CLAMP transistor should have the same current capability as the PNP transistor of the external booster. R_{B_CLAMP} is the base resistor for the PNP_CLAMP transistor, and the sizing is according to PNP_CLAMP transistor. R_P is used as a pull-up resistor for safety reasons, and the recommended value is in 10kΩ range (to limit the current which runs through R_P in mA range to save power).

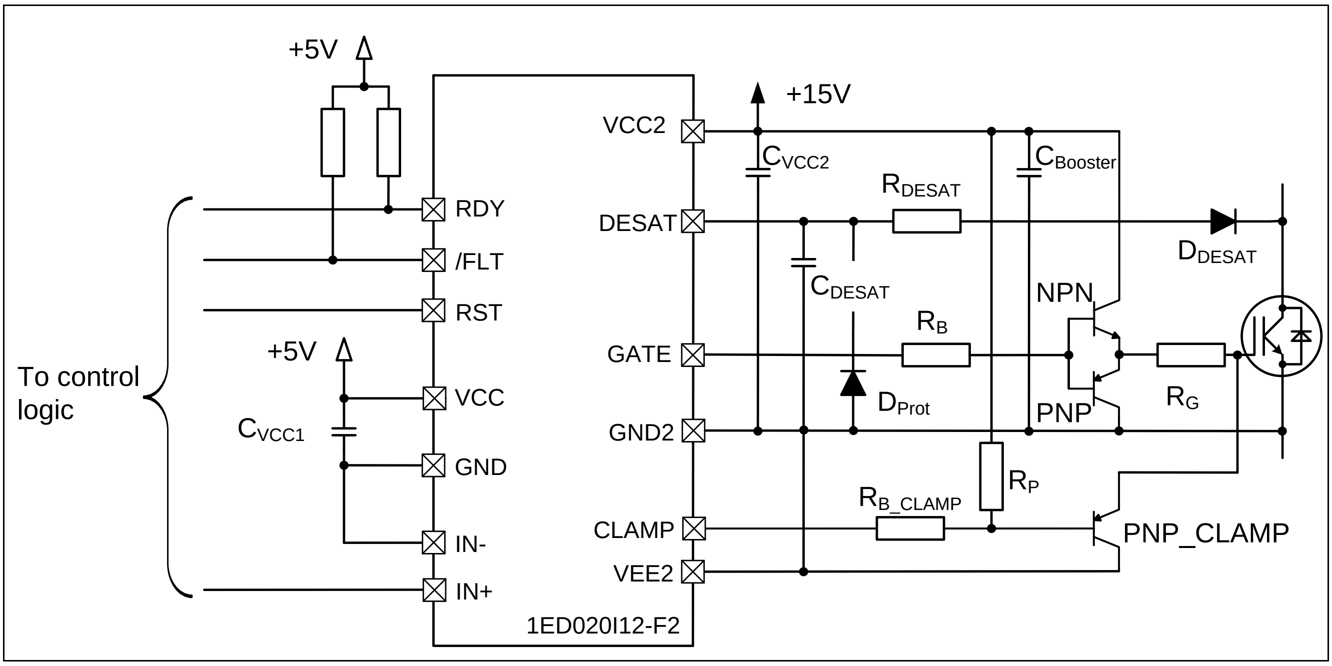

Figure 4 Example circuit for Active Miller Clamp feature with external booster (unipolar supply for driver IC)

2) It is possible when the bipolar supply is used that VEE2 is not at same potential as GND2 but has a negative value. In this situation, the Active Miller Clamp feature is normally not necessary. The CLAMP pin can simply be left open (as depicted in Figure 1). The resistance values of R_G and R_B need to be adjusted accordingly since the voltage step (ΔV_{out} = VCC2 –VEE2) is changed.

3) If the bipolar supply needs to be used together with the Active Miller Clamp feature, the additional sinking path (PNP_CLAMP and R_{B_CLMAP} as shown in Figure 4) needs to be adjusted accordingly with different VEE2 value. Note that this configuration is possible since the CLAMP pin is internally reference to VEE2 for Infineon 1ED driver IC family.

4) The DESAT (desaturation detection) feature is functional and is not influenced by the external booster.
5) The TLTO (Two-Level Turn-Off) feature from the 1ED020I12-FT/BT driver IC is still functional with the bipolar external booster, but can NOT be realized when using the MOSFETs external booster.
6) The power supply and the decoupling capacitor C_{VCC2} (as seen in Figure 1) need to be adjusted according to the external booster to ensure the quality of supply voltage, which should be enough to support the three main parts of the power consumption: the driver IC, the load (IGBT) and the external booster. Alternatively a separate decoupling capacitor solution can be used to optimize the layout: C_{VCC2} closes to the driver IC and $C_{BOOSTER}$ closes to external booster transistors (as shown in Figure 4).
7) When doing the layout, large parasitic inductance and especially capacitance should be avoided (e.g. shorten the loop, avoid the overlap between the high dv/dt path and the ground path, etc…).

5 Design example

To better understand it thoroughly, consider the calculations in the following example with real data. Using Figure 1 as the reference design, the 1ED020I12-F2 is the driver IC. The Infineon 600A IGBT module FZ600R12KP4 is used as the load, which can be driven properly by a 10A peak current. Now for the external booster, the ZXTN2031F [3] is the NPN transistor and ZXTP2025F [4] is the PNP transistor, which are paired transistors to each other and have similar parameters.

The operating conditions are:

Voltage step to drive the load with bipolar power supply: ΔV_{out} = 15.0V – (-8.0V) = 23.0V

Switching frequency: f_s = 5kHz

Ambient temperature: T_A = 80°C

According to the datasheet of the IGBT module FZ600R12KP4 [5]:

Gate charge: Q_G = 5.6µC (-15V…+15V value, for -8V…+15V range, it will be smaller)

R_{Gint} = 1.3Ω

R_G = 1.2Ω

According to the datasheet of driver IC 1ED020I12-F2 [6]:

Output peak current: I_{OUTH} = I_{OUTL} = 2A (ΔV_{out} = 23V)

According to the datasheet of bipolar transistors:

Collector-emitter breakdown voltage: $V_{(BR)CEO}$ = 50V > ΔV_{out} (23V)

Maximum allowed junction temperature: T_{Jmax} = 150 °C

Thermal resistance: R_{THJA} = 125 °C/W

For ZXTN2031F:

Pulse peak current: I_{CM} = 12A

Static forward current transfer ratio: h_{FE} = 80 (minimum value is use)

For ZXTP2025F:

Pulse peak current: I_{CM} = 10A

Static forward current transfer ratio: h_{FE} = 70 (minimum value is taken)

First the calculation for the NPN transistor ZXTN2031F, which is responsible for turning on IGBT will be explained:

According to equation (3) I_{Cpk} is calculated as:

$I_{Cpk} = \Delta V_{out} / (R_{Gint} + R_G) = 23V / (1.3\Omega + 1.2\Omega) = 9.2A < I_{CM}$ (12A)

According to equation (5), the power dissipation for the booster transistor is:

$P_D = ½ \cdot \Delta V_{out} \cdot f_S \cdot Q_G – (R_{Gint} + R_G) \cdot (f_S \cdot Q_G)^2$

$= ½ \cdot 23V \cdot 5kHz \cdot 5.6\mu C – (1.3\Omega + 1.2\Omega) \cdot (5kHz \cdot 5.6\mu C)^2$

$= 322mW – 70mW = 252mW$

$T_J = T_A + R_{THJA} \cdot P_D$

$= 80\,^oC + 125^oC/W \cdot 252mW$

$= 80\,^oC + 31.5\,^oC$

$=105.7\,^oC < T_{Jmax}$ (150^oC)

It is apparent with the above mentioned operating conditions, that the peak current and the junction temperature are both under the maximum rating values, showing that this example application is running in the safe range.

Now consider how to size the base resistor R_B. This resistor is used to define the base current so as to control the collector current according to the current gain h_{FE} of the booster transistor. Since the most critical time during switching is the peak current time, the I_{Cpk} value is used to derive the minimum base resistance requirement, according to equation (1):

$I_B = I_C / h_{FE}$

$= 9.2A / 80$

$= 0.115A$

From driver IC side, the driver IC output resistance $R_{DS(on)}$ can be calculated approximately by the voltage step ΔV_{out} divided by driver IC rated peak current:

$R_{DS(on)} = \Delta V_{out} / I_{OUTH}$

$= 23V / 2A$

$= 11.5\Omega$

At the moment of turn on (peak current moment), the voltage step ΔVout is applied across the driver IC output resistance $R_{DS(on)}$ and the base resistance R_B. Now the minimum base resistance R_B can be calculated as:

$R_{B\_min} = \Delta V_{out} / I_B – R_{DS(on)}$

$= 23V / 0.115A – 11.5\Omega$

$= 188.5\Omega$

The calculation for the PNP transistor ZXTN2025F follows the same procedure and the same criterion.

In case the unipolar supply and the Active Miller Clamp features are used as depicted in Figure 4, the calculation needs to be adjusted by the new voltage step (ΔV = VCC2). The sizing procedure and the calculation of the clamping transistor PNP_CLAMP is similar to the PNP transistor of the external booster.

Concerning the power dissipation of the driver IC itself, please refer to the corresponding chapter in Application Note 1ED family: Technical description [7].

6 References

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