EVERLIGHT

APPLICATION NOTE

EL3120   IGBT Gate Drive Optocoupler

Introduction

The global trend now are attention to green energy and environmental protection, replacing traditional fossil fuels with electric energy, Therefore, selecting high-efficiency power switching devices is the key to solving environmental pollution and reducing carbon emissions.

This article first explains the main characteristics of IGBT, then introduces the most circuit configuration of IGBT gate driver EL3120 in different applications.

Insulated Gate Bipolar Transistor (IGBT) Introduction：

Insulated Gate Bipolar Transistor (IGBT) combines the characteristics of metal-oxide-semiconductor field-effect transistor (MOSFET) and bipolar transistor (BJT), with the performance of the fast switching capability of the MOSFET and the high current capability of a BJT. In addition, the IGBT has a lower conduction voltage(Vce) and a high voltage withstand, and the IGBT equivalent circuit can be simplified to using a MOSFET as the driven transistor.

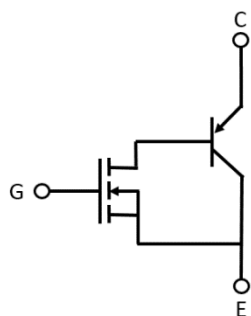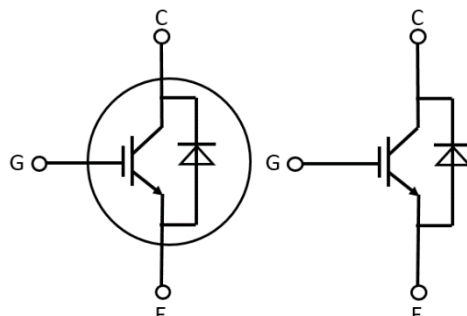Figure. 1 – IGBT Equivalent Circuit

Figure. 2 - IGBT Module Representative symbol

IGBT Switching behavior

The on and off characteristics of IGBT determine the performance of the switching power devices and affect to the power loss. The turn-on and turn-off speed is determined by the input capacitance (C_{GE}) and Miller capacitance (C_{GC}) inside the IGBT. Figure 3 is a schematic diagram of IGBT parasitic capacitance.
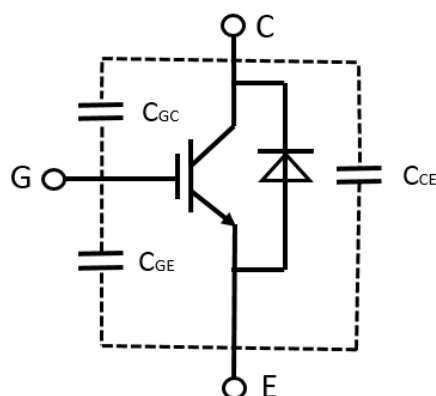
C_{GE} = Input capacitance

C_{GC} = Miller capacitance

C_{CE} = Output capacitance

Figure. 3 - IGBT

IGBT parasitic capacitances (Table 1)。

IGBT Specification Capacitance Parameters	
CAPACITANCE	IGBT
Input	$C_{ies} = C_{GE} + C_{GC}$
Reverse transfer	$C_{res} = C_{GC}$
Output	$C_{oes} = C_{GC} + C_{CE}$

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During the IGBT on-state, the rising gate charging voltage will have a flat for a period of time, which is called the Miller platform. The Miller capacitor（C_{GC}）will affect the width of the Miller platform and then affect the IGBT on and off speed. The IGBT gate charging voltage is shown in Figure 4. The amount of charge required to the rated voltage(VDD) of gate is Qg . This parameter can be found in the IGBT specification.
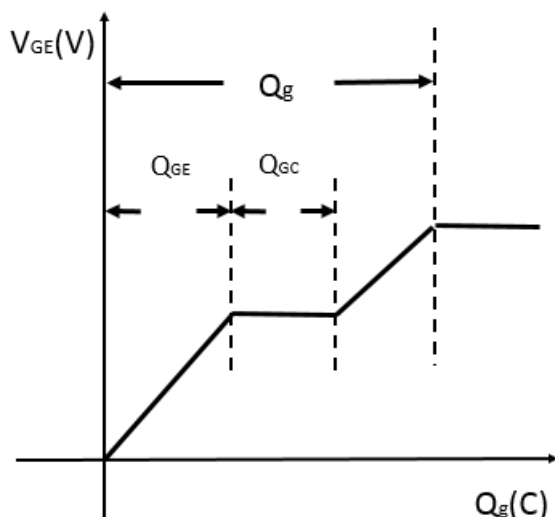

Figure.4 Gate voltage charging waveform

The IGBT conduction behavior is shown in Figure 5 below. From time t0 to t1, The driver starts to charge the gate (C_{GE}) until the gate-emitter voltage reaches $V_{GE(th)}$. During this time, the IGBT will not turn on, and the collector voltage and current remain unchanged, which is called the turn-on delay. From time t1 to t2, The gate voltage continues to rise above $V_{GE(th)}$, at this time the collector current Ic starts to rising until the current reaches the load current, the interval ends.

During the period t2-t3, the collector voltage starts to decrease rapidly, and the IGBT carries full load current. After the end of this interval, the gate voltage will be clamped at same level. During t3-t4, only the Miller capacitor C_{GC} is in charging, which is called the Miller platform, until the Miller platform accomplished. V_{CE} drops to $V_{CE(sat)}$, and the IGBT is fully turned on.
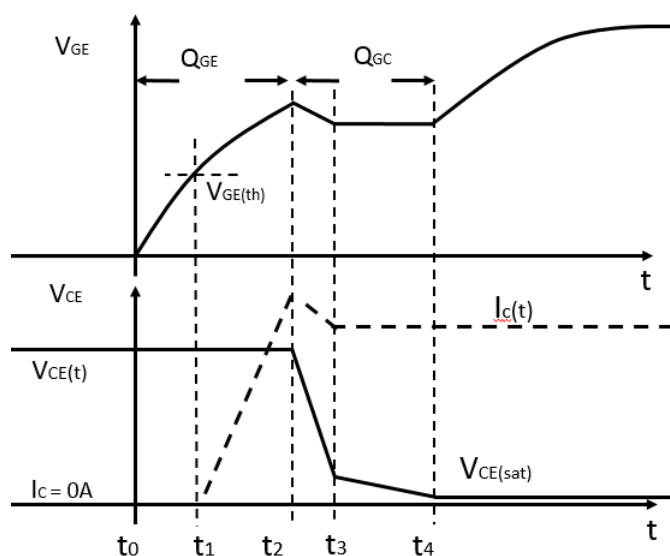
Figure. 5   IGBT Turn-on Sequence

The turn-off characteristics of the IGBT are shown in Figure 6 . From time t1 to t2, V_{GE} voltage continues to decrease until the Miller platform occurs. During t2-t3, the Ic remains constant, and the V_{CE} voltage starts to rise slightly. At this time, the V_{GE} voltage remains constant due to the Miller effect by the C_{GC} capacitor until the Miller platform accomplished.
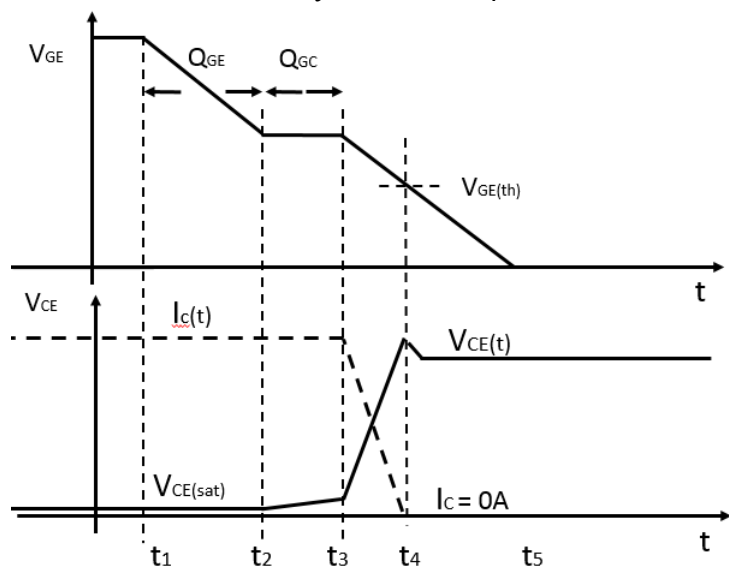

Figure. 6   IGBT Turn-off Sequence

The external gate resistor (Rg) connected to the IGBT can change the rate of rising and falling of the gate voltage. It shows the dV_{CE} / dt slope between collector and emitter during the turn-on and turn-off transitions. As shown in Figure 7, the smaller the Rg value, the larger dV_{CE} / dt and I_{GC}.
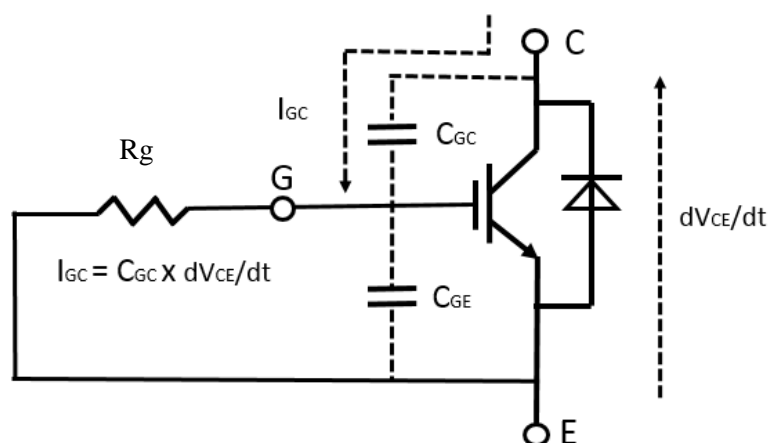
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Figure. 7   Rg Effect on dV_{CE}/dt

The gate resistance (Rg) has a significant impact on performance of the IGBT. A smaller Rg can charge and discharge the IGBT input capacitance faster, thereby reducing switching time and reducing switching losses. However, smaller Rg will cause the IGBT input capacitance and parasitic inductance to induce oscillation. Generally, Rg is designed to be used between 10Ω ~ 30Ω.

IGBT is a voltage drive devices, which needs gate voltage to trigger the collector and emitter turn on or off. Because the IGBT input capacitance (C_{GE}) is larger, using negative voltage as the driver source while the gate turns off can ensure the voltage is below zero, and resists the interference of the Miller effect on the gate and prevents unexpected restarting. Figure 8 shows a gate drive circuit with a negative power source.

When the IGBT is turned off, the collector voltage will be rising rapidly, and a larger voltage will be generated at the gate. Therefore, put a zener diode is reversely connected to the gate and the emitter of the IGBT, it can prevent the gate damaged by overvoltage (limits the gate voltage by clamping) and prevents V_{GE} being broken down.
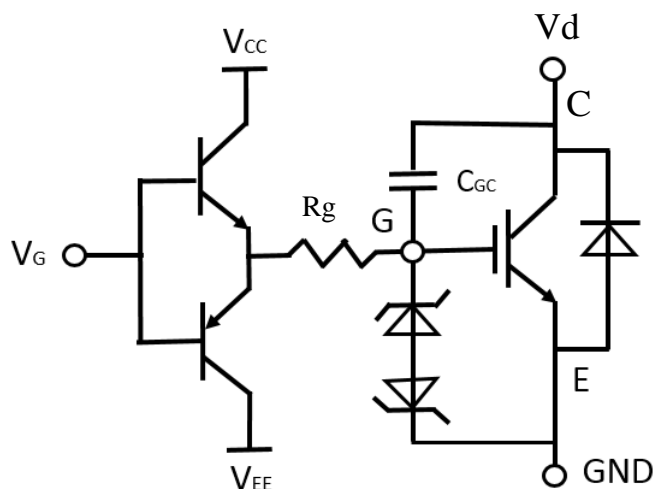
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Figure.8   IGBT gate driver circuit with a negative power source(V_{EE})

EL3120 Drive introduction (IGBT Gate Driver) :

EL3120 is an 8-pin packaged IGBT GATE DRIVER with a maximum drive current of 2.5A. It features a high-speed drive and low power consumption. It has a ± 25KV common mode noise rejection (CMTI), which is very suitable for IGBT driver applications.

Gate Driver Under Voltage Lockout Feature (UVLO)

The EL3120 driver contains an under voltage lockout (UVLO) feature that is designed to ensure EL3120 stops to drive the IGBT gate when the power supply voltage is under voltage.

IGBT Gate driver: EL3120 Power Dissipation Calculation

During operation the driver will generate heat, and its temperature will affect its stability. The heat dissipation must be considered. The heat dissipation design can be performed according to the application conditions.
The driver power consumption is divided into three parts as shown in Figure 9. The first part is the input power consumption $P_{Emitter}$ caused by the emitter LED, the second part is the power consumption of the driver itself (quiescent current) $P_{Internal}$, and the third part is the

driver switching power consumption P_Output caused by internal resistance, the following is the calculation formula.

Total power consumption :
$$P_{(tot)} = P_{Emitter} + P_{Internal} + P_{Output}$$

Drive emitter power consumption :
$$P_{Emitter} = I_F \times V_F \times D$$
D : maximum LED duty cycle

Driver itself Power consumption :
$$P_{Internal} = I_{CC} \times (V_{CC} - V_{EE})$$
Icc : Driver supply current (quiescent current)

Driver output power consumption :
$$P_{D(On)} = \frac{R_{OH} \times V_{GE} \times Qg \times f_{sw}}{2(R_{OH} + Rg + R_{Gint})}$$
$$P_{D(Off)} = \frac{R_{OL} \times V_{GE} \times Qg \times f_{sw}}{2(R_{OL} + Rg + R_{Gint})}$$
$$P_{Output} = P_{D(On)} + P_{D(Off)}$$

R$_{OH}$: Driver High side MOSFET on-resistance
R$_{OL}$: Driver Low side MOSFET on-resistance
R$_{Gint}$: IGBT inside resistance

Suppose $R_{OH} \approx R_{OL}$, then,
$$P_{Output} = \frac{R_{OH} \times V_{GE} \times Qg \times f_{sw}}{R_{OH} + Rg + R_{Gint}}$$
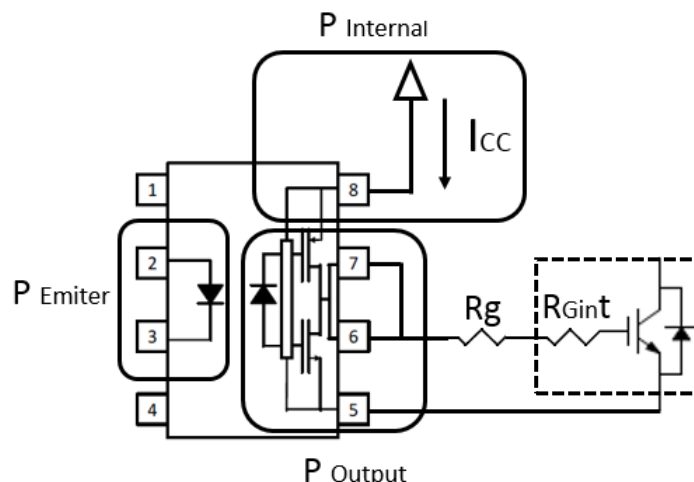

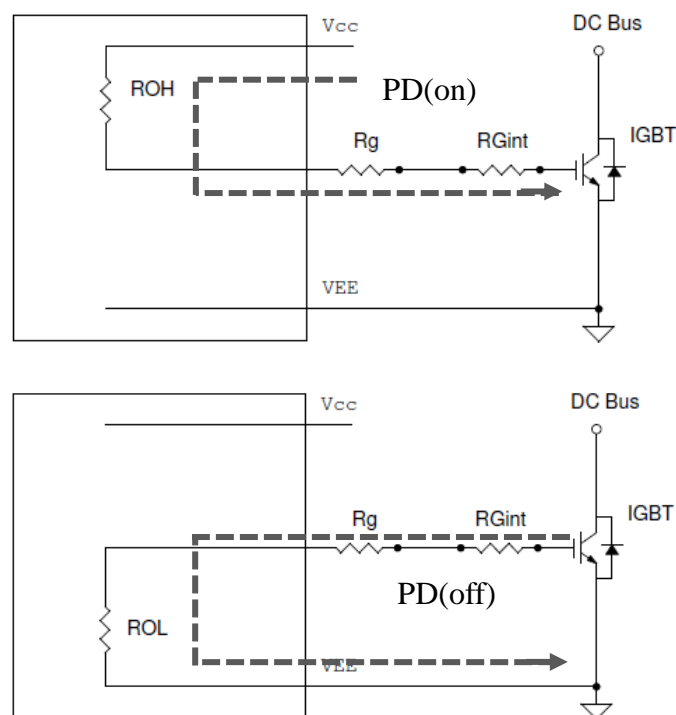Figure. 9-1 Power consumption diagram

Figure. 9-2   Output consumption diagram

The purpose of IGBT gate driver power consumption calculation is to prevent the driver exceeding the rating of power consumption during operation. If the driver exceeds the rating of power consumption, Drive can be damaged due to high temperature. For better heat dissipation of the driver you could introduce air convection or increasing the copper area of the PCB.

IGBT Driver Application Example

The following is an application case. The equivalent circuit of EL3120 is shown in Figure 10. The internal MOSFET has a low on-resistance (R_{OH}/R_{OL}). EL3120 can choose using a negative power source or not, to turn off the IGBT. When user not using a negative power source, when turning off the gate voltage VOL must be less than 0.5V, which can ensure that the IGBT will not restart due to the Miller platform effect and cause IGBT short through.
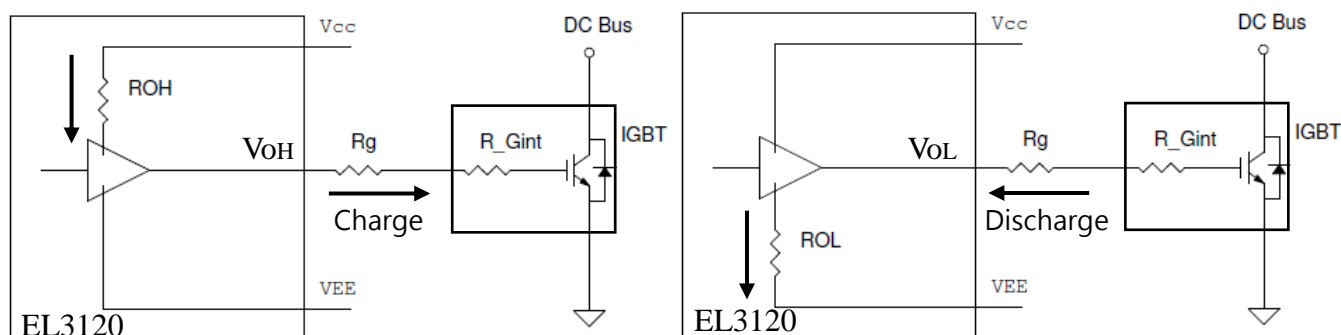

Figure.10 IGBT On/Off Equivalent circuit

The internal gate resistance of IGBT is (R_{Gint}). When the output of the EL3120 is low level, the path of the IGBT gate to ground is R_g + R_{OL} + R_{Gint}, if the path resistance is lower, the less the IGBT gate is affected by the Miller effect. The longer gate's discharge path, the larger parasitic inductance and resistance will be, and it will be easily affected by noise interference. Therefore, it is recommended to shorten the PCB layout path as much as possible.

When calculating the driver power loss, the related component parameters were given as following.

(1) Driver MOSFET R_{OL}、R_{OH}

(2) Gate resistance（Rg）

The driver and IGBT parameter list is as follows:

EL3120 parameter

Item	Unit	Description
V_{CC}	18V	Positive voltage source
V_{EE}	-6V	Negative voltage source
I_{CC}	3.2mA	Consumption current (Standby)
I_{o_peak}	2.5A	Maximum output current

I$_F$	10mA	Input LED maximum current
V$_F$	1.4V	Input LED forward voltage
Duty	60%	PWM Duty cycle
f$_{SW}$	10KHz	Switching frequency

IGBT parameter (FF150R12ME3G)

Item	Unit	Description
Qg	1.4uC	Gate charge
V$_{CES}$	1200V	Collector-emitter maximum voltage
R$_{\_Gint}$	1.3Ω	Internal Gate resistance

(1) Calculate R$_{OL}$ 、R$_{OH}$
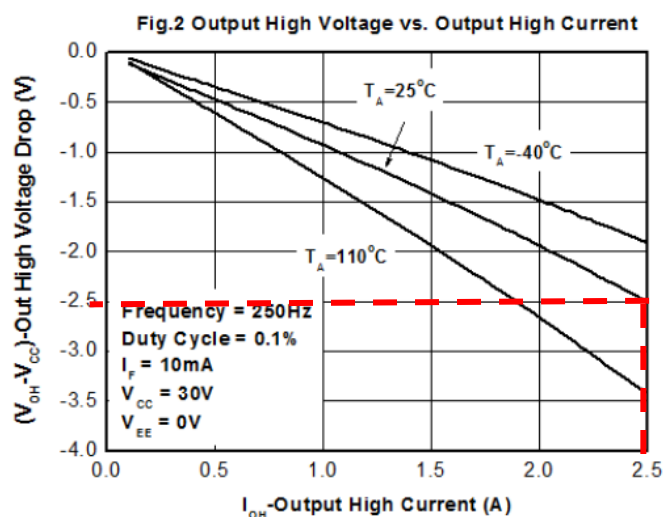
Figure.11 Output High Voltage vs. Output High Current

Figure.12 Output Low Voltage vs. Output High Current

R$_{OH}$ Peak current 2.5A :

R$_{OH}$ =2.5V÷2.5A= 1Ω

R$_{OL}$ Peak current 2.5A:

R$_{OL}$ =2.2V÷2.5A= 0.88Ω ≈1Ω

(2) Calculate the minimum resistance of the gate resistance (Rg)

Calculate Rg Minimum from the Io_Peak Specification. Figure 13 shows a simple circuit for IGBT and R_g.
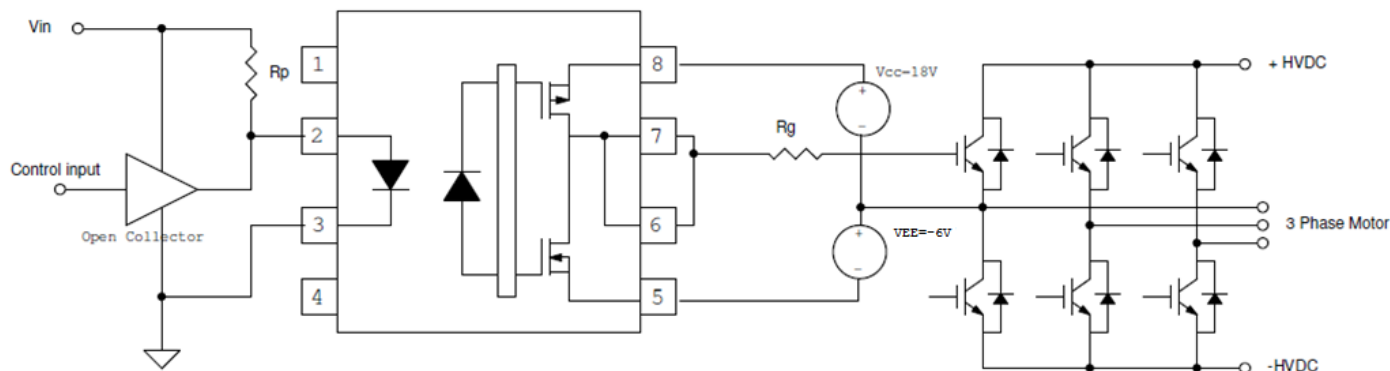

Figure.13 Application circuit with negative power source of IGBT

$$R_{OL} + Rg + R_{Gint} > \frac{Vcc - VEE}{Ig\_peak} = \frac{18 - (-6)}{2.5A} = 9.6 \ \Omega$$

$$Rg > 9.6 - 1 - 1.3 = 7.3 \ \Omega$$

In the formula, Ig uses the peak current of 2.5A to calculate the minimum value of Rg. If non negative power is used, the VEE in the formula is 0V. If the Rg is smaller than the calculated value, unstable condition may occur during operation, so Rg is recommended to be slightly larger than the calculated value. Since efficiency and EMI are often related to each other, the faster IGBT driver switching, the smaller switching loss caused, but often the larger dV / dt and the larger EMI interference. Therefore, it can be adjusted by tunning the value of Rg in order to meet the requirements of EMI and efficiency.

Gate driver Power Dissipation

In the IGBT on/off driving, power consumption will be consumed in the driver, gate and drive paths, respectively. The gate driver total power consumption includes the power emitted by LED (emitter), the internal power consumption of the driver (internal), and the power consumption of the driver output.

The driver total power consumption is calculated as below.

$$P(\text{tot}) = P(\text{emitter}) + P(\text{internal}) + P(\text{output})$$

$$P(\text{tot}) = (IF \times VF \times D) + (Icc \times \Delta V) + (\frac{R_{OH} \times V_{GE} \times Qg \times f_{sw}}{R_{OH} + Rg + R_{Gint}})$$

$$
\begin{aligned}
P(\text{emitter}) &= IF \times VF \times D \\
&= 10mA \times 1.8V \times 0.6 \\
&= 10.8 \text{ mW}
\end{aligned}
$$

$$
\begin{aligned}
P(\text{internal}) &= Icc \times \Delta V \\
&= 3.2mA \times (18V-(-6V)) \\
&= 76.8 \text{ mW}
\end{aligned}
$$

$$
\begin{aligned}
P(\text{output}) &= \frac{R_{OH} \times V_{GE} \times Qg \times f_{sw}}{R_{OH} + Rg + R_{Gint}} \\
&= (\frac{1 \times (18-(-6)) \times 1.4uF \times 10K}{1+7.3+1.3}) \\
&= 35mW
\end{aligned}
$$

$$P(\text{tot}) = 10.8mW + 76.8mW + 35mW = 122.6 \text{ mW}$$

The total power consumption of the drive is 122.6mW (Less than specification rating 300mW)

The calculation of above shows the basic of the IGBT. In many applications, the IGBT is generally used as the driver devices of the motor. Therefore, an optocoupler driver is required as an isolation device to improve noise immunity and safety.

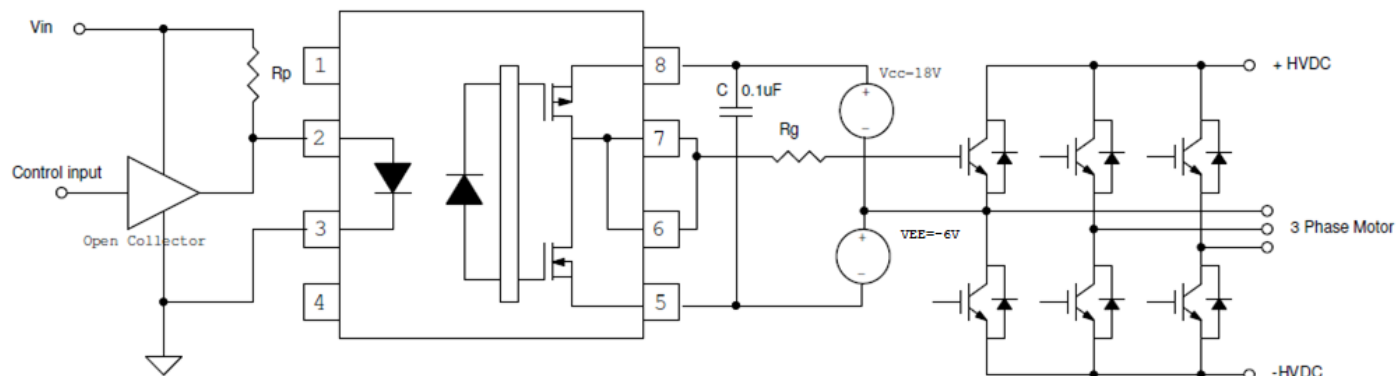## Typical IGBT driver application circuit

Figure.14   Application circuit with negative power source of IGBT
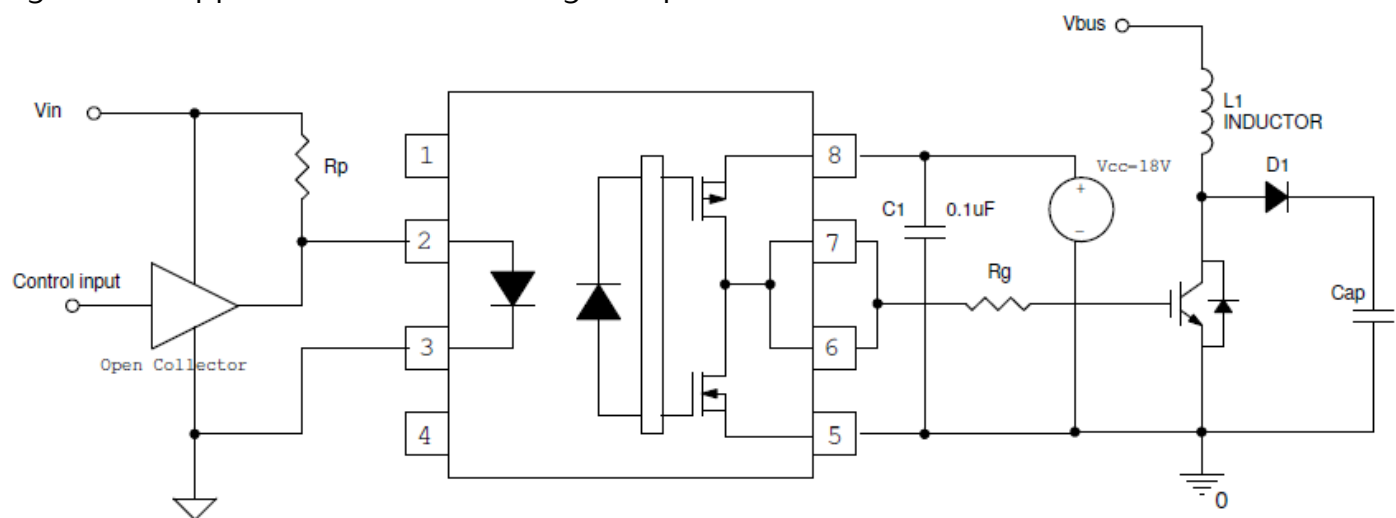

Figure.15   Boost Converter Application
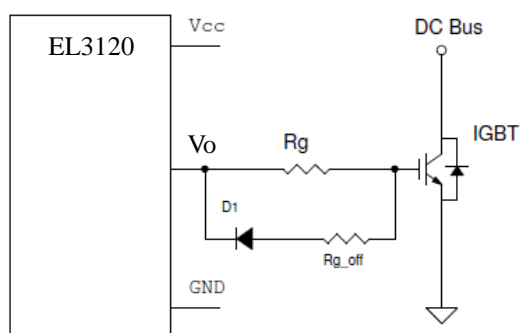

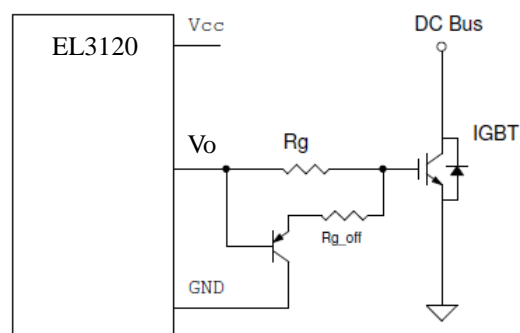Figure.16   IGBT Miller clamp circuit (1)

Figure.17   IGBT Miller clamp circuit (2)

The information in this application note only provides for customers design reference. Please verify the actual application of the product. If you have any other questions, please contact to Everlight Electronics for advanced technical support.