IGBT GATE Driver Circuit

November 11, 2024

1 Introduction to IGBT

An IGBT stands for Isolated Gate Bipolar Transistor.It is a power device having a combination of the following good characteristics: large power characteristics of bipolar transistors and high-speed switching and voltage drive characteristics of MOSFET. Unlike the bipolar transistor, which is current driven, IGBT, Power MOSFETs, with their insulated gates, are voltage driven. A basic knowledge of the principles of driving the gates of these devices will allow the designer to speed up or slow down the switching speeds according to the requirements of the application.

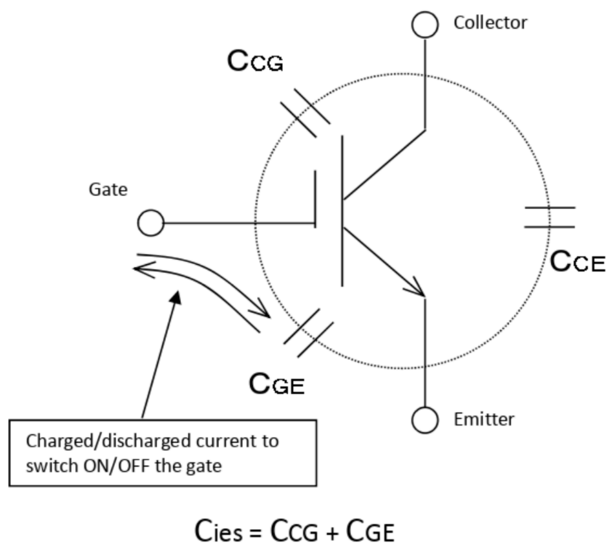

Figure 1: Symbol of IGBT

2 Construction of IGBT

Figure 2 depicts the basic structure of an IGBT. It is constructed virtually in the same manner as a Power MOSFET. There is, however, a major difference in the substrate, The n^+ 1ayer substrate at the drain in a PMOSFET is now subtituted in the IGBT by a p^+ layer substrate called collector C. Like a power MOSFET, an IGBT has also thousands of basic Structure cells conected appropriately on a single chip of silicon. In IGBT, p^+ substrate is called injection layer because

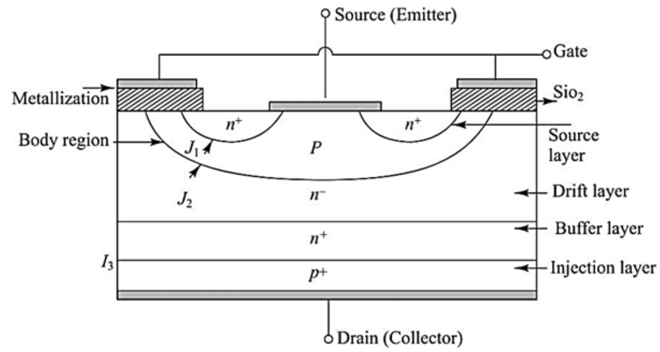

Figure 2: Construction of IGBT

it injects holes into n^- 1ayer. The n^- layer is called drift region. As in other semiconductor devices, thickness of n^- layer determines the voltage blocking capability of IGBT. The p layer is called body of IGBT. The n^- layer in between p^+ and p regions serves to accommodate the depletion layer of pn^- junction i.e. junction J2.

2.1 Equivalent Circuit of IGBT

An examination of Fig.2 reveals that if we move vertically up from collector to emitter, we come across p^+, n^-, p layers. Thus, IGBT can be thought of as the combination of MOSFET and p^+n^-p transistor Q1 as shown in Fig. 3 (b). Here R_d is resistance offered by n^- drift region, Fig. 3 (b) gives an approximate equivalent circuit of an IGBT.

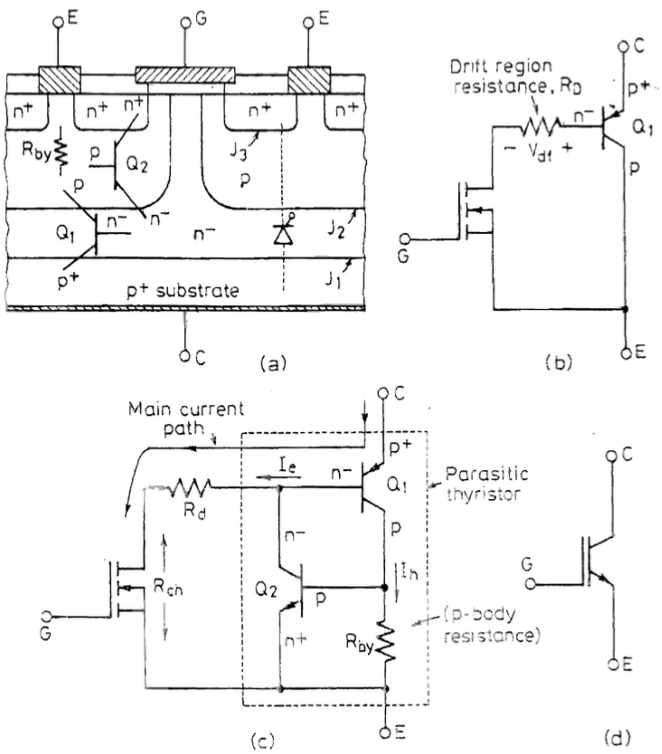

Figure 3: IGBT (a) basic structure showing parasitic transistors and thristor (b) approximate equivalert circuit (c) exact equivalent circuit and (d) circuit symbol.

Fig. 3 (a) also shows the existence of another path from collector to emitter; this path is collector, p^+, n^-, p (n-channel), n^+ and emitter. There is, thus, another inherent transistor Q2 as n^-pn^+ in the structure of IGBT as shown in Fig. 3 (a). The interconnection between two transitors Q1 and Q2 is shown in Fig. 3 (c). This figure gives the complete equivalent circuit of all IGBT. Here R_{by} is the resistance offered by p region to the flow of hole current I_h. The two transistor equivalent circuit shown in Fig. 3 (c) illustrates that an IGBT structure has a parasitic thyristor in it. Parasitic thyristor is also shown dotted in Fig. 3 (a). Fig. 3 (d) gives the circuit symbol of an IGBT.

3 Working of IGBT

The two terminals of IGBT collector (C) and emitter (E) are used for the conduction of current while the gate (G) is used for controlling the IGBT. Its working is based on the biasing between Gate-Emitter terminals and Collector-Emitter terminals.

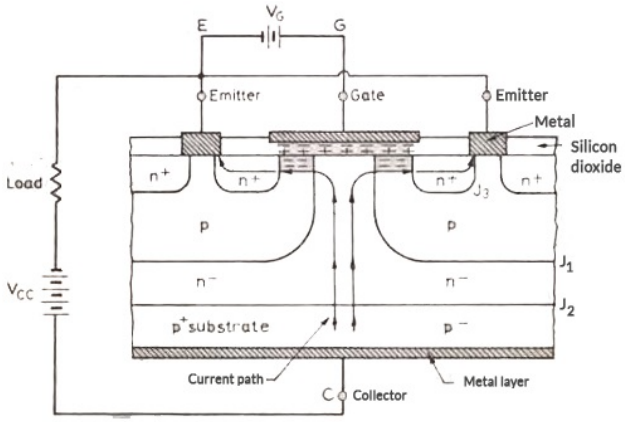

Figure 4: Working of IGBT

The collector-emitter is connected to V_{CC} such that the collector is kept at a positive voltage than the emitter. The junction J1 becomes forward biased and J2 becomes reverse biased. At this point, there is no voltage at the gate. Due to reverse J2, the IGBT remains switched off and no current will flow between collector and emitter.

Applying a gate voltage V_G positive than the emitter, negative charges will accumulate right beneath the SiO2 layer due to capacitance. Increasing the V_G increases the number of charges which eventually form a layer when the V_G exceeds the threshold voltage, in the upper P region. This layer form N-channel that shorts N^- drift region and N^+ region.

The electrons from the emitter flow fromN^+ region into N^- drift region. While the holes from the collector are injected from the P^+ region into the N^- drift region. Due to the excess of both electrons and holes in the drift region, its conductivity increase and starts the conduction of current. Hence the IGBT switches ON.

4 Need for Driver Circuit

- While an IGBT is a voltage drive type element, charge/discharge for input capacity (Cies), refer Fig.1, is needed to turn on and off the gate because of the presence of capacity between the individual terminals as shown in Fig.1. Therefore, switching an IGBT needs a gate charge/discharge circuit. One gate drive circuit is needed for each IGBT element.
- Driver circuits provides isolation between the low voltage side microcontroller and the high voltage side of the power circuit.
- Provides protection features like overcurrent shutdown, over temperature monitoring,under-voltage lockout etc.
- It also controls the losses in the device during switching as well as steady conduction states.

5 Optocoupler based Gate Drive

There are many methods for driving a gate of IGBTs, one of them being using an optocoupler which essentially gives a totempole output. An optocopler based gate drive circuit is mainly composed of three sections. One is an optocoupler which electrically isolates signals. Another is an interface circuit which receives and amplifies signals which come from the optocoupler. The other is a switching transistor which serves to charge and discharge the IGBT gate capacity.

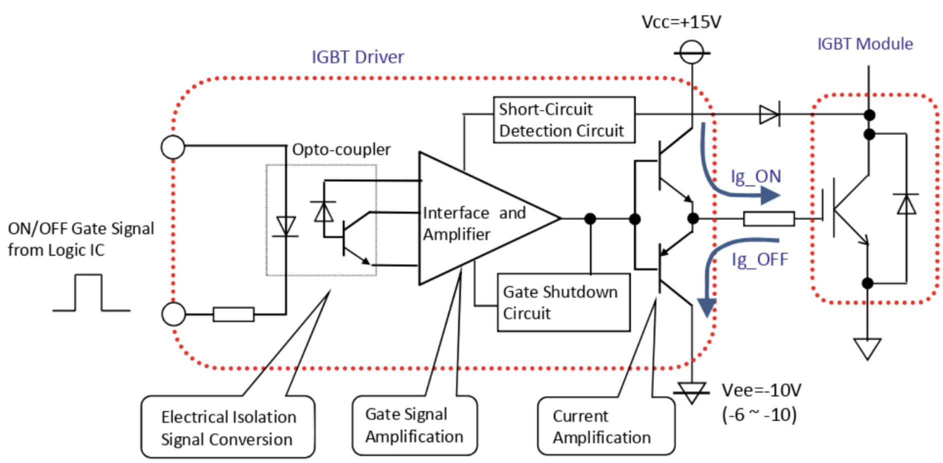

Figure 5: Optocoupler based Gate Drive

When an IGBT is switched on, the gate voltage needs positive bias to 15V. When it is switched off, the gate voltage needs negative bias to around -10V. The gate capacity charge and discharge which are needed at this time must be executed at high speed.

6 IGBT Drive Conditions and Main Characteristics

IGBT drive haracteristics are shown below. An IGBTs main characteristics change according to the values of V_{GE} and R_G, so it is important to use settings appropriate for the intended use of the equipment in which it will be installed.

Table 7-1 IGBT drive conditions and main characteristics

Main characteristics	$+V_{GE}$ rise	$-V_{GE}$ rise	$R_{G(ON)}$ rise	$R_{G(oFF)}$ rise
$V_{CE(sat)}$	Fall	-	-	-
t_{on} E_{on}	Fall	-	Rise	-
t_{off} E_{off}	-	Fall	Rise	Rise
Turn-on surge voltage	Rise	-	Fall	-
Turn-off surge voltage	-	Rise	-	Fall [*1]
dv/dt malfunction	Rise	Fall	Fall	Fall
Current limit value	Rise	-	-	-
Short circuit withstand capability	Fall	-	-	-
Radiational EMI noise	Rise	-	Fall	Fall

*1: Dependence of surge voltage on gate resistance is different for each series

Figure 6: IGBT drive conditions

Two characteristics are useful to understand the behaviour of any power device.

- Static characteristic
- Switching characteristic

Both these are controlled by the gate driver circuit.

6.1 Static characteristics of IGBT

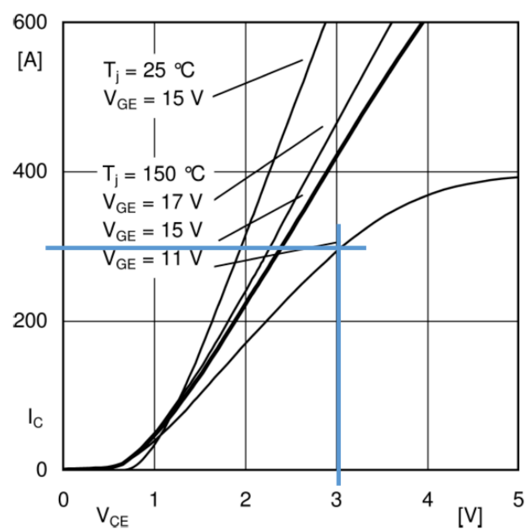

Figure 7: IGBT Static Characteristics

- The static (or ON state) characteristics is useful because it tells us the power loss when the device is fully turned on.
- The on state V_{ce} is important here. V_{ceON} in IGBTs should be low to ensure low power losses when ON.
- V_{ceON} is a function of V_{GE}. V_{GE}=15V is a good starting point.

6.2 Components used in Driver Circuit

- Bipolar supply (i.e. $+V_{DD}$ and $-V_{EE}$) are often used.
- It gives faster turn off and immunity against spurious turn on.

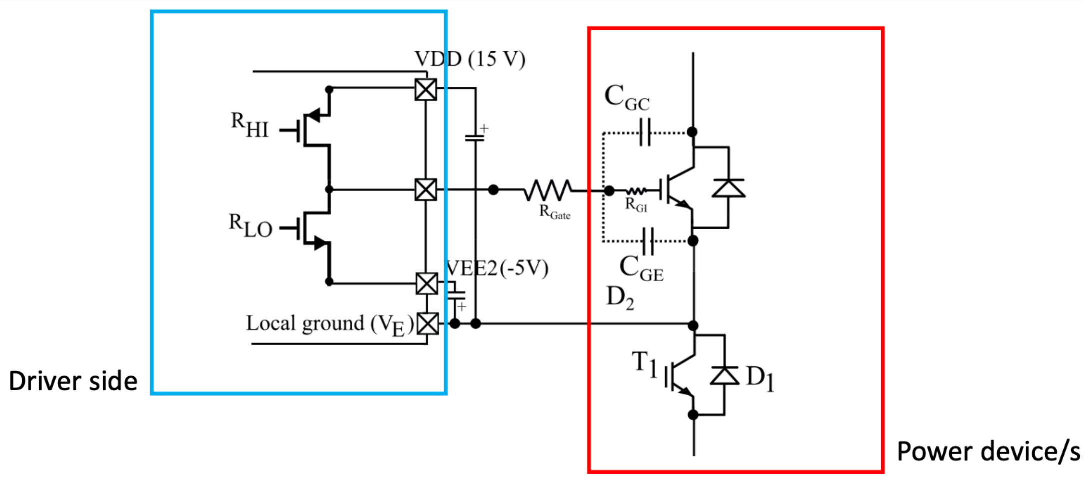

Figure 8: Components of IGBT Gate Circuit

6.3 Turn on in IGBT

- The turn on process in IGBT takes place in four stages. At first, C_{GE} is charged to V_{TH} (e.g. 5V). This period is also called turn on delay (t_{dON}).
- Beyond threshold voltage, the IGBT starts to conduct current. This is the linear region of IGBT, also denoted by t_{ri}. Both V_{GE} and I_c rises linearly. V_{CE} is not falling because the other device in the circuit (e.g. lower diode in half bridge) is still conducting.
- Once the IGBT conducts, the gate driver sees an input capacitance $C_{ISS} = C_{GE} + C_{GC}$.
- At the third stage, the V_{CE} voltage starts to fall. The capacitor C_{GC} is rapidly discharging. The entire gate current is utilized in discharging C_{GC}. It is called the Miller plateau region.
- Observe that C_{GC} was charged to DC bus voltage before this time.
- At the fourth stage, V_{GE} rises to a higher voltage close to applied voltage V_{DD}. (e.g. 15V: good design practice).

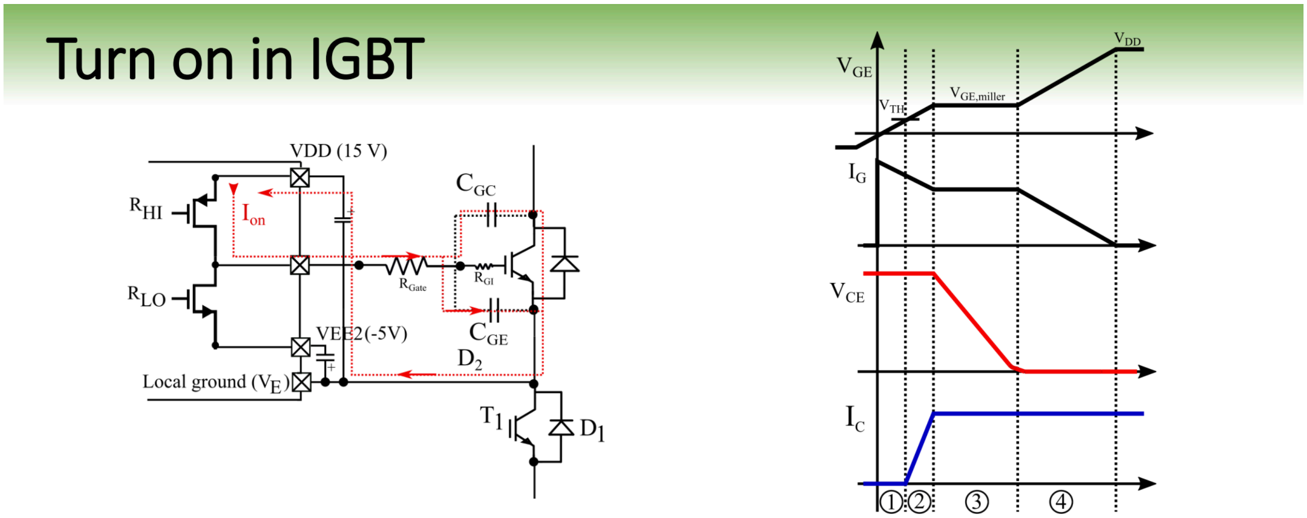

Figure 9: Turn On Characteristics

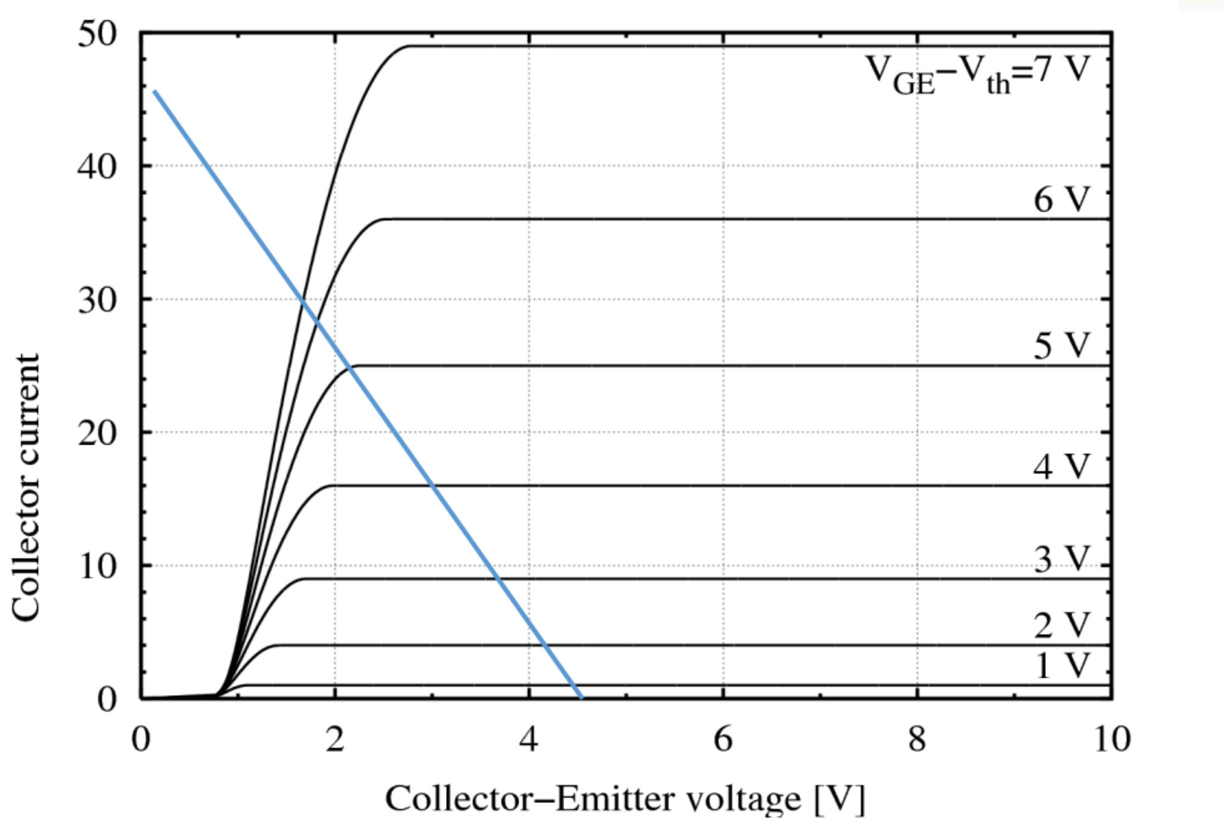

Figure 10: I_C vs. V_{CE}

- The final V_{CE} of the IGBT depends on the final V_GE that gets impressed. Too high V_CE will cause a high current during short circuit. Too low V_{CE} will cause higher conduction losses after turn on.
- The gate current is almost zero after the IGBT has fully turned on.

6.4 Turn off in IGBT

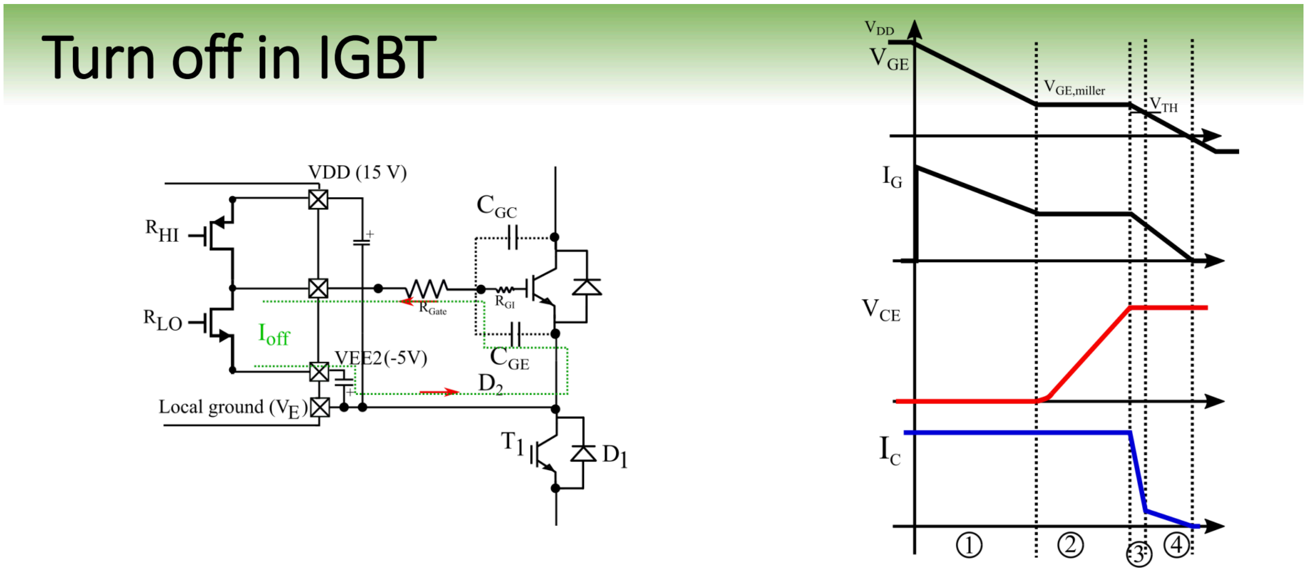

Figure 11: Turn Off Characteristics

- The reverse process happens during turn off.
- First, the capacitances ($C_{ISS} = C_{GE} + C_{GC}$) discharges from its initial value to the Miller plateau level.
- Next, the collector to emitter voltage starts to rise to the blocking voltage level. At the third interval, C_{GE} starts discharging. V_{GE} starts to decrease further.
- At the last stage, V_{GE} is reduced to zero, or a negative value. The IGBT now turns off. Recommended value is -5V.
- A negative value helps to reduce the time of the tail current.

7 Selection of the Gate Resistor(R_G)

With change in gate resistance we can have multiple effects and hence has to be selected carefully.
1. Low gate resistance will

- Increase the gate current and hence faster turn on.
- Increase the chances of high dv/dt across the device.
- Radiated EMI increases.

2. High gate resistance will

- Decrease the gate current and hence more switching losses.
- Decrease surge voltage on gate emitter terminal.

8 Isolation Techniques

- Isolation is important for system reliability and human safety.
- An isolation electrically isolates circuitry from low voltage gate side to the high voltage power side by having separate grounds.
- This provides safety to the personnel involved and also protects the control circuit during short circuits in the power circuit.
- Three main types of electrical isolation : Optical, Magnetic and Capacitive.

8.1 Magnetic Isolation

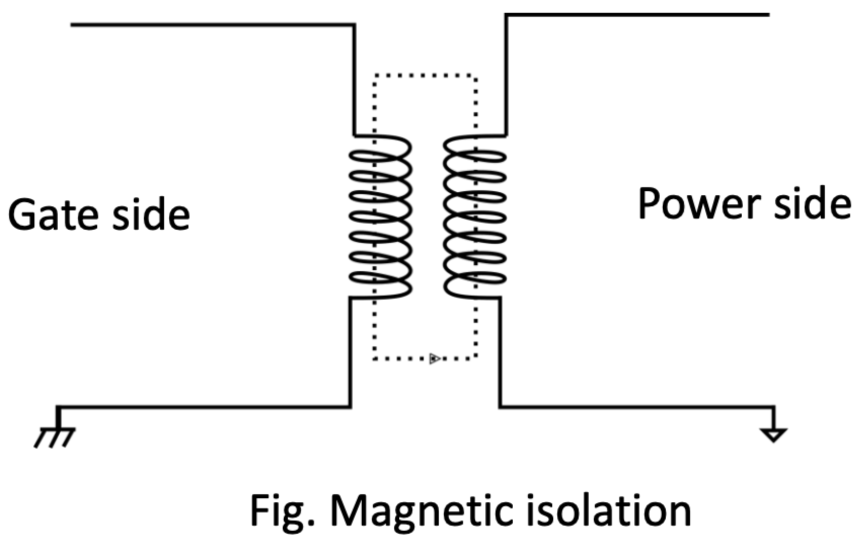

Figure 12: Magnetic Isolation

- Uses magnetic coupling, typically through transformers or inductors, to transfer signals across an isolation barrier without direct electrical connection.
- Preferred in high-speed, high-power applications such as motor drives, inverters, and large power supplies.

8.2 Optical Isolation

- These use an LED on one side of the isolation barrier to send signals to a photodetector on the other side. The photodetector converts the optical signal back into an electrical signal.
- Often used for lower power applications, digital signal isolation, and circuits where compact size and lower cost are essential.
- These drivers integrate optocoupling elements for direct control of high-speed switches (e.g., MOSFETs, IGBTs).
- We will be using this type of Isolation.

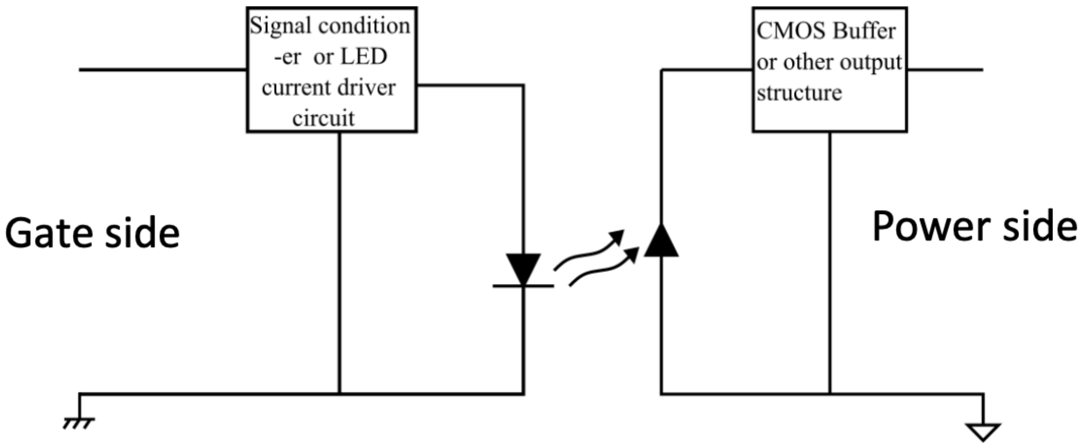

Fig. Optical isolation

Figure 13: Optical Isolation

9 Circuit Design

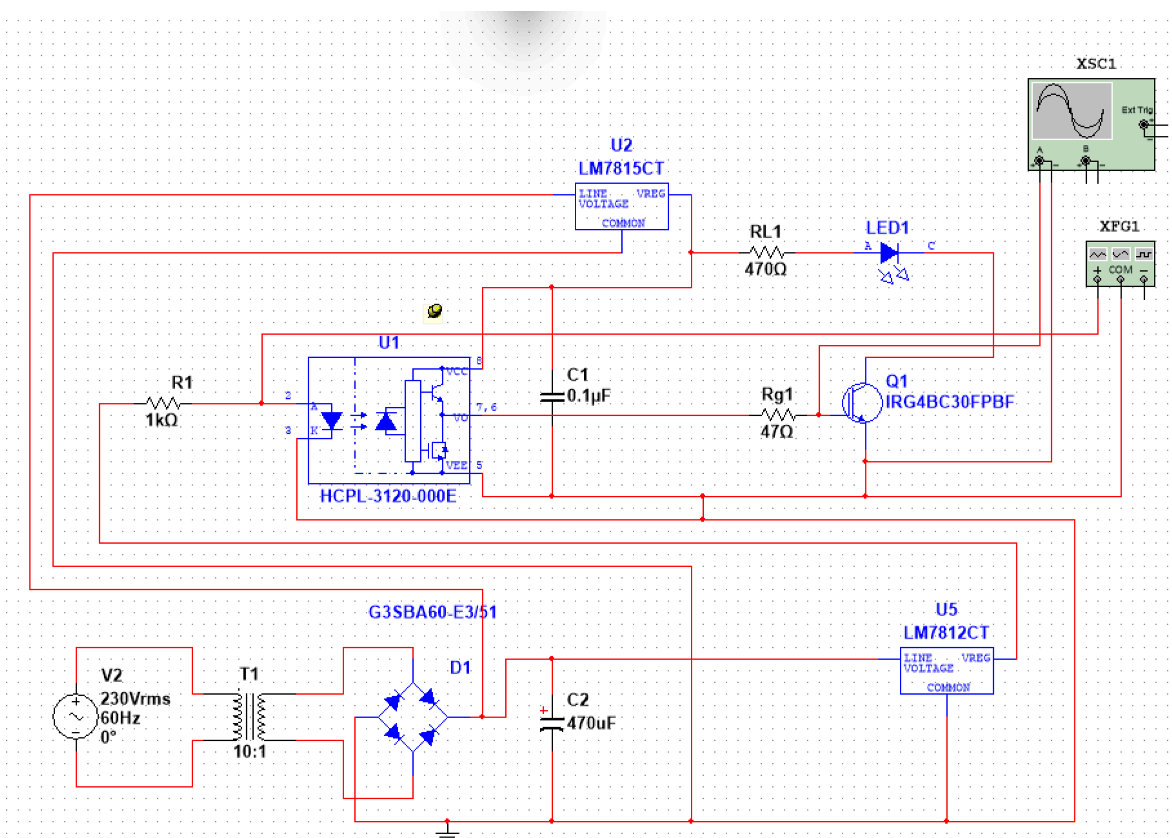

Figure 14: Circuit Design in Multisim

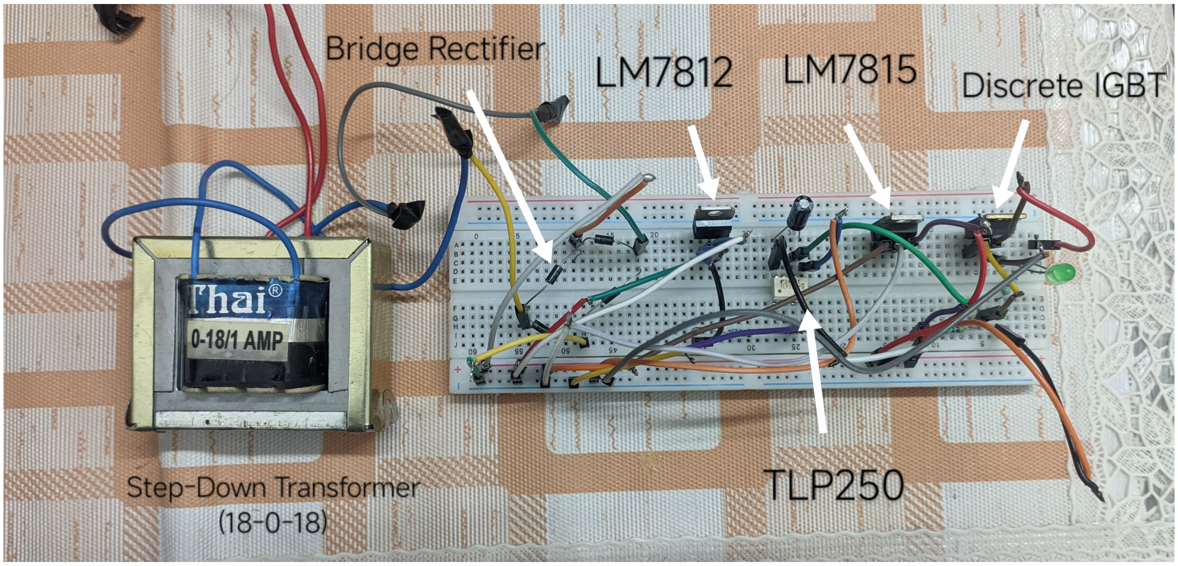

Figure 15: Circuit on Breadboard

10 Simulation

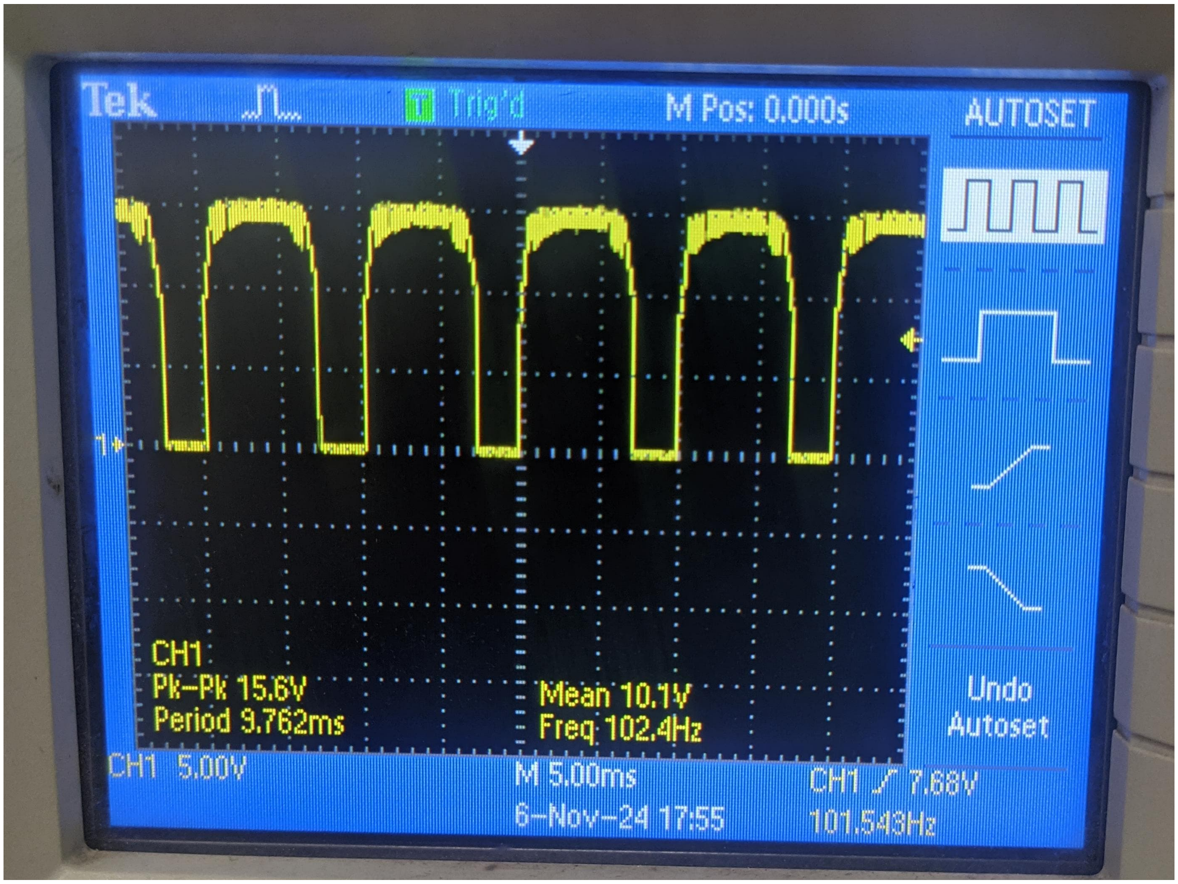

Figure 16: Gate Pulse Waveform on DSO

11 Conclusion and Discussion

The development of an IGBT gate driver circuit using an optoisolator successfully achieves the primary goal of providing reliable switching control with robust isolation between the control and power stages. This project aimed to design a gate driver capable of managing high-speed and high-power applications while ensuring the protection of sensitive control electronics from high-voltage transients and noise.

The choice of optoisolation proved to be an effective solution for providing electrical isolation while maintaining signal integrity across the isolation barrier. Optoisolators enable safe and efficient signal transmission by using light, thus preventing direct electrical contact. This not only protects the low-voltage control circuitry but also minimizes electromagnetic interference, which is essential in high-power environments like those involving IGBTs.

Throughout this project, key design parameters such as switching speed, drive voltage, and power dissipation were carefully optimized to meet the operational requirements of the IGBT. The optoisolated gate driver circuit was tested and validated, demonstrating consistent performance in both normal and high-stress conditions. With proper thermal management and robust design, this gate driver solution exhibits reliable performance and can be readily integrated into power electronics applications.

In conclusion, the project highlights the effectiveness of using optoisolation for gate drivers in high-power applications, providing both protection and performance. Future work could focus on enhancing switching efficiency further or exploring integration with digital control schemes for more complex systems, opening pathways for advanced power electronics applications in renewable energy, automotive, and industrial automation.