الجـــــــــــــــــــــمـهـوريــــة الجـــــــــــزائـريـة الديمــــــــقـراطيـة الـشـــــــــــعـبيـة

RÉPUBLIQUE ALGÉRIENNE DÉMOCRATIQUE ET POPULAIRE

وزارة التـــــــــــــــــــــــــــــعـليـم العـــــــالي والبـــــــــــحث العـــلـمـــي

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

جامعة محمد البشير الإبراهيمي – برج بوعريريج

Université de Mohamed El-Bachir El-Ibrahimi - Bordj Bou Arreridj

Faculté des Sciences et de la Technologie

Département d'Electromécanique

MÉMOIRE

Présenté pour l'obtention du **diplôme** de **MASTER**

En : (**électromécanique**)

Spécialité : (**électromécanique**)

Par : - Chelihi khalil

- Negrech Ahmed Abdelaziz

Sujet

Design and Implementation of a Mosfet/Igbt Gate Driver

Soutenu publiquement, le 02 / 07 /2025 , devant le jury composé de :

Zebiri Fouad	MCA	**Univ-BBA**	Président
Merabet Elkhier	PR	**Univ-BBA**	Examinateur
Choudar Adel	MCB	**Univ-BBA**	Encadrant

Année Universitaire 2024/2025

Table of Contents

List of Figures

List of Tables

List of Abbreviations

SI : silicone

SIC : silicon carbide

GAN : gallium nitride

WBG : wide band gap

P-type : positive type

N-type : negative type

EG : energy band gap

PWM : pulse width modulated

AC : alternating current

DC : direct current

MOSFET : metal oxide field effect transistor

EMI : Electromagnetic interference

DCM : Discontinuous Conduction Mode

CCM : Continuous Conduction Mode

QG : gate charge

FSW : switching frequency

QGD : gate-drive charge

QSD : source-drive charge

VDD : Drive voltage

CMTI : common mode transient immunity

LED : light emitting diode

IGBT : Insulated-gate bipolar transistor

General Introduction

The development of power electronics has long relied on advancements in semiconductor materials. While silicon (Si) has historically dominated due to its low cost and established manufacturing processes, it faces significant limitations in high-frequency, high-power, and high-temperature applications due to its narrow band gap and low critical electric field. These constraints have led to the growing use of Wide Band Gap (WBG) materials such as Silicon Carbide (SiC) and Gallium Nitride (GaN), which offer superior electrical, thermal, and switching characteristics.

To fully utilize the benefits of WBG semiconductors, efficient and well-designed gate drivers are essential. Gate drivers control the voltage and current applied to the gate of power switches like MOSFETs and IGBTs, enabling high-speed and reliable switching. However, fast switching introduces challenges such as EMI, voltage overshoot, and thermal stress. This thesis focuses on the study and design of MOSFET gate driver circuits, examining their operation, performance parameters, and isolation techniques. The goal is to explore how gate drivers can be optimized to work efficiently with WBG devices in applications such as buck converters.

1. Chapter 1

Introduction to Semiconductor Material

1.1. **Introduction**

The evolution of power electronics has been fundamentally driven by advancements in semiconductor materials, which dictate the performance limits of power switching devices. Historically, silicon (Si) has been the cornerstone of power semiconductor technology due to its well-understood properties and mature manufacturing processes. However, the inherent physical limitations of Si, particularly its bandgap energy and breakdown electric field, impose constraints on device performance, especially in high-power, high-frequency, and high-temperature applications. This chapter explores the foundational principles of semiconductors, establishing the context for understanding the limitations of silicon and the emergence of Wide Band Gap (WBG) materials. Specifically, it will delve into the superior material properties of Silicon Carbide (SiC) and Gallium Nitride (GaN) .

1.2. **Concept**

A semiconductor is a material whose ability to conduct electricity can be precisely controlled. Its conductivity is between that of an insulator (which impedes electric flow) and a conductor (which easily lets electricity flow) .

1.3. **History**

The first transistor was invented by experts such as William Shockley, John Bardeen and Walter housebrattain in 1947. In 1958, Jack Kilby installed resistors, capacitors and transistors on a chip and invented the first integrated circuit [1], they used germanium at first due to its much higher electron mobility then that of silicon; but it had its drawbacks mainly its poor thermal management (its performance plummeted at 75°), in terms of chemical properties each has its own merits, the band gap of silicone is much higher than that of germanium so silicone is much more heat resistant, but germanium won because its price was lower, In 1959, the unit price of a silicon transistor was $14.53, while that of germanium transistor was only $1.96 [2] .

1.4. **Value**

Semiconductor, the core of every major technological advancement in. the last century, it’s the supporting pillar of most electrical and electronics word ranging from a simple led bulb to the international space station, its economical and strategical value is immense, being developed in many sectors ranging from medical to military .

1.5. Operating Principal

Semi-conductors are materials with properties that range from a good conductor to a good insulator they can be in either the state of electrical conductivity or the state of electrical insulation and that is their main purpose to conduct electricity a semiconductor must check two conditions which are :

-In the valence band (the band of electron orbitals that electrons can jump out of, moving into the conduction band when excited) need to not be full have and electron imbalance

-Under certain conditions e.g., heat exchange, doping or light variation triggering the free movement of electrons throughout the semiconductor .

Electron movement in the semi-conductor depends on its structure in inorganic types like silicon while organic semiconductor relies on molecular orbitals .

Silicon is most commonly used but it must be doped to conduct. N-type doping adds extra electrons, while P-type doping creates holes by removing electrons .

A key structure is the p-n junction, where P-type and N-type materials meet. It controls current flow through the depletion zone, allowing current in one direction but blocking it in the other. This principle is the foundation for diodes and transistors, which are critical to modern electronics .

1.6. History of Silicon Carbide

Silicon carbide was discovered by the American inventor Edward Goodrich Acheson in 1891 while trying to find a way to produce artificial diamonds, the invertor heated a mixture of clay and powdered coke in an iron bowl He noticed shiny hexagonal crystals attached to the carbon arc light used for heating and called the new material carborundum .

Acheson patented the method for making silicon carbide powder on February 28, 1893, Acheson also developed the electric batch furnace, a design that remains the basis for commercial SiC production to this day .

About the same time Acheson made his discovery, in 1893, French chemist Henri Moissan discovered naturally occurring silicon carbide in a meteorite from the Canyon Diablo crater.

In 1955, Jan Anthony Lely proposed the concept of growing high-quality silicon carbide (SiC) crystals, and since then SiC has been regarded as an important electronic material The relatively high crystal quality of the resulting Lely platelets .

In 1978–1981, Soviet researchers Yuri M. Tairov and Valery F. Tsvetkov developed new way to for growing high-quality single-crystal silicon carbide (SiC) boules. They introduced a 6H-SiC seed into a sublimation growth furnace, established a controlled temperature gradient to guide material transport, Davis and Carter significantly refined this method. The first commercialization of SiC (6H-SiC) wafers occurred in 1991 .

In 1989, Bantval Jayant Baliga highlighted the remarkable potential of SiC-based power devices, and a systematic theoretical analysis of the performance was published in 1993 by the same group .

1.7. Band Gap

***In a semiconductor (or any solid material in general) a band gap is the energy difference between its valence band and its conduction band and is one of the main criteria to choose a semiconductor material with breakdown field strength, saturation electron velocity and thermal conductivity ***

The band gap is a key parameter in solid-state physics and the most important aspect of a semiconductor material.

Physically the band gap is the energy range between the valence band(electrons) and the conduction band (electron holes), its existence is due to the forbidden energy region between the filled valence band and empty conduction band .

The band gap is an indicator of a material electrical conduction, material with little to small band gap are good conductors inversely insulators don’t conduct electricity in a good manner due to their big band gap .

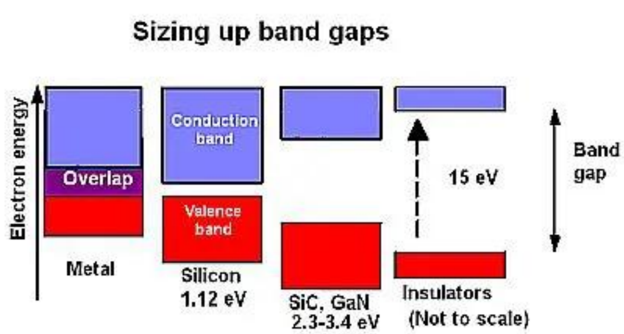

Figure 1.1 : Band Gap Size in Different Kinds of Material

1.7.1. **Classification of Band Gap Categories**

Semiconductors are summarized in 3 categories :

- Narrow Band Gap Semiconductors (Eg<1.1 eVEg<1.1eV) : These materials are easily excited by ambient thermal energy, making them suitable for low-voltage and low-temperature applications. However, they suffer from leakage currents and thermal instability, especially under high-temperature or high-field conditions .

- Medium Band Gap Semiconductors (1.1≤Eg≤2.2 eV1.1≤Eg≤2.2eV) : Silicon is the most widely used semiconductor due to its availability, well-developed production and balanced properties. However, its limited thermal conductivity and average breakdown field restrict its use in high-voltage/temperature applications .

- Wide Band Gap Semiconductors (Eg>2.2 eVEg>2.2eV) : These materials can withstand much higher voltages and temperatures. which results in lower leakage currents and superior performance in harsh environments (high/low temps) .

1.7.2. **Significance of Wide Band Gap (WBG) Semiconductors**

Wide Band Gap semiconductors have started to compete in the market in power electronics, RF systems, and optoelectronics. Their material properties allow for more efficient, compact devices .

1.7.3. **Advantages of WBG Semiconductors**

- High Breakdown Electric Field: The breakdown electric field of SiC and GaN is significantly higher than that of silicon. For instance, SiC can withstand electric fields approximately 10 times higher than Si before breaking down. This allows for thinner and more compact devices, which operate at higher voltages without the risk of becoming permanent conductors.
- Higher Thermal Conductivity and Stability : WBG materials maintain performance at higher temperatures. SiC, in particular, has high thermal conductivity, enabling more efficient heat dissipation, which reduces the need for cooling and increases device lifetime.
- Faster Switching Speeds : The high electron mobility in WBG semiconductors lead to faster switching times. This makes them ideal for high-frequency applications such as power supplies and RF amplifiers.

• Energy Efficiency: Devices made from WBG materials can operate with lower switching and conduction losses, leading to higher overall system efficiency.

1.7.4. **Functioning Under Extreme Conditions**

One of the WBG semiconductors strongest advantages lies in their ability to perform in environments where conventional silicon-based devices fail. Their physical property's lets them function in harsh environments (extreme temps), high frequency applications and radiation hardened environments

1.7.5. **Comparison between Semiconductor Material**

Table 1.1 : Matter Properties of Si, Sic, Gan

Property	**Silicon (Si)**	**Silicon Carbide (SiC)**	**Gallium Nitride (GaN)**
1. Band Gap Energy (Eg)	1.12 eV (narrow)	3.26 eV (wide)	3.4 eV (wide)
2. Critical Field	0.3 MV/cm	3.0 MV/cm	3.3 MV/cm
3. Thermal Conductivity	150 W/m·K	370 W/m·K	130 W/m·K
4. Electron Mobility	1,400 $cm^2/V{\cdot}s$	900 $cm^2/V{\cdot}s$	2,000 $cm^2/V{\cdot}s$
5. Saturation Velocity	1.0×10^7 cm/s	2.0×10^7 cm/s	2.5×10^7 cm/s

Based on the physical and chemical material properties, different semiconductor materials are suited for different applications. Silicon (Si)-based devices are commonly used in standard power electronics due to their established manufacturing and low cost. for high-frequency/power applications—such as wireless power transfer systems used in medical devices and electric vehicles-wide band gap (WBG) materials like Silicon Carbide (SiC) and Gallium Nitride (GaN) are more suited. The difference is in the band gap width (size). Silicon has a relatively small band gap, while SiC/GaN has a wide band gap, allowing them to be more efficient in high-voltage/frequency use cases.

When it comes to high-frequency operation, both electron mobility and electron saturation velocity are critical. GaN excels in these areas, outperforming both Si and SiC, SiC's low performance is due to its crystal structure (Strong Covalent Bonding). The critical electric field is crucial due to the point that it directly influences the size/power ratio. Thermal conductivity is an especially in power electronics, where heat dissipation is crucial. SiC offers the highest thermal conductivity among the three, which means reduced cooling. Which means its more suited to higher temp cases (e.g., power electronics).

In summary, while silicon remains dominant in conventional power electronics due to its maturity and affordability, GaN's frequency advantages put it in a position for 5G and consumer electronics, whereas SiC dominates high-power applications. The industrial, automotive, and renewable energy industries will see a faster shift from silicon to WBG technology. In recent years Resolving material-level flaws, standardizing manufacturing procedures, and building robust supply networks has been a focus point due to that the Si market has an up incoming rival.

1.8. **Conclusion**

In conclusion, this chapter has thoroughly examined the fundamental properties of semiconductor materials, highlighting the intrinsic limitations of silicon and the compelling advantages offered by Wide Band Gap (WBG) materials such as Silicon Carbide (SiC) and Gallium Nitride (GaN). The analysis demonstrated that WBG semiconductors possess superior characteristics, including larger bandgap energies, higher critical electric fields, and enhanced thermal conductivity, which collectively enable devices with significantly improved performance metrics. These advancements translate directly into power devices capable of operating at higher switching frequencies, sustaining higher breakdown voltages, and withstanding elevated operating temperatures, all while exhibiting substantially reduced conduction and switching losses. The transition from Si to WBG materials is not merely an incremental improvement but represents a fundamental shift towards achieving greater power density, higher efficiency, and enhanced reliability in power electronic systems .

2. Chapter 2

Gate Drive and Buck Converter Analysis

2.1. Buck Converter

2.1.1. Introduction to the Buck Converter

A buck converter, or step-down switching converter, is used to reduce a higher input voltage to a lower, regulated output voltage. The popularity of switch-mode regulators is due to their high efficiency, compact size, and switching operation, which makes them integral to modern electronics. Buck converters transfer small packets of energy using a pulse-width modulation (PWM) controller, a transistor switch, an inductor, a capacitor, and a diode (Schottky diodes are commonly preferred due to their low forward voltage drop and very fast switching action).[21]

One of the main advantages of the buck converter is its ability to step down voltage while increasing the available current, making it ideal for components that require more current at a lower voltage.

2.1.2. Operating Principle of Buck Converter

The operating principle of the buck converter involves controlled energy transfer from the input to the output through switches, an inductor, and a capacitor. A high-side switch (usually a MOSFET) and a low-side switch (typically a diode) are employed in the buck converter to control the current flow through the inductor. By adjusting the duty cycle of the high-side switch, the average output voltage can be regulated proportionally to the input voltage.[22]

The switching element is controlled by pulse-width modulation (PWM). It is a method of controlling the amount of power delivered to a circuit by adjusting the pulse width of a digital signal. The duty cycle of the pulses defines the amount of power provided, while the frequency of the pulses determines the speed of the control. The power sent to the circuit can be changed by varying the frequency and duty cycle of the PWM signal.[23]

2.1.3. Circuit Topology and Key Components

Buck converter in Figure 1. It is a basic buck or step-down converter circuit, it includes a DC power supply a switch S (MOSFET), a diode D, a low pass LC filter, and a load R.

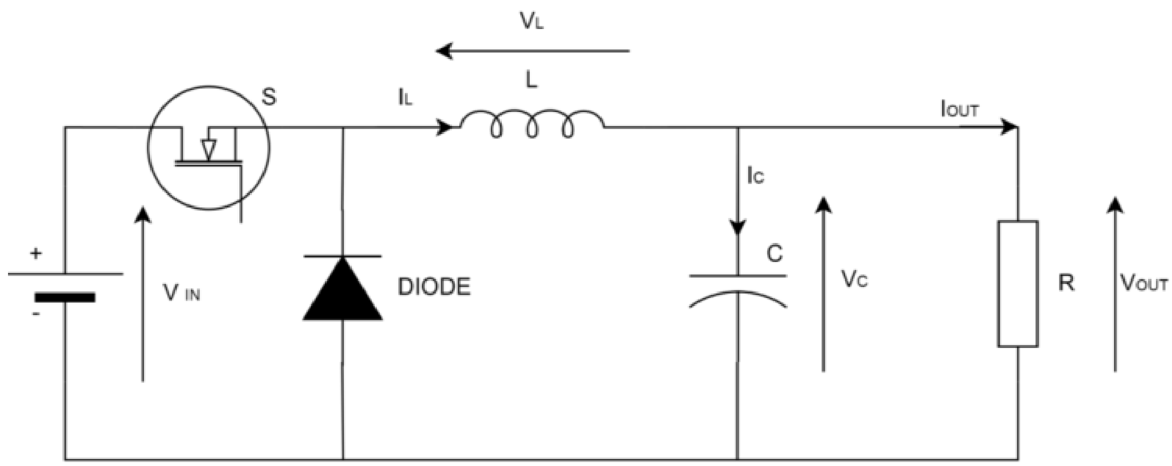

Figure 2.1 : Buck Converter Circuit Diagram

When the switch S is turned on, current flows from the battery through the circuit. It charges the capacitor and also flows through the load resistor. At this moment, diode D is reverse-biased. The inductor current IL begins to increase, and as it does, the magnetic field in the inductor builds up. During this process, the inductor stores energy in its magnetic field.

While storing energy, the polarity across the inductor is such that it opposes changes in current. As a result, the inductor drops part of the supply voltage, reducing the voltage seen by the load resistor. The voltage across the inductor can be expressed as:

$$\boldsymbol{VL = VIN - VOUT} \qquad (\mathbf{2.1})$$

1.1.1. When the switch S is turned off, the current that is flowing through the inductor will begin to decrease and as that happens the magnetic field will begin to collapse the magnetic field across an inductor is dependent and proportional to the amount of current that flows through it now as the magnetic field collapses it’s going to induce a voltage with the opposite polarity so the inductor becomes a current source now if the voltage across the inductor is greater than the voltage across the capacitor it can charge the capacitor during its time if they’re equal both the inductor and the capacitor can discharge themselves through the load resistor so nevertheless current from the inductor can flow through R and it can flow back through so when the switch is open and the inductor is releasing its energy D is now active it’s in forward bias mode so this diode is in the on state.

The output voltage depends on two things the input voltage and the duty cycle

$$\boldsymbol{VOUT = VIN\,(D)} \qquad (\mathbf{2.2})$$

the duty cycle is equal to the time where **S** is closed divided by the time period.

2.1.4. Continuous and Discontinuous Conduction Modes

- Continuous Conduction Mode (CCM): In this mode, the current flowing through the inductor never drops to zero during the entire switching cycle.
- Discontinuous Conduction Mode (DCM): In DCM, the current through the inductor falls to zero for a portion of the switching cycle when the load current is lower than the average inductor current.

2.2. Gate Drive

2.2.1. Definition of a Gate Driver

The primary function of a gate driver is to control the gate voltage to charge and discharge the MOSFET efficiently. With the more efficient control we can increase the switching speed, but this may lead to faults and problems (higher EMI, Switching transient, …). To address this, gate drivers often provide electrical isolation, protection against overcurrent, and contribute to thermal management by minimizing heat generation.[5]

2.2.2. Operating Principles

To design a mosfet gate drive one must understand first the intrinsic characteristics of a mosfet gate the gate behaves as a capacitive load, characterized by three primary parasitic capacitances:

input capacitance (Ciss), output capacitance (Coss), and reverse transfer capacitance (Crss), also known as Miller capacitance[5]. For a mosfet to switch state a specific amount of charge (gate charge ‘Qg’) must be delivered or removed from the gate (capacitance).

The Miller capacitance (Crss = CGD) has a profound impact on the switching rate. During the Miller plateau region, the gate voltage remains relatively constant while the drain-source voltage undergoes a rapid transition. This phenomenon occurs because the gate driver's current is predominantly consumed in charging or discharging the Miller capacitance as the drain voltage swings.

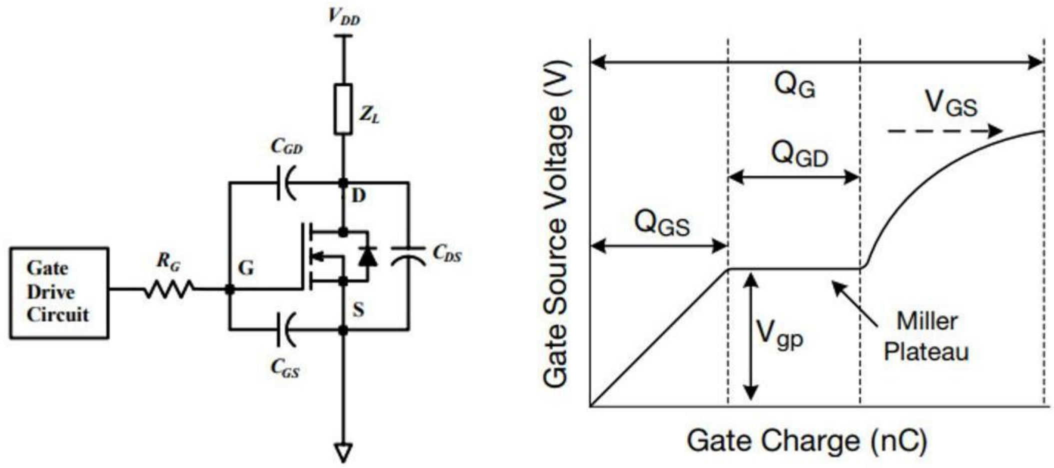

Figure 2.2 : Miller Effect

2.2.3. **Performance Parameters**

To design an effective gate drive that are many parameters that are taken into consideration a few important one's are

2.2.3.1. Gate Current Requirements and Drive Strength

-Peak source/sink current : The current provided by the driver must be high enough to rapidly charge and discharge the gate capacitance of the mosfet, the required drive current depends on the gate charge (Qg) delivered by the driver and the desired switching frequency calculated as where higher switching frequency requires higher current [8].

$$\boldsymbol{I = Qg/t} \qquad (\mathbf{2.3})$$

-Gate charge : The total gate charge is divided into three charges gate-source charge (Qgs) (represents turn-on requirement), gate-drain charge (Qgd), and the Miller plateau charge (represents miller plateau duration),

2.2.3.2. Switching Timing Parameters

-Rise and fall times : These include (turn on td(on), rise time (tr), turn-off delay time td(off), and fall time (tf)) to optimize these parameters one must balance switching speed with Emi consideration [10].

-propagation delay : Propagation delay is the input signal command and the output transition; this parameter is essential in high frequency switching where precise time control is essential.

2.2.3.3. Thermal and Power Consideration

-Gate drive power consumption : It depends on switching frequency (Fsw), gate charge (Qg), drive voltage (Vdd) At higher switching frequency losses can become quite high, which increases junction temp and would requires more cooling

2.2.3.4. Parasitic Inductance Impact

Parasitic inductance in gate drive circuit has a negative effect and will affect switching performances and causes voltage overshoots and oscillations. [13]. Source inductance (Ls), drain inductance (Ld), and gate driver loop inductances must be minimized through careful layout design

2.2.3.5. Emi and dv/dt Control Parameters

For a reliable gate driver to be it must balance between Emi generation and switching speed. Higher slew rates lowers switching losses but could cause voltage overshoot and Emi issues, on the contrary lower slew rates reduce Emi but would increase switching losses which

For a reliable gate driver to be it must balance between Emi generation and switching speed. Higher slew rates lowers switching losses but could cause voltage overshoot and Emi issues, on the contrary lower slew rates reduce Emi but would increase switching losses which at high frequency can be quite detrimental. [10]

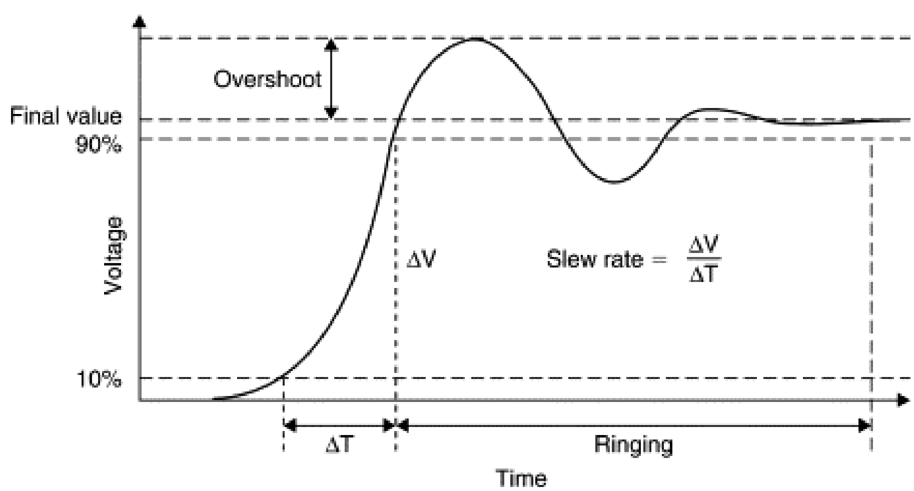

Figure 2.3 : Slew Rates of Currents

-Gate resistance : The gate resistance includes driver output resistance, external gate resistance, and the Mosfet's internal gate resistance. [15] Optimal gate resistance selection requires considering switching losses, EMI generation, and parasitic ringing.

2.2.3.6. Dead Time and Protection Parameters

-Dead time requirements : Dead time is used mostly in bridge configuration to prevent short circuit (shoot-through currents) by making sure both Mosfet's aren't conducting at the same time, dead time must exceed the maximum turn off time of the switching device.

-Isolation voltage and safety : Isolated gate drive has for purpose to isolate the power circuit from the control circuit using an optical or galvanic (magnetic or capacitive) isolation thus protecting it from high voltage transients.

2.2.3.7. Conclusion

To design an optimal gate driver isn't just a matter of meeting individual specs, but to understand the role and effects of each component and their intricate interplay. As an example, the mosfet High gate capacitance is the direct reason to need a higher driving current. While we can see that gate driver have many advantages. It has many drawbacks, for example, achieving faster switching speeds can increase Emi generation, even decreasing gate resistance would increase the chance of a parasitic turn-on, even if the gate drive is designed with protective features against these faults, it would add much complexity and cost to the device.

2.2.4. **Comparison of MOSFET Gate Driver Isolation Techniques**

Isolation in power electronics systems is a fundamental consideration, serving both safety and functional purposes by separating different voltage levels (control side and power side), there are many techniques to isolate a circuit that gate drives use each with distinct principles, applications, advantages, and limitations.

2.2.4.1. **Non-Isolated Gate Drivers**

Non isolated gate drives are the simples and most straight forward gate drive circuits, their main difference from other isolated techniques is the have a shared common ground between the control circuit and power switching stage.

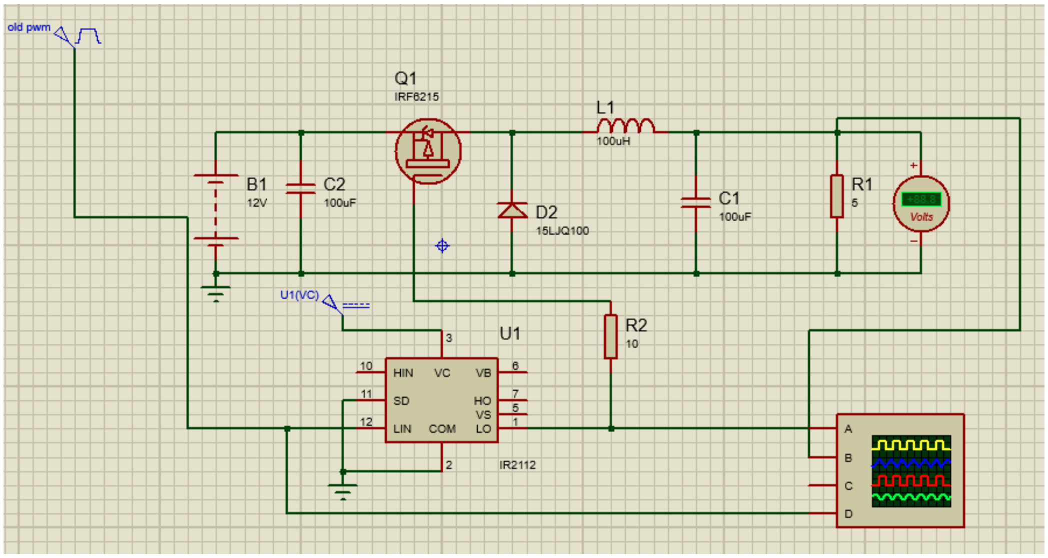

Figure 2.4 : Circuit of IR2112 Gate Driver Linked to a Buck Converter

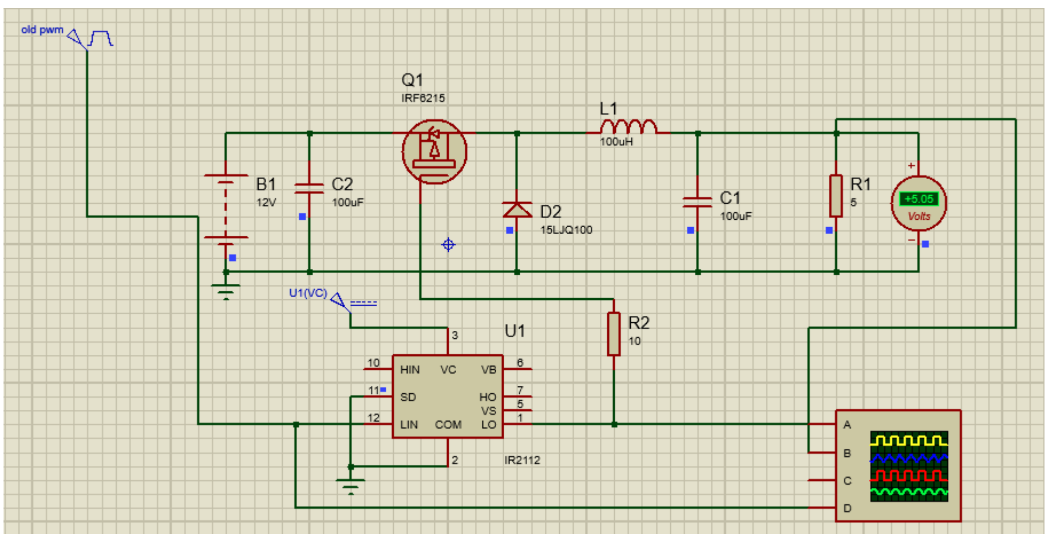

Figure 2.5 : Circuit of IR2112 Gate Driver with Buck Converter while Turned On

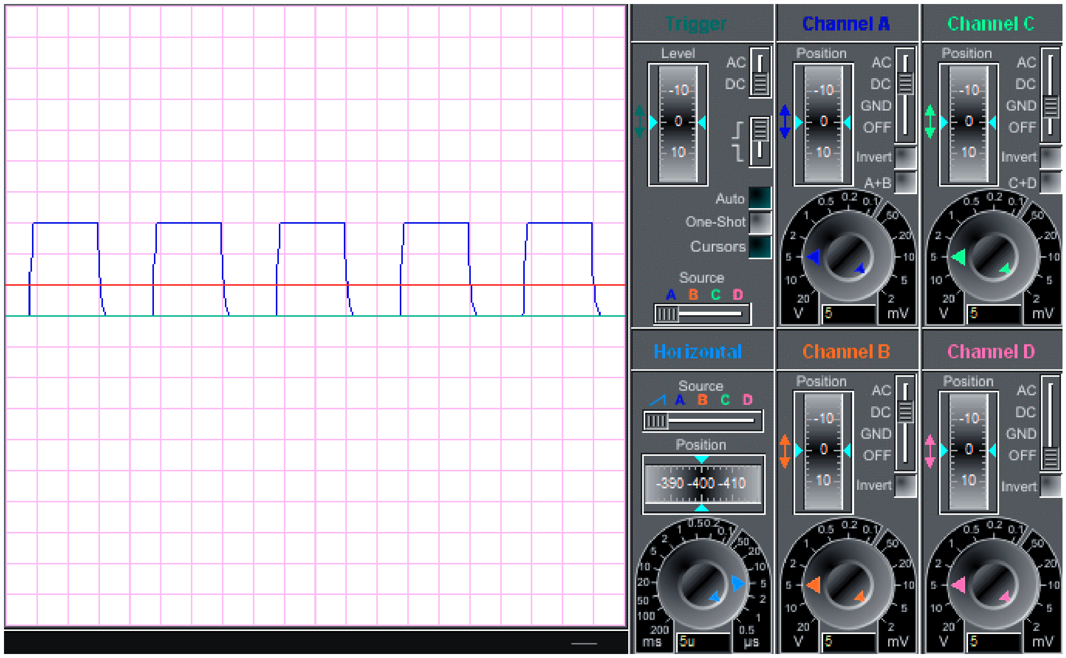

Figure 2.6: Oscilloscope of the Output from Buck (red) and Gate Charge Current (bleu)

Here we used Proteus software to simulate the circuit of the IR2112 mosfet/igbt gate driver linked to the mosfet of a buck converter the IR2110 is power by a pwm logic signal. It gets its power from a dedicated power supply (U1)

2.2.4.2. Isolated Gate Drives

Galvanic isolation is a fundamental concept in electrical engineering it provides complete electrical isolation between the control and power circuit, which is a critical requirement in high-power application. This separation ensures that even in the event of a fault in the power circuit, hazardous current does not reach the low voltage control circuit of human operator and causing irreparable damage. On a technical side, galvanic isolation is crucial for breaking ground loops (unwanted ground loops, potential difference, …). In these circuits the signal/power is transmitted using non-direct electrical connection, the most prominent are magnetic, capacitive, and optical.

2.2.4.2.1. Optically Isolated Gate Drivers

Optically isolated gate drivers also known as optocouplers, they consist of an input light emitting diode and a receiving photodetector to close the connection (conduction state), the isolation layer of the octocopter is usually built using air, epoxy or mold compound, both sides of the circuit need their own power supply, due to the optocouplers light transferred signal through isolation layer it might decay over time which means it would need more isolating material.

Cons: it does not transfer large signals so it needs amplifiers and that would decrease the efficiency.

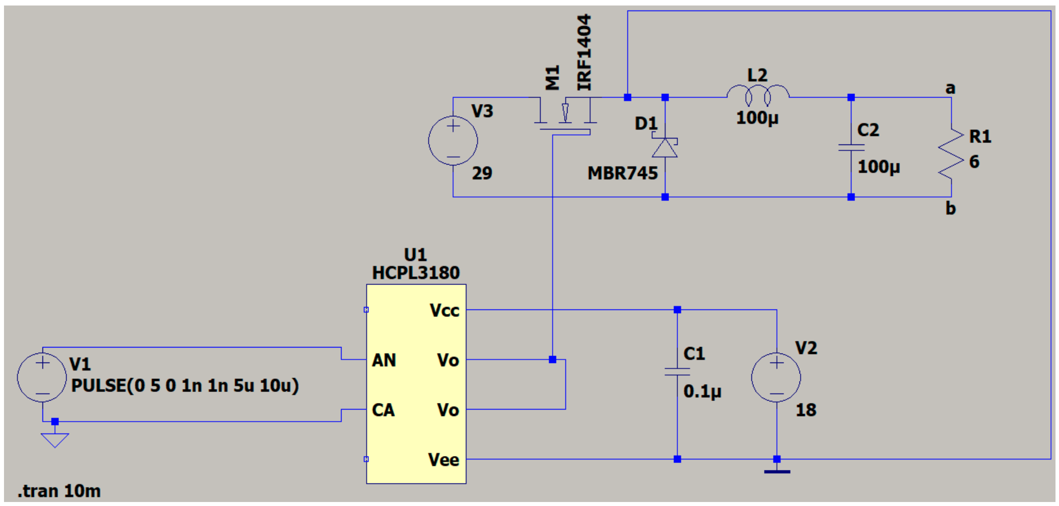

Figure 2.7 : Simulated Circuit of HCPL3180 Gate Driver Linked to a Buck Converter

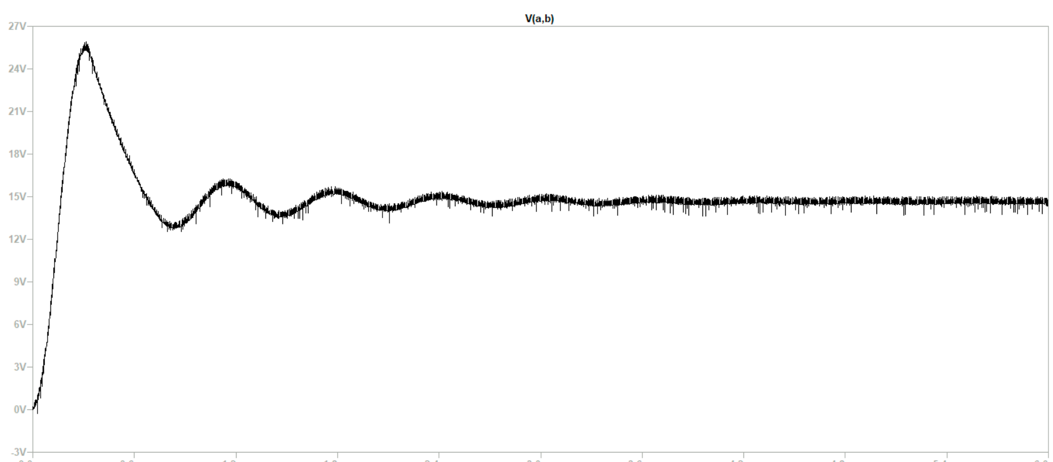

Figure 2.8: Output Voltage of the Buck Converter (Previously Simulated Circuit, fig 8)

Figure 8 is the simulation schematic, showing how the input signal is transmitted via light across an isolation barrier to the driver's output stage. This requires separate power supplies for the control and power sides. Figure 9 shows the resulting output voltage of the buck converter, which settles to a stable DC value after an initial transient overshoot.

2.2.4.2.2. **Magnetic Isolated Gate Drivers**

Magnetic isolation is transformer based, also known as inductive coupling, uses magnetic field to transfer an input signal applied at the primary winding to the secondary winding. The logic input is used to generate an electromagnetic field and to transfer proportional energy signals across the inductive Transformer barrier. the Transformer based isolated drivers can transfer power in large amounts than optic coupler and sometimes they don't require secondary isolated power supply as well it supports a high switching frequency due to the magnetizing calls used in Transformer the size of the circuit increases and becomes bulkier. you'll find magnetic isolated gate drivers in various configurations. There are single-ended transformer-coupled gate drives and double-ended transformer-coupled gate drives, each suitable for different circuit designs. They are commonly used in DC-DC converters and work in conjunction with PWM controllers to manage the switching of power devices [19].

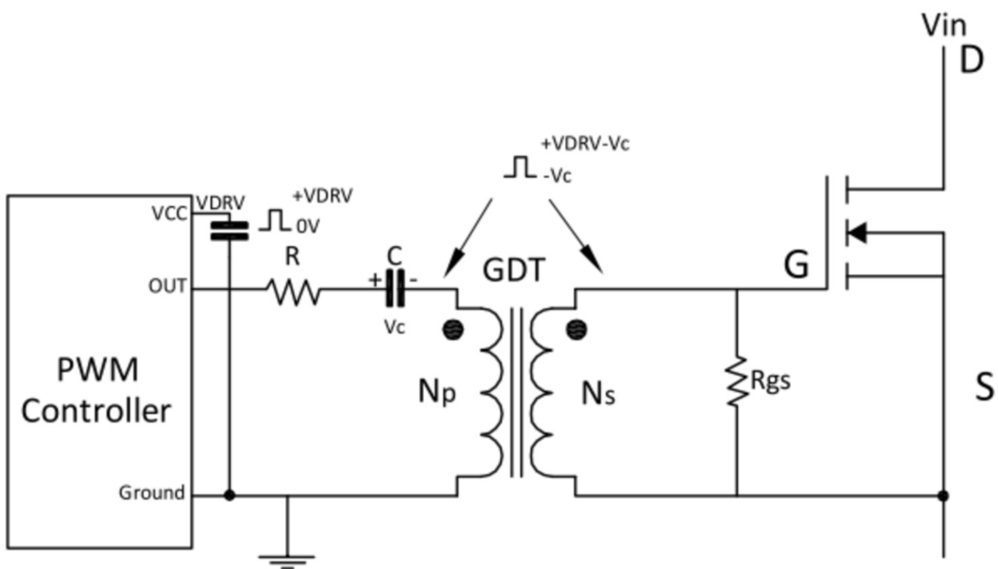

Figure 2.9 : Single Ended Transformer-Coupled Gate Drive. [20]

This circuit is limited to 50% duty ratio. For wide duty cycle applications such as buck converters, it does not provide adequate gate drive voltage and thus a DC restoration circuit has to be added on the secondary side of the transformer (capacitor and diode). Coupling capacitor voltage increases with duty ratio increase and also reduces actual gate drive voltage (for turn on) and increases negative bias (during off time). Adding a capacitor and diode in the circuit helps restore the original gate drive amplitude on the secondary side of the transformer. [20]

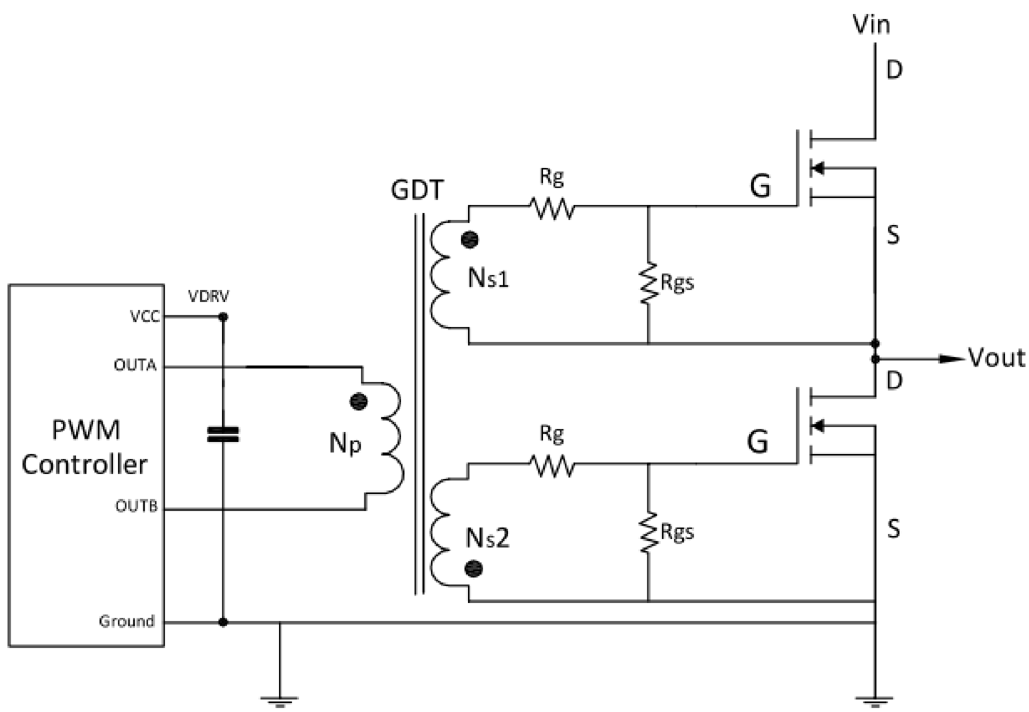

Figure 30 : Double-Ended Transformer-Coupled Gate Drive Circuit Diagram. [20]

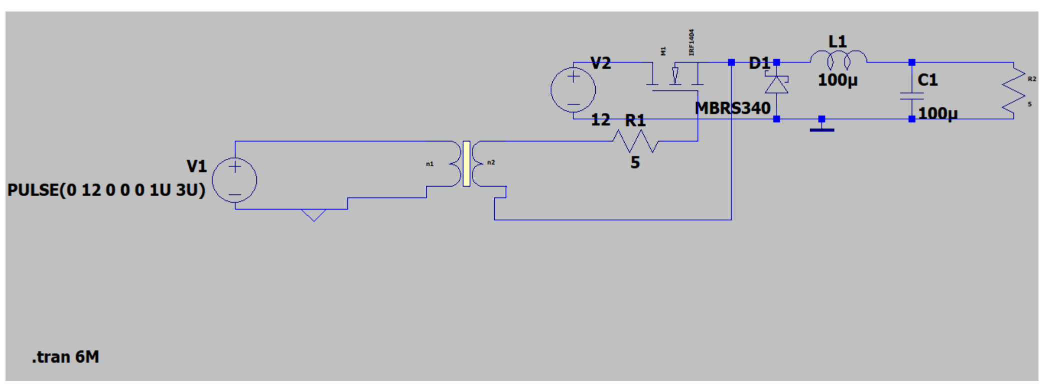

Figure 4.11 : Simulated Circuit of Pwm Signal Linked to a Buck Converter Isolated with a Transformer

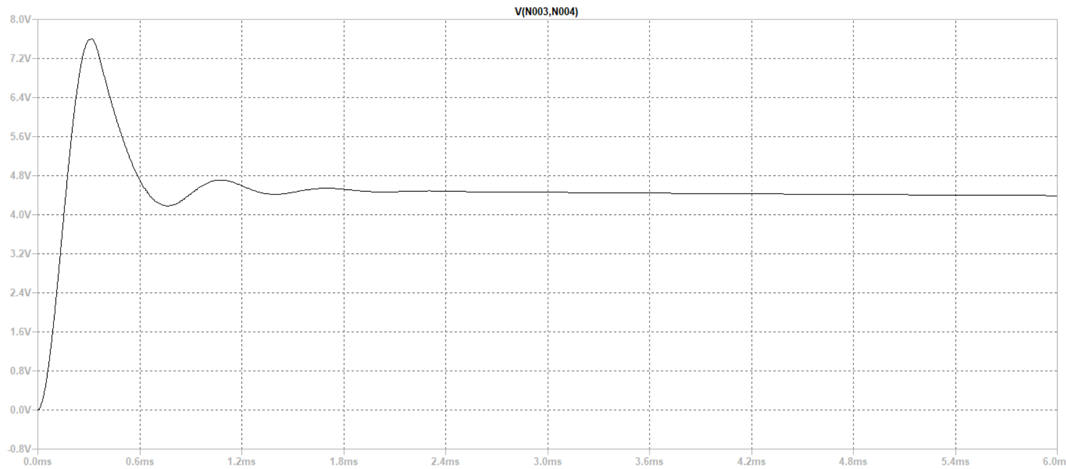

Figure 2.12 : Output Voltage of the Buck Converter

Figure 12 presents a simulation where a transformer provides isolation for the mosfet gate control circuit from a buck converter. Figure 13 displays the output voltage from this transformer-isolated circuit, which is visually similar to the output from the optically isolated driver in Figure 9.

2.2.4.2.3. **Capacitively Isolated Gate Driver**

It is based on energy transfer across the silicon dioxide or CMOS barrier through a high frequency carrier on the input side a digital signal is applied after that it gets modulated and then it flows across the capacitive noise after that the signal is demodulated which is proportional to its input and finally the original signal is provided at the output are made with the highest dielectric strength material for isolation so that have high data rates low thermal profiles and long life. They have weak common mode transient immunity

2.2.4.3. **Conclusion**

The choice of isolation method for a MOSFET gate driver is a complex decision involving a multi-dimensional trade-off between safety requirements, performance metrics, cost, and design complexity. Each isolation technology presents a unique set of characteristics that make it suitable for specific applications.

Non-isolated drivers are the simplest and most cost-effective, ideal for low-side switching and applications where galvanic isolation is not mandated. However, their lack of isolation poses significant safety risks in high-voltage environments and makes them vulnerable to noise and ground loop issues.

Galvanically isolated drivers, encompassing transformer-based and capacitive technologies, provide the essential electrical separation for high-voltage and safety-critical applications. They enhance safety, improve noise immunity, and break ground loops. While transformer-based solutions are robust and can transfer power, they tend to be bulkier and have higher propagation delays. Capacitive isolators, conversely, offer high integration, faster speeds, and superior CMTI, making them increasingly popular for high-performance systems.

Optically isolated drivers (optocouplers) have historically provided a cost-effective means of galvanic isolation. However, their limitations in switching speed, susceptibility to LED aging, and lower CMTI compared to modern digital isolators (capacitive/magnetic) often make them less suitable for the demanding requirements of WBG devices.

2.3. **Conclusion**

This chapter has comprehensively explored the multifaceted aspects critical to the design of a high-performance gate driver: precise parameter control, robust isolation, and efficient power supply. It was established that meticulous attention to gate drive parameters such as voltage levels, current capabilities, and switching speeds is essential to optimize the performance of power MOSFETs and IGBTs, directly impacting their switching losses and overall system efficiency. The discussion on isolation highlighted its indispensable role in ensuring safety by separating high-voltage power stages from low-voltage control circuitry, while also mitigating noise and ground loop issues that can degrade performance. Various isolation technologies, including optocouplers, digital isolators, and pulse transformers, were examined, each offering distinct trade-offs in terms of CMTI, propagation delay, and cost, necessitating careful selection based on application requirements. Finally, the principles and advantages of buck converters were detailed, underscoring their importance in providing a stable, efficient, and regulated power supply to the gate driver, which is crucial for consistent and reliable operation. The interdependencies between these elements are profound: an optimized gate drive requires not only precise signal delivery but also a robust, isolated power supply to function reliably in high-power environments. This integrated understanding forms the bedrock for the practical circuit realization discussed in the subsequent chapter, ensuring that the theoretical considerations translate into a functional and efficient gate driver design.

3. Chapter 3

MOSFET/IGBT Gate Driver Circuit Design

3.1. **Introduction**

With the foundational understanding of advanced semiconductor materials and the critical parameters governing gate driver operation established, this chapter transitions from theoretical concepts to the practical realization of a MOSFET/IGBT gate driver circuit. The successful implementation of a gate driver requires meticulous attention to component selection, circuit topology, and physical layout to ensure optimal performance, reliability, and protection of the power switch. This chapter will detail the various architectural choices for gate driver circuits, from basic configurations to more advanced integrated solutions, considering factors such as driving capability, voltage levels, and switching speed. Key components, including the gate driver ICs, gate resistors, bootstrap capacitors, and power supply decoupling, will be discussed in the context of their specific roles and selection criteria. Furthermore, the chapter will address essential protection features, such as desaturation detection for IGBTs and active clamping for MOSFETs, which are vital for safeguarding the power device against overcurrents and overvoltages.

3.2. **Design of a Pwm Generator Circuit**

To drive a mosfet one needs a pulse width modulating signal, in this chapter we realize the pwm generator circuit :

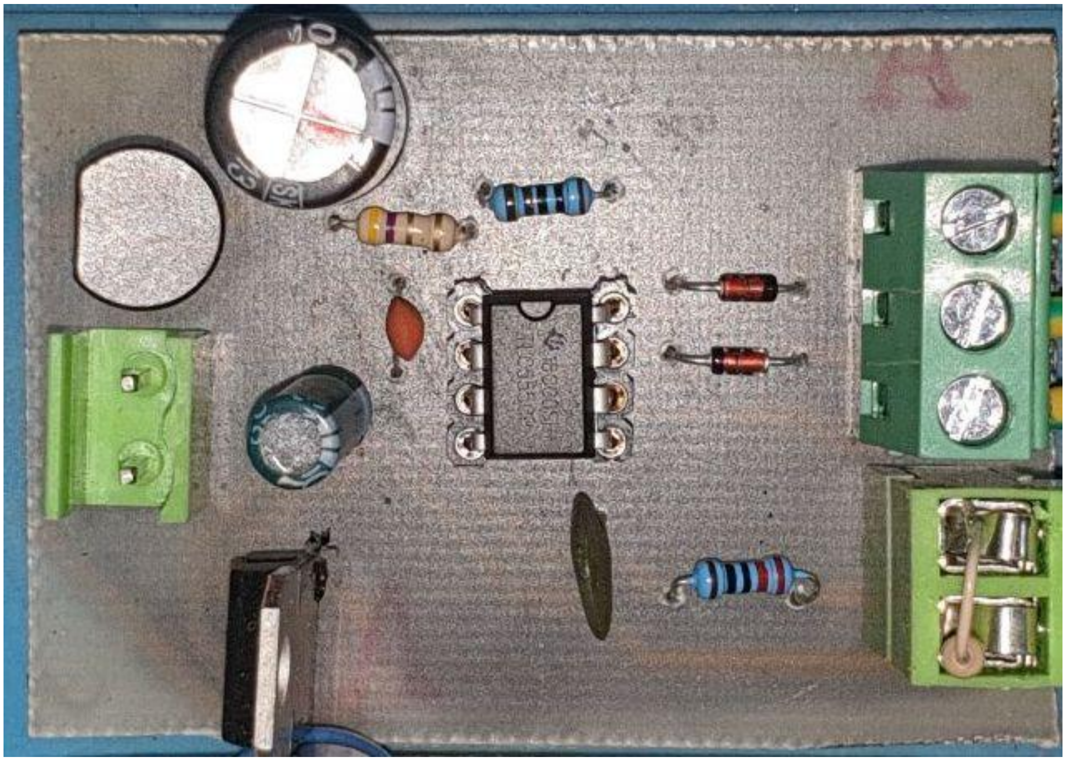

Figure 3.1 : Pwm Generator Realised Physical Circuit

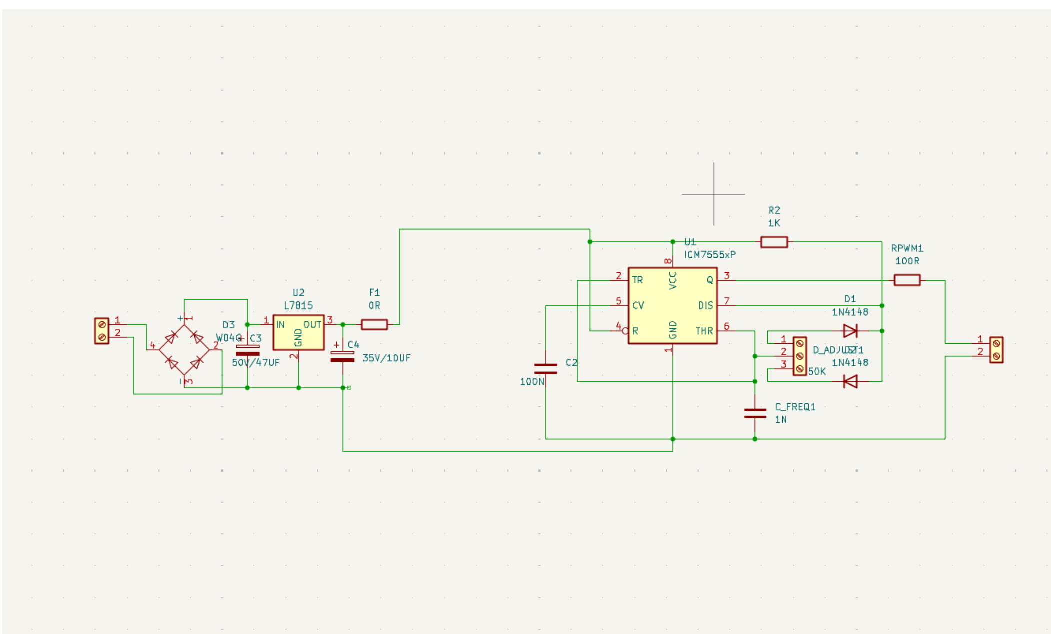

Figure 3.2 : Pwm Generator Circuit

The circuit begins with a power supply section. The full-bridge rectifier (D3, D4, D5, D6) converts any AC input into pulsating DC, or ensures correct polarity for a DC input. Following this, the large smoothing capacitor (C3) filters this pulsating DC, providing a relatively stable, but unregulated, DC voltage. This voltage then feeds into the L7815 voltage regulator (U2), which outputs a steady 15 volts. Another capacitor (C4) at the regulator's output further smooths this 15V, ensuring a clean power supply for the rest of the circuit.

The core of the PWM generation lies with the 555 timer (U1). Its operation relies on an RC timing network. The timing capacitor (C_FREQ1) is central to this, as its continuous charging and discharging cycles determine the output frequency and pulse width. The charging and discharging paths are controlled by resistor (R2) and the potentiometer (RPWM1), which is a variable resistor.

To achieve adjustable duty cycle, especially below 50%, two diodes (D1, D2) are strategically placed around the potentiometer. Diode D1 allows the timing capacitor to charge through R2 and one part of the potentiometer, while diode D2 allows it to discharge through the other part. By adjusting the potentiometer, we can independently control these charge and discharge times, thus varying the duty cycle. Finally, a small capacitor (C2) connected to the 555 timer's control voltage pin (pin 5) helps to filter out noise, ensuring stable and reliable PWM output .

The design uses diodes and a potentiometer to allow for an adjustable duty cycle by independently controlling the voltage divider .

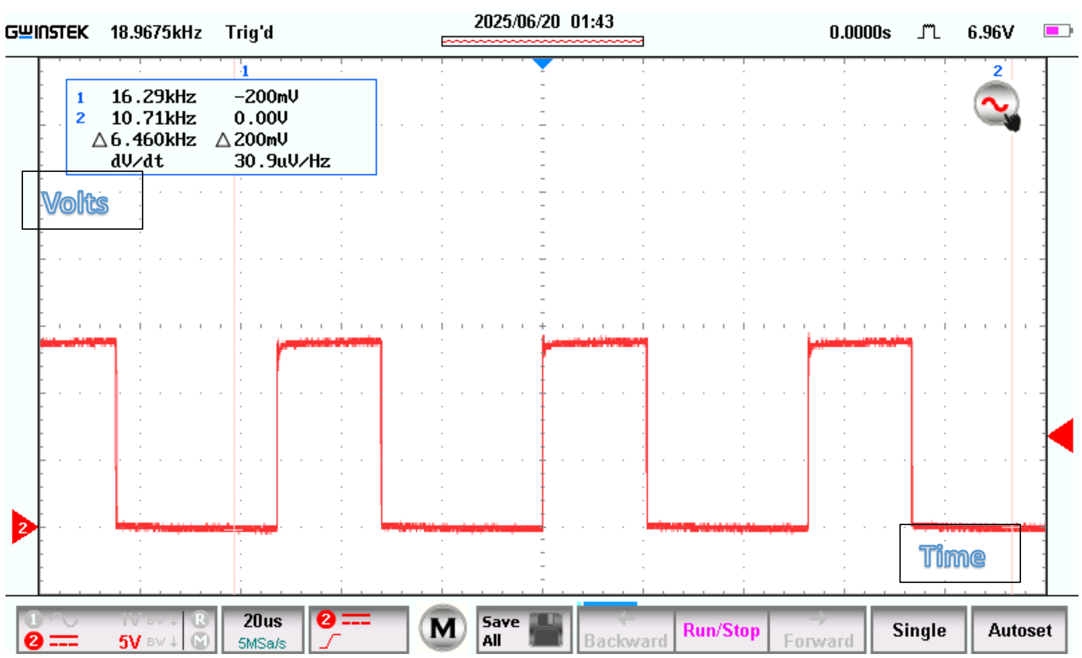

Figure 3.3 : Clean 0–15 V Square Wave with Adjustable Duty Cycle, Suitable as a Logic-Level MOSFET Gate Drive form Circuit (generated by the above circuit, fig 14)

Here we can see that the signal is clean, near-ideal square wave to drive a mosfet, While the output is enough to drive a mosfet in this example, it isn’t the most effective choice, due to its simple design and lack of features .

3.3. Design of Gate Drive using TC4422

In this part were going to add a TC422 gate drive to the output of the pwm generator

Figure 3.4 : PWM Generator Circuit with TC44222

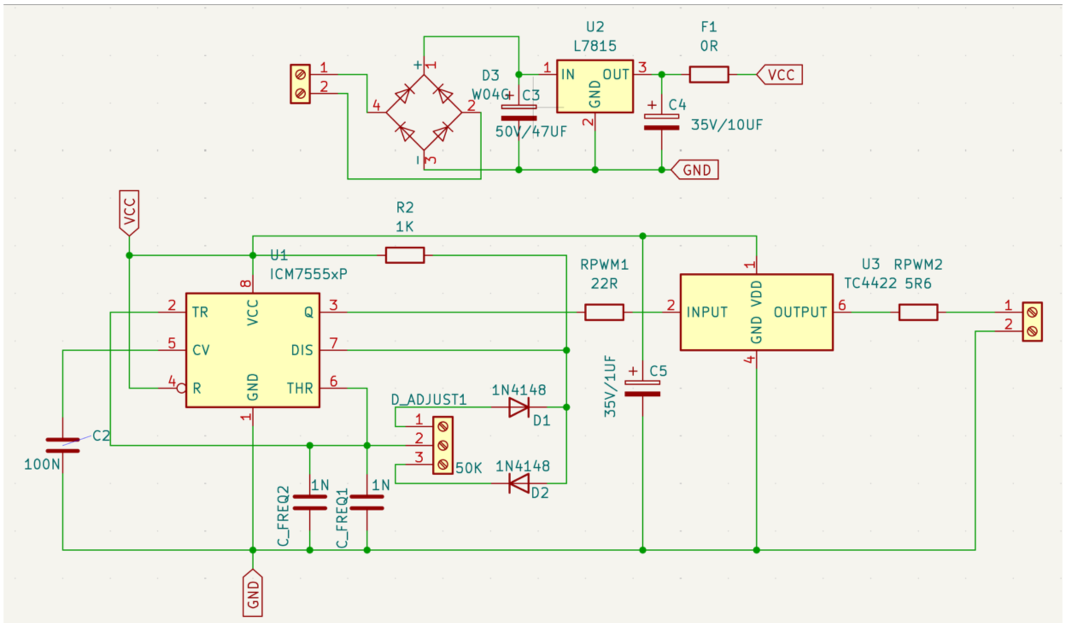

Figure 3.5 : Gate Drive Circuit using a TC4422

In this circuit we added the TC4422 (U3), a high-speed MOSFET gate driver. Its primary role is to act as a powerful buffer and current amplifier. providing a high peak output current of 9 Amperes for both sourcing and sinking, ensuring fast turn-on and turn-off of the power device. This rapid switching is crucial for minimizing power losses in the MOSFET. it also features short propagation delays and fast rise/fall times, further contributing to efficient operation. A new component is the capacitor (C5).it is a decoupling capacitor connected to the TC4422's power supply pins. Its job is to provide a stable, localized charge reservoir for the driver, supplying the instantaneous high currents needed to switch the MOSFET's gate. This prevents voltage dips on the supply rail that could affect the driver's performance. The resistor (RPWM2), connected in series with the output of the TC4422 to the MOSFET's gate, is the external gate resistor.

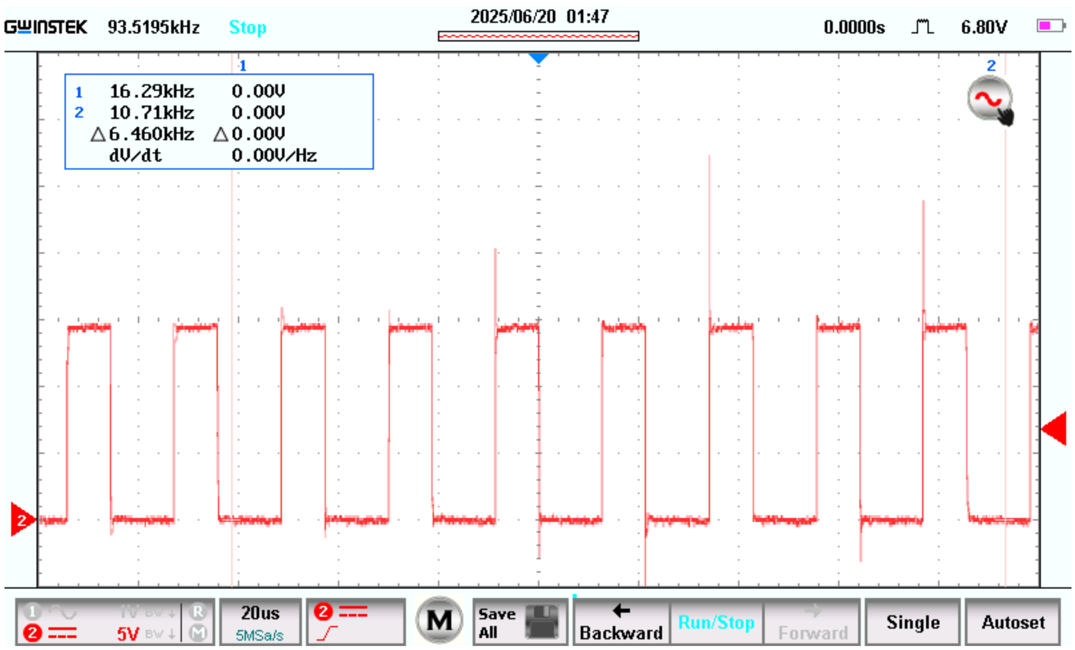

Figure 3.6 : Displays the Output Waveform from the TC4422, which is a sharp, clean signal ready to Drive a Power Switch (generated by the above circuit, fig 17)

The signal high value spikes are caused due to the measuring probe parasitic .

3.4. Design of Gate Drive using HCPL 312

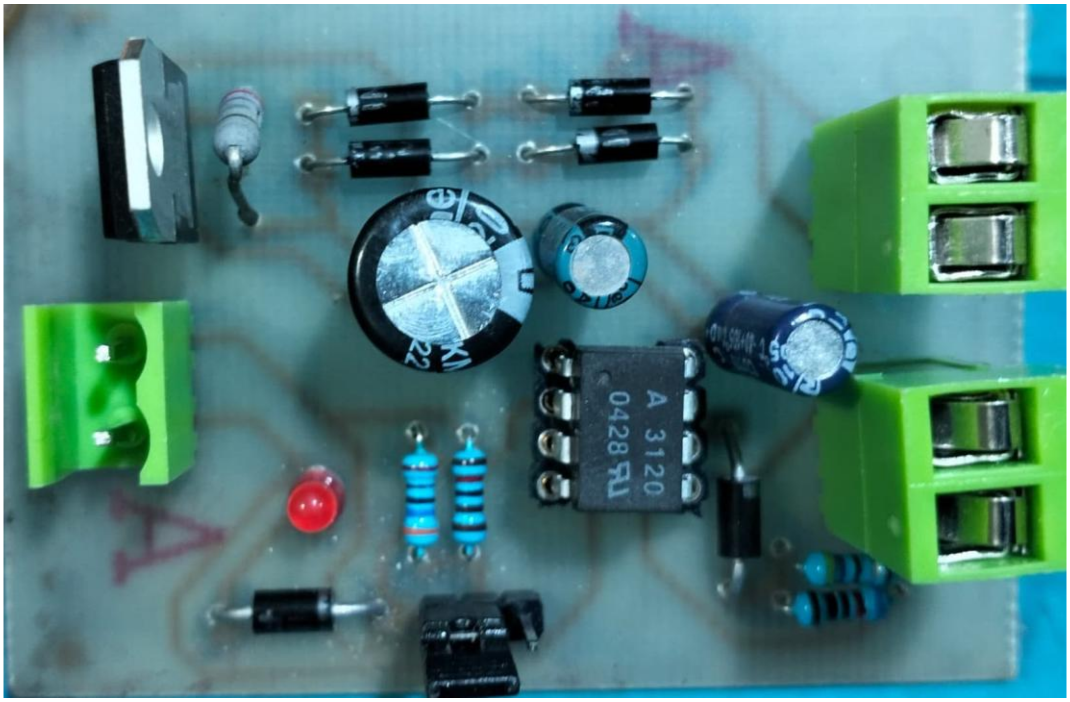

Figure 3.7 : A Practical Implementation using an HCPL3120 (Isolated Gate Driver)

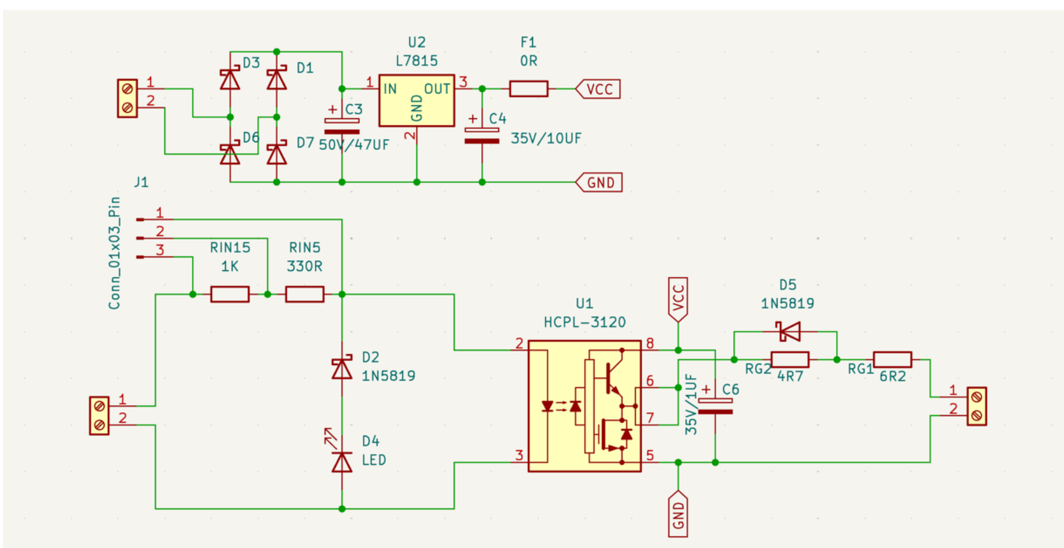

Figure 3.8 : Gate Drive Circuit using an HCPL3120

In the last section we used the HCPL3120 optically isolated gate driver on the input side of the HCPL-3120, resistors (RIN15, RIN5) are used in series with the input signal. Their primary function is to set to either the 3.3V USB connection or the 15V from the previous pwm controller, the internal LED of the optocoupler, ensuring it operates within its safe specifications and preventing damage.

Diode (D2), a 1N5819 Schottky diode and D4 led are there in case of reversed polarity so that the led inside HCPL3120 doesn't burn. The Rg1 and Rg2 resistance are the external gate resistors.

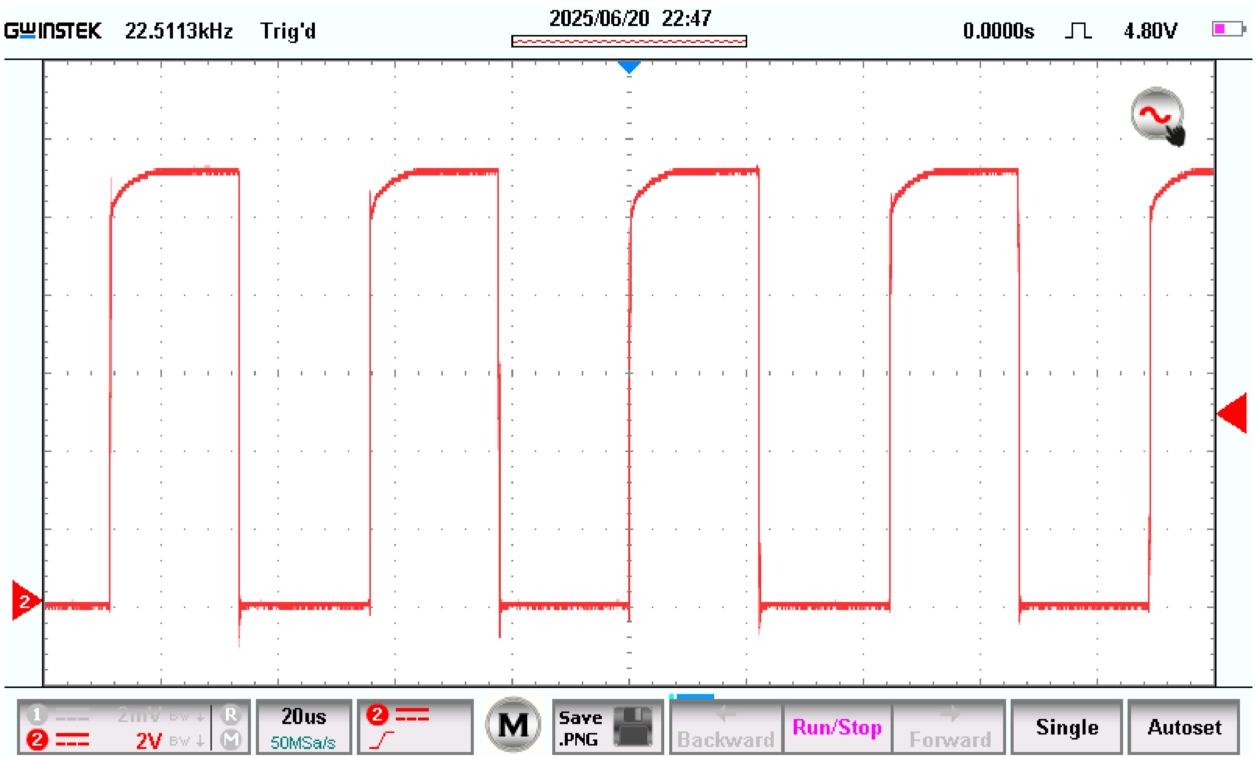

Figure 3.9 : The Final Output Voltage from the Isolated Driver, a Square Wave 0 to 15V, Demonstrating a Successful and Robust Gate Drive Signal (Generated by the Above Circuit, fig 20)

3.5. **Conclusion**

This chapter has provided a comprehensive overview of the practical considerations involved in the circuit realization of a MOSFET/IGBT gate driver, bridging the gap between theoretical understanding and functional implementation. Various gate driver circuit topologies were explored, emphasizing the importance of selecting appropriate driver ICs, gate resistors, and bootstrap capacitors to meet the specific requirements of the power switch. The discussion underscored that the precise selection of these components directly impacts the gate driver's ability to deliver the necessary voltage and current profiles for efficient and reliable switching. Furthermore, the critical role of protection mechanisms, such as desaturation detection for IGBTs and active clamping for MOSFETs, was highlighted as indispensable for ensuring the longevity and robustness of the power device under fault conditions.

The successful realization of a gate driver circuit is thus an iterative process of careful component selection, thoughtful circuit design, and meticulous physical layout. The knowledge gained from this chapter is crucial for translating the theoretical advantages of WBG materials and optimized gate drive parameters into a high-performing, reliable, and practical power electronic system.

General Conclusion

This thesis explored the transition from conventional silicon-based semiconductors to advanced Wide Band Gap materials, emphasizing their impact on power electronics. It highlighted the importance of gate drivers in achieving high-efficiency, high-frequency switching using devices like SiC and GaN MOSFETs. Key gate driver parameters such as drive strength, timing, thermal considerations, and EMI control were examined in detail.

Through theoretical analysis and practical circuit implementations, including PWM generation and isolated/non-isolated gate drivers, the study demonstrated the critical role of proper gate drive design in ensuring reliable and efficient converter operation. The comparison of different isolation methods, such as optical, magnetic, and capacitive, provided insight into their suitability for various applications. Ultimately, this work underlined that optimal gate driver design is essential for unlocking the full potential of modern WBG semiconductors in power electronics systems.

References

[1] : J. 1 1 U. of E. S. Song and C. Technology of China, "The history and trends of semiconductor materials' development," *ProQuest*, p. 012019, Oct. 2023, doi: https://doi.org/10.1088/1742-6596/2608/1/012019.

[2] : D. M. Brown and E. Downey, "Silicon carbide MOSFET technology," *Solid-State Electronics*, vol. 39, no. 11, pp. 1531–1542, Nov. 1996, doi: https://doi.org/10.1016/0038-1101(96)00079-2.

[3] : A. Oliveros, A. Guiseppi-Elie, and S. E. Saddow, "Silicon carbide: a versatile material for biosensor applications," *Biomedical Microdevices*, vol. 15, no. 2, pp. 353–368, Jan. 2013, doi: https://doi.org/10.1007/s10544-013-9742-3.

[4] : Y. Xu, "Applications and challenges of Silicon Carbide (SiC) MOSFET technology in electric vehicle propulsion systems: A review," *Applied and Computational Engineering*, vol. 40, no. 1, pp. 180–186, Jan. 2024, doi: https://doi.org/10.54254/2755-2721/40/20230647

[5] : Drex, "Analysis of 7 Common Functions of MOSFET Gate Drive Circuit - DRex Electronics," *DRex Electronics*, Dec. 20, 2024. https://www.icdrex.com/analysis-of-7-common-functions-of-mosfet-gate-drive-circuit/ (accessed Jul. 06, 2025).

[6] : n.d. (2023). *Basics and Design Guidelines for Gate Drive circuit* (No. 66AN032E Rev.003). Retrieved from Rohm website

[7] : Ritesh Oza.(2021). Understanding and Comparing Peak Current Capability of tGate Drivers(SLUAAA2). Retrieved from Texas instrument website

[8] : *Estimating the important parameters of a gate Gate driver*. (2025, June 20). https://community.infineon.com/t5/Knowledge-Base-Articles/Estimating-the-important-parameters-of-a-gate-Gate-driver/ta-p/816852

[9] : *SiC MOSFETs Gate Drive Optimization. (TND6237/DRev. 3, August – 2023)*

[10] : Asif Jamal, Vashist Bist, Praveen Kathani and Narsimhan Trichy Allegro MicroSystems *PRACTICAL CONSIDERATIONS FOR MOSFET SLEW-RATE CONTROL IN SMART GATE-DRIVER APPLICATIONS*. (AN296347 MCO-0001885)

[11] *:* J. Stiles, *Gate Propagation Delay*. University of Kansas, 2004.

[12] : "Challenges in Isolated Gate Drivers Design," *Monolithicpower.com*, 2025. https://www.monolithicpower.com/en/learning/mpscholar/isolation-solutions/isolated-gate-drivers/challenges-in-isolated-gate-drivers (accessed Jul. 06, 2025).

[14] : "Active Gate Drivers for EMI and dv/dt Control," *Vt.edu*, 2024. https://cpes.vt.edu/library/viewnugget/1085 (accessed Jul. 06, 2025).

[15] : "Proceedings of the 2021 Asia Pacific International Symposium on Electromagnetic Compatibility (APEMC)," *2022 Asia-Pacific International Symposium on Electromagnetic Compatibility (APEMC)*, pp. 1–1, Sep. 2021, doi: https://doi.org/10.1109/apemc49932.2021.9597029

[16] : Infineon Technologies AG, "High and low side drivers - Infineon Technologies," *Infineon.com*, 2025. https://www.infineon.com/cms/en/product/power/gate-driver-ics/high-and-low-side-drivers (accessed Jul. 06, 2025).

[17] : "Low-side Drivers | TI.com," *Ti.com*, 2025. https://www.ti.com/power-management/gate-drivers/low-side-drivers/overview.html (accessed Jul. 06, 2025).

[18] : "Working Principles of Isolated Gate Drivers," *Monolithicpower.com*, 2024. https://www.monolithicpower.com/en/learning/mpscholar/isolation-solutions/isolated-gate-drivers/working-principles

[19] : J. Shepard, "Gate drive transformer specifications and applications - Power Electronic Tips," *Powerelectronictips.com*, 2021. https://www.powerelectronictips.com/gate-drive-transformer-specifications-and-applications-faq (accessed Jul. 06, 2025).

[20] : Admin. (2020, September 21). *Gate drive transformers and circuits*. The Talema Group. https://talema.com/gate-drive-transformers-circuits

[21] : "Closed Loop Control," *Archive.org*, 2025. https://web.archive.org/web/20091101220657/http://www.powerdesignersusa.com/InfoWeb/resources/pe_html/ch07s1/intro.html (accessed Jul. 06, 2025).

[22] : "Buck Converters (Step-Down Converter)," *www.monolithicpower.com*. https://www.monolithicpower.com/en/learning/mpscholar/power-electronics/dc-dc-converters/buck-converters

[23] : Tavotech.com, "How a buck converter works," *TavoTech*, Feb. 2023. https://tavotech.com/how-a-buck-converter-works (accessed Jul. 06, 2025)

Abstract

The thesis explores the design and optimization of MOSFET gate driver circuits, particularly for use with Wide Band Gap (WBG) semiconductors like Silicon Carbide (SiC) and Gallium Nitride (GaN). It begins with an overview of semiconductor materials, highlighting the advantages of WBG over traditional silicon. It then analyzes buck converter operation and the key parameters influencing gate driver performance, such as gate charge, switching speed, EMI, and isolation. The final chapter presents practical implementations of both isolated and non-isolated gate drivers, supported by simulations and circuit design examples.

Résume

Ce mémoire traite de la conception et de l'optimisation des circuits de commande de grille pour transistors MOSFET, notamment pour une utilisation avec des semi-conducteurs à large bande interdite comme le carbure de silicium (SiC) et le nitrure de gallium (GaN). Il commence par une présentation des matériaux semi-conducteurs, en soulignant les avantages des matériaux à large bande par rapport au silicium traditionnel. Ensuite, il analyse le fonctionnement du convertisseur Buck ainsi que les paramètres clés influençant les performances des drivers de grille : charge de grille, vitesse de commutation, EMI et techniques d'isolation. Le dernier chapitre présente des implémentations pratiques de drivers isolés et non isolés, appuyées par des simulations et des circuits réels.

ملخص

تتناول هذه الأطروحة تصميم وتحسين دوائر قيادة بوابة ترانزستوراتMOSFET ، خاصةً للاستخدام مع أشباه الموصلات ذات الفجوة العريضة مثل السيليكون كربيد (SiC) و الغاليوم نيتريد (GaN). تبدأ بمقدمة حول مواد أشباه الموصلات، مبيّنة مزايا الفجوة العريضة مقارنةً بالسيليكون التقليدي. ثم تحلل مبدأ عمل محول "Buck" والمعايير الأساسية التي تؤثر على أداء دائرة القيادة، مثل شحنة البوابة، وسرعة التبديل، والتداخل الكهرومغناطيسي(EMI) ، والعزل الكهربائي. ويعرض الفصل الأخير تطبيقات عملية لدارات القيادة المعزولة وغير المعزولة، مدعومة بمحاكاة وتصميمات فعلية للدوائر.