Preliminary Report on

To Investigate the use of SI Carbide MOSFETs in an H-Bridge

by

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This report is submitted in partial fulfilment of the requirements of the Honours Degree in Electrical and Electronic Engineering (DT021A) of the Technological University Dublin (TU Dublin).

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Supervisor: **Colm Murray**

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1 Introduction & Objectives

1.1 Summary

The aim of this Project Preliminary Report (PPR) formal type document is to include events, activities and planning related to this project “To investigate the use of SI Carbide MOSFET in an H-Bridge” proposed by Colm Murray.

1.2 Introduction

The project is an investigation to observe the behaviour of silicon carbide (SiC) MOSFET in an H-Bridge, where MOSFET stands for Metal oxide semiconductor field-effect transistor. The MOSFET requires a gate driver to perform on/off operations at the desired frequency.

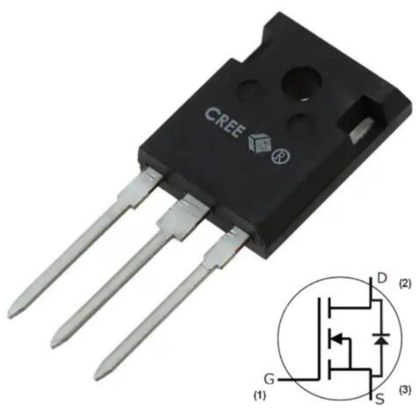


Figure 2 C3M0065090D Silicon Carbide Power MOSFET [2]

Figure 1 PT62SCMD17 Silicon MOSFET Driver [3]

C3M0065090 SiC Power MOSFET will be used along with PT62SCMD17 silicon MOSFET Driver. The gate driver is a power amplifier that will require a low-power input from a controller (Arduino) and produces a high-current drive input for the gate of a high-power MOSFET. MOSFET requires a higher voltage than the rated gate threshold voltage (Vth) to turn on. The MOSFET gate drive consumes no power, when in a steady on or off state. The MOSFETs gate-source capacitance seen by the driver output varies with its internal state. MOSFET operation & features are described in the research section.

The microcontroller will be used to supply Pulse with modulation (PWM) varying from 0 to 5v into the gate of the driver.

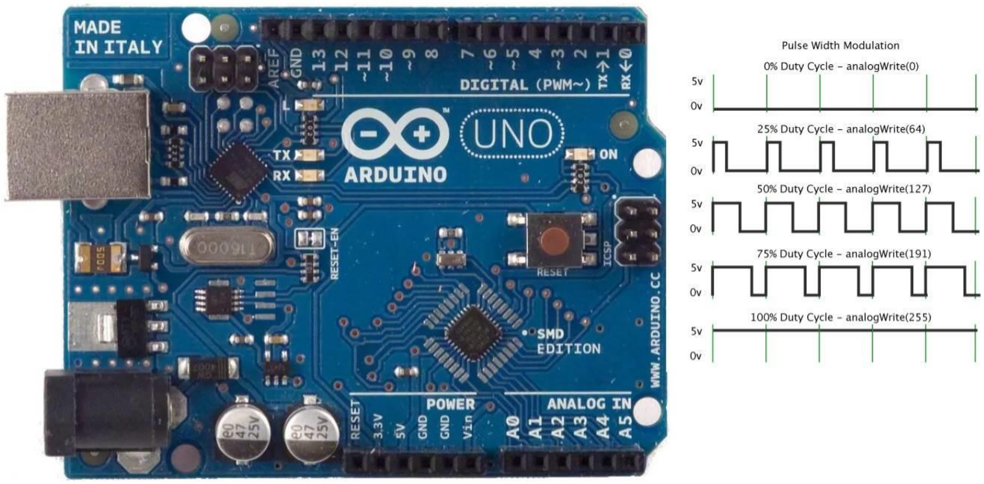


Figure 3 Arduino Uno microcontroller supplies PWM (0-5v) [4]

1.2.1 Circuit Diagram

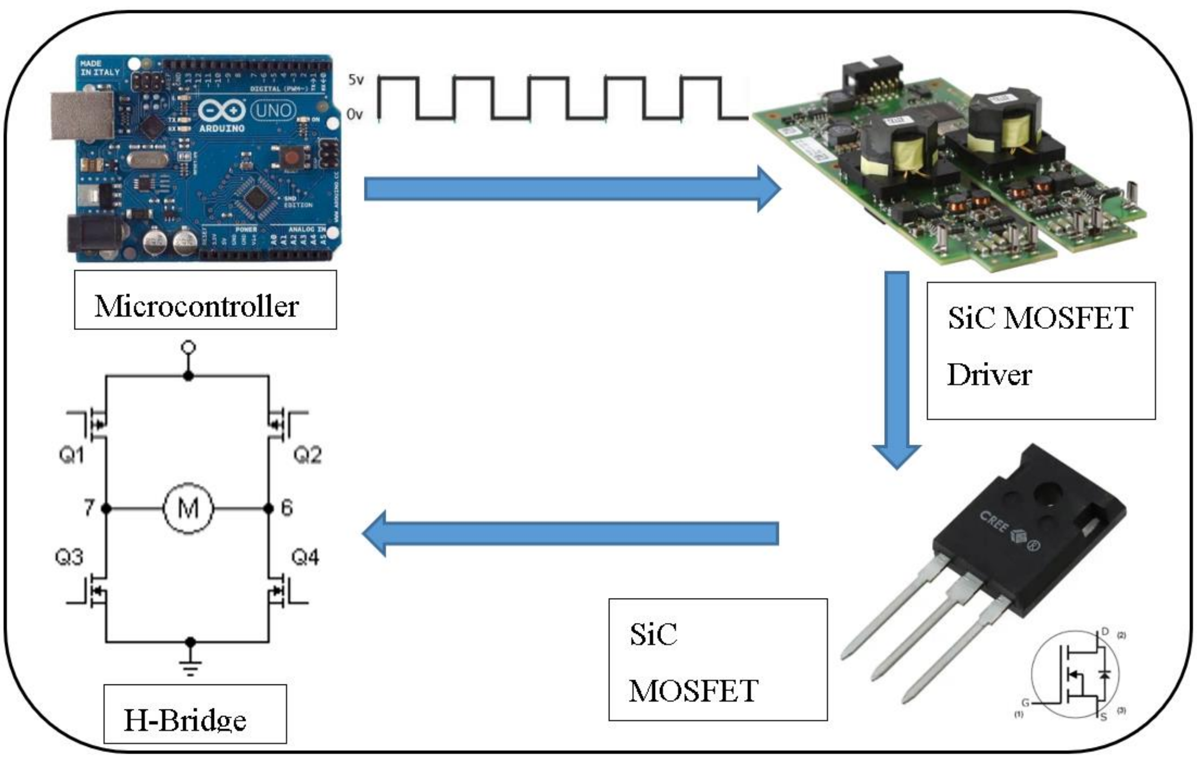


Figure 4 Circuit Diagram

1.2.2 List of Components & Equipment

Components: 4 SIC MOSFET, SIC MOSFET driver, flying back diode, and Arduino.

Equipment: Instantaneous voltages and currents, Multimeter, Oscilloscope, wire, breadboard, and soldering Iron.

1.3 Objectives

Silicon Carbide MOSFETs have significant benefits when compared to traditional Si MOSFET technology. This project investigates the use of these Silicon Carbide MOSFETs, involving a construction of a high-power electronic switching approximately 100 Kilo Watts (KW) power at relatively high speeds 100 Kilo Hertz (KHz) using Si Carbide MOSFET in an H-Bridge.

Construction and testing of a SiCarbide MOSFET will carry out. The H-bridge only be implemented once the first MOSFET testing is successful. The controller and gate drive system will also be built and tested.

Testing protocol to investigate the behaviour of the power SiC MOSFETs using driver circuit to test over a range of frequencies, voltages, and currents.

Instrumentation setup to test the system to measure the performance of MOSFET bridge into the resistor as a function of a load, voltage, current and switching frequency.

2 Ethics

2.1 Engineering Safety Ethics

Safety is the number one priority, especially when dealing with high power supply units, whether in the university laboratory or anywhere else. If a positive or negative spike gets onto the drain of the power MOSFET via gate capacitance, the MOSFET can explode in a cloud of flame and black smoke. However, it is important to follow the engineering ethical standard because otherwise, it can cost someone’s life and these small mistakes might be the very thing that causes a disaster. Since modern societies are heading towards an era of technology, where all members of society will be affected, electrical engineers need to follow a **code of engineering ethics**.

2.2 Power Design Awareness

The poor designs of the power circuits can cost a lot of money, inefficiency, non-functional and dangerous circuitry can harm the environment and can destroy other technology due to the excess temperature, currents, or voltages. It is important to read the datasheet for each component used in the circuit design to be aware of the ratings and limitations to avoid any casualties. Unknown information’s must be not implemented in the designs and development of the project.

2.3 Researching effectively

There are bibliography meatheads available to reference someone else’s work that is published but utilizing reliable academic resources while researching to avoid plagiarism and stealing someone else idea is unacceptable.

2.4 Climate

Climate change ethical problem’s biggest victims are people and change impacts are potentially catastrophic around the world. Modern technologies are emitting large amounts of carbon dioxide, causing global warming. are operated by fossil fuel. fewer natural resources, including energy, producing less a negative impact to the environment.

Modern technology like Silicon Carbide materials is used in many driver and semiconductor applications which will allow us to capture naturally energy and convert it into electricity or useful heat through devices such as solar panels, wind, and water turbines, which reflects a highly positive impact of technology on the environment.

3 Research

3.1 MOSFET

MOSFET is a well-known semiconductor device that is used in amplifier circuits, digital switches, and power applications to achieve faster switching speeds and amplification. It stands for Metal Oxide Semiconductor Field Effect Transistor and is a form of a FET and is a voltage-controlled device, where currents in the FET depends upon the electric field. The MOSFET usually has three terminals: gate, drain, and source as shown in figure 5.

MOSFETS are classified into 2 types depending upon the channel or majority carries present in it.

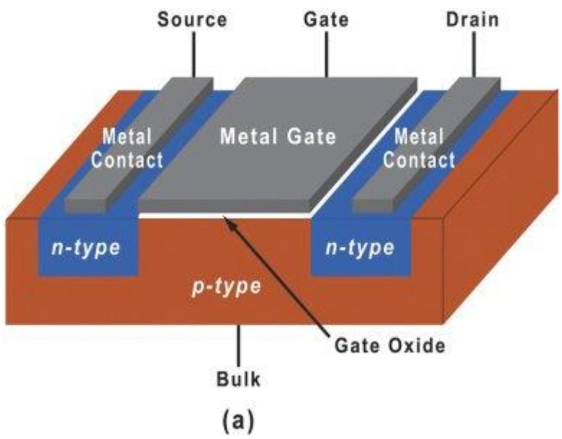


Figure 5 P-type (a) MOSFETS [1]

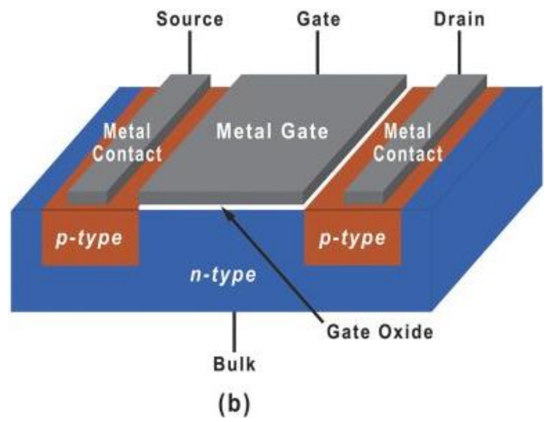


Figure 6 N-type (b) MOSFETS [1]

- In NMOSFET, the substrate is p-type and depending upon the gate voltage applied the channel present between source and drain is converted into n-type. The minimum gate voltage to be applied to make it conduct is known as the threshold voltage. It can be positive or negative depending upon the mode of operation of MOSFET, i.e enhancement or depletion mode.
- The substrate is n-type in PMOSFET, and the channel is of p-type.

Classification depending on modes of operation or channel formation is of 2 types.

Enhancement mode:

Channel is not formed initially but on the application of appropriate gate voltage, the channel is formed. For n-channel type, positive gate voltage should be applied for channel formation whereas, for p channel MOSFET, the negative voltage should be applied.

Depletion mode:

Channel is already present, and it conducts even if no gate voltage is applied. It can be operated both in enhancement and depletion modes.

MOSFETs have a higher power density advantage when compared to other types of transistors, for example, BJTs (Bipolar Junction Transistors), where MOSFETs require a minimal amount of input current to control the load current. [5]

3.2 Silicon carbide MOSFET

Silicon Carbide (SiC) is a wide-bandgap semiconductor material that has several promising properties for use in power electronics applications. [6] It enables higher switching frequencies and reduces the size of components like inductors, capacitors, filters & transformers. It replaces silicon devices to enable lower switching and conduction losses with higher blocking voltages and avalanche capability, where “avalanche capability” is how much energy loss can resist at a time. the VDSS is exceeded, current will flow despite the MOSFET being in the OFF state, so this generates high loss and can damage the MOSFET. [6]

The SiC device compares favourably to the Si device tested as well as other Si devices available on the market for a similar voltage range.

Silicon carbide (SiC) is a wide-bandgap semiconductor material with a bandgap energy of 3.3 eV compared to 1.1 eV for silicon (Si). SiC has a single silicon-carbon bond that gives it that higher bandgap energy as well as several other (W/cmK) useful properties. These properties allow higher voltage blocking, lower switching losses, and improved high-temperature performance compared to Si, making the material very attractive for power electronics applications.[7]

Table 1 Si Carbide vs Sidifferences

No.	Properties	Si Carbide	Si
1	Bandgap, Eg (eV)	3.3	1.1
2	Critical field, Ec $\left(\frac{MV}{cm}\right)$	2.2	0.25
3	Electron Saturation velocity, V_{sat} $\left(\frac{10^7 V}{cm}\right)$	2	1
4	Electron mobility, Mn $\left(\frac{cm^2}{Vs}\right)$	947	1350
5	Hole mobility Mp $\left(\frac{cm^2}{Vs}\right)$	120	480
6	Dielectric constant (Er)	9.7	11.8
7	Melting point (°C)	2820	1420

3.3 Advantages of SiC over Si

Silicon Carbide has a good few advantages over Si when used in semiconductor technology, which includes the following:

- A higher critical breakdown field, meaning a voltage rating can be maintained while still reducing the thickness of the device. [5]
- A wider bandgap, leading to lower leakage current at relatively high temperatures. [5]
- A higher thermal conductivity, which supports a higher current density. [5]
- An overall reduction in energy losses. [5]
- Reduced switching losses, which impact losses that occur when the MOSFET is transitioning from blocking to conducting (and vice versa). [5]
- Higher switching frequencies, which means smaller peripheral components (e.g., filters, inductors, capacitors, transformers) can be used. [5]
- Increased critical breakdown strength, about 10x what is achievable with Si.[5]
- Higher temperature operation, which means simplified cooling mechanisms (e.g., heat sinks). [5]
- When compared to their Si counterparts, SiC MOSFETs offer better overall performance, higher efficiency, higher switching frequencies, and more compact components. More and more engineers are turning to SiC MOSFETs and taking advantage of the superior properties that they offer. [5]

4 Work Plan

4.1 Project work break structure

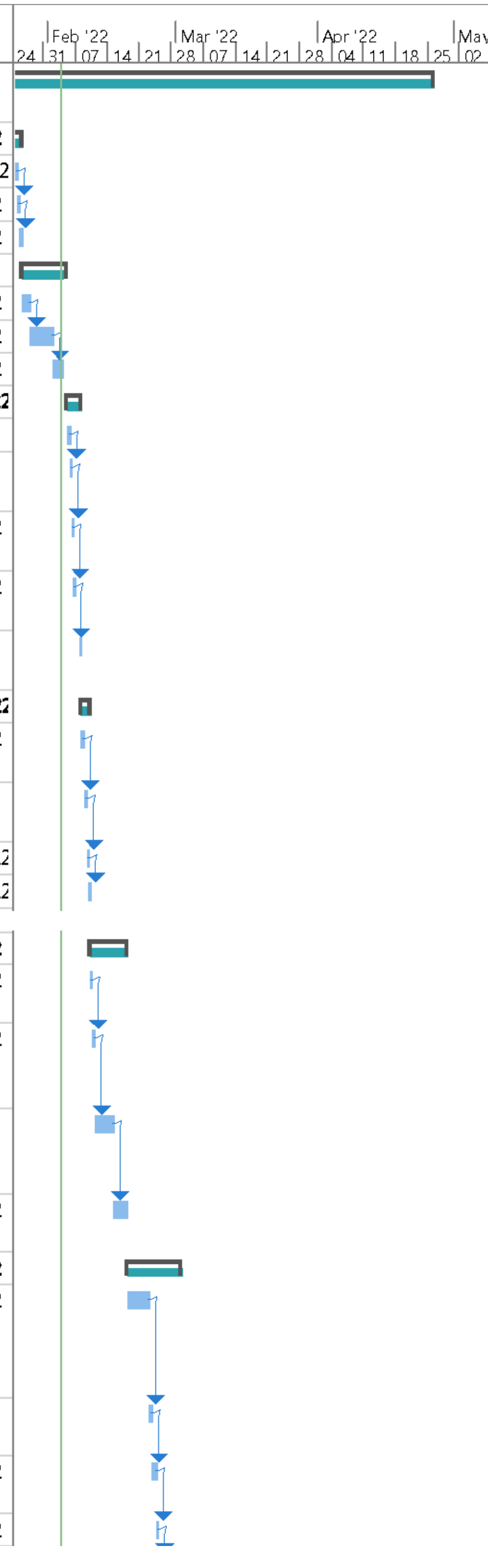
Table 2 Work breakdown structure

Start Date: 24/01/2022 ≈ End Date: 25/04/2022		
Weeks	**Date**	**Tasks**
1	24/01/2020	**Perform Investigation** • Research SiC MOSFET • Research SiC MOSFET Driver • Research bandgap
2	31/01/2020	**Complete Preliminary report** • Project Safety plan • Planning • Gather Datasheets
3	07/02/2020	**Project Setup** • Order SiC MOSFETS • Organize Equipment's & Components • Template created for Logging data weekly • Carry safety procedure with a lab technician • Check component ratings and operation with high voltages
4	14/02/2020	**Programming** • Program microcontroller to control the gate of the SiC driver • Calculate values and circuit characteristics • Breakdown circuit tasks • Testing the microcontroller
5	21/02/2020	**Construction design** • Find out gate power supply requirements and peak current • Calculate gate resistor same switching performance as in the datasheet • Calculate the gate driver internal power dissipation & the gate resistor power dissipation • Verify the power dissipation with datasheet values
6	28/02/2020	**Testing & Validation** • Testing the gate driver circuit to see if the driver is powerful enough to drive the power MOSFET. • Power dissipation matches the limits in the datasheet • Debug any faults in case iteration loops occur • Check the short circuit protection • Check output characteristics of MOSFET • Identify types of fault/issues • Begin developing of a circuit

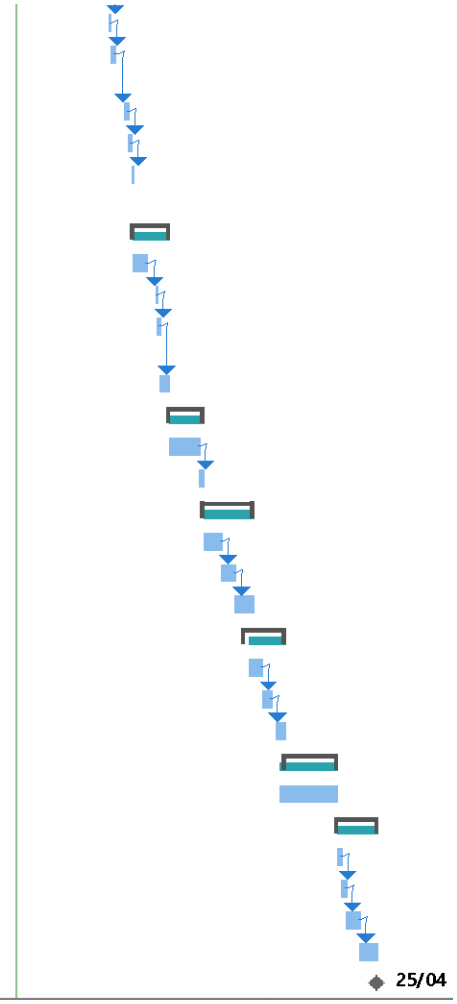
		• Calculating the heatsink required for MOSFET
7	07/03/2020	**Analysis** • Testing the circuit • Analysing the switching speeds Observing data on the oscilloscope and capturing • Analysing the behaviour
8	14/03/2020	**Investigating in an H-Bridge** • Implementing H-bridge • Review data from 1st MOSFET
9	21/03/2020	**Testing** • Gathering data • Testing with various frequencies • Reviewing data
10	28/03/2020	**Testing** • Collecting data • Verifying • Analysing
11	04/04/2020	**Work on Report** • Logbook completed
12	11/04/2020	**Work on Report**
13	18/04/2020	**Final Submission week** • Work on Report • Complete Logbook • Preparation for Presentation • Preparation for Interview
14	25/04/2020	**All project complete**

Table 3 Project Gantt Chart

ID		Task Mode	Task Name	Duration	Start	Finish
1			**Investingating the use of SIC MOSFET in H-bridge**	**70 days**	**Mon 24/01/22**	**Mon 25/04/22**
2			**Perform Investigation**	**2 days**	**Mon 24/01/22**	**Tue 25/01/22**
3			Research SiC MOSFET	1 day	Mon 24/01/22	Mon 24/01/22
4			Research SiC MOSFET Driver	0.8 days	Tue 25/01/22	Tue 25/01/22
5			Research bandgap	0.2 days	Tue 25/01/22	Tue 25/01/22
6			**Complete Preliminary report**	**8 days**	**Wed 26/01/22**	**Fri 04/02/22**
7			Project Safety plan	2 days	Wed 26/01/22	Thu 27/01/22
8			Planning	3 days	Fri 28/01/22	Tue 01/02/22
9			Gather Datasheets	2 days	Wed 02/02/22	Thu 03/02/22
10			**Project Setup**	**3 days**	**Sat 05/02/22**	**Mon 07/02/22**
11			Order SiC MOSFETS	0.5 days	Sat 05/02/22	Sat 05/02/22
12			Organize Equipment's & Components	0.5 days	Sat 05/02/22	Sat 05/02/22
13			Template created for Logging data weekly	0.3 days	Sun 06/02/22	Sun 06/02/22
14			Carry safety procedure with a lab technician	0.5 days	Sun 06/02/22	Sun 06/02/22
15			Check component ratings and operation with high voltages	0.2 days	Mon 07/02/22	Mon 07/02/22
16			**Programming**	**2 days**	**Tue 08/02/22**	**Wed 09/02/22**
17			Program microcontroller to control the gate of the SiC	0.8 days	Tue 08/02/22	Tue 08/02/22
18			Calculate values and circuit characteristics	0.5 days	Tue 08/02/22	Wed 09/02/22
19			Breakdown circuit tasks	0.5 days	Wed 09/02/22	Wed 09/02/22
20			Testing the microcontroller	0.2 days	Wed 09/02/22	Wed 09/02/22
21			**Construction design**	**6 days**	**Thu 10/02/22**	**Thu 17/02/22**
22			Find out gate power supply requirements and peak current	0.5 days	Thu 10/02/22	Thu 10/02/22
23			Calculate gate resistor same switching performance as in the datasheet	0.5 days	Thu 10/02/22	Thu 10/02/22
24			Calculate the gate driver internal power dissipation & the gate resistor power dissipation	2 days	Fri 11/02/22	Mon 14/02/22
25			Verify the power dissipation with datasheet values	3 days	Tue 15/02/22	Thu 17/02/22
26			**Testing & Validation**	**8 days**	**Fri 18/02/22**	**Tue 01/03/22**
27			Testing the gate driver circuit to see if the driver is powerful enough to drive the power MOSFET.	3 days	Fri 18/02/22	Tue 22/02/22
28			Power dissipation matches the limits in the datasheet	0.8 days	Wed 23/02/22	Wed 23/02/22
29			Debug any faults in case iteration loops occur	1 day	Wed 23/02/22	Thu 24/02/22
30			Check the short circuit protectio	0.2 days	Thu 24/02/22	Thu 24/02/22



30			Check the short circuit protectio	0.2 days	Thu 24/02/22	Thu 24/02/22
31			Check output characteristics of MOSFET	1 day	Fri 25/02/22	Fri 25/02/22
32			Identify types of fault/issues	1 day	Mon 28/02/22	Mon 28/02/22
33			Begin developing of a circuit	0.5 days	Tue 01/03/22	Tue 01/03/22
34			Calculating the heatsink required for MOSFET	0.5 days	Tue 01/03/22	Tue 01/03/22
35			**Analysis**	**6 days**	**Wed 02/03/22**	**Wed 09/03/22**
36			Testing the circuit	3 days	Wed 02/03/22	Fri 04/03/22
37			Analysing the switching speeds	0.5 days	Mon 07/03/22	Mon 07/03/22
38			Observing data on the oscilloscope and capturing	0.5 days	Mon 07/03/22	Mon 07/03/22
39			Analysing the behaviour	2 days	Tue 08/03/22	Wed 09/03/22
40			**Investigating in an H-Bridge**	**6 days**	**Thu 10/03/22**	**Thu 17/03/22**
41			Implementing H-bridge	5 days	Thu 10/03/22	Wed 16/03/22
42			Review data from 1st MOSFET	1 day	Thu 17/03/22	Thu 17/03/22
43			**Testing**	**7 days**	**Fri 18/03/22**	**Mon 28/03/22**
44			Gathering data	2 days	Fri 18/03/22	Mon 21/03/22
45			Testing with various frequencies	3 days	Tue 22/03/22	Thu 24/03/22
46			Reviewing data	2 days	Fri 25/03/22	Mon 28/03/22
47			**Testing**	**8 days**	**Sun 27/03/22**	**Mon 04/04/22**
48			Collecting data	3 days	Mon 28/03/22	Wed 30/03/22
49			Verifying	2 days	Thu 31/03/22	Fri 01/04/22
50			Analysing	2 days	Sun 03/04/22	Mon 04/04/22
51			**Work on Report**	**10 days**	**Tue 05/04/22**	**Sat 16/04/22**
52			Report & Logbook completed	10 days	Mon 04/04/22	Sat 16/04/22
53			**Final submission week**	**7 days**	**Sun 17/04/22**	**Mon 25/04/22**
54			Work on Report	1 day	Sun 17/04/22	Sun 17/04/22
55			Complete Logbook	1 day	Mon 18/04/22	Mon 18/04/22
56			Preparation for Presentation	3 days	Tue 19/04/22	Thu 21/04/22
57			Preparation for Interview	2 days	Fri 22/04/22	Mon 25/04/22
58			**All project complete**	**0 days**	**Mon 25/04/22**	**Mon 25/04/22**



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