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Table of Contents

Table of Contents ii

List of Figures ii

List of Tables iii

List of Abbreviations iii

Executive Summary 1

1 Introduction 2

1.1 Background to system (type of converter) being investigated 2

2 Design Process 2

3 Simulations 3

4 Practical Results 4

5 Discussion 6

6 Conclusions 7

7 Recommendations 7

8 Appendix A 8

8.1 Bread board circuit 8

8.2 Strip board circuit 9

8.2.1 Heavy current laboratory setup 9

8.2.2 Heavy current laboratory results 11

9 References 13

List of Figures

Figure 1: Low side switch Ltspice® circuit 3

Figure 2: Ltspice® simulation results of circuit 4

Figure 3: Bread board circuit, IGBT switching at 30V 5

Figure 4: 300V low side switch for dc motor 50% duty cycle 6

Figure 5: bread board circuit 8

Figure 6: Bread board results, optocoupler input at 50% duty cycle 8

Figure 7: Bread board circuit results optocoupler output at 50% duty cycle 9

Figure 8: heavy current laboratory test bench 9

Figure 9: dc motor 10

Figure 10: Circuit schematic to built the strip board. 10
Figure 11: strip board final circuit 11
Figure 12: Strip board circuit 30V switching at 50% duty cycle, TiePie results 11
Figure 13: Heavy current laboratory minimum duty cycle with dc motor load 12
Figure 14: Heavy current laboratory maximum duty cycle with dc motor load 12

List of Tables

Table 1: Simulation parameters of low side switch 4
Table 2: Duty cycle results at 300V input with dc motor load in heavy current laboratory 6

List of Abbreviations

Abbreviation	Meaning
IGBT	Insulated-gate bipolar transistor
MOSFET	Metal-oxide-semiconductor field-effect transistor
dc	Direct current
PWM	Pulse width modulation
V	Voltage
A	Ampere
F	Farad
H	Henry

Executive Summary

A low side switch was designed and built to control the speed of a dc motor. Calculations where done to create a concept circuit design for the low side switch. The circuit was then simulated in Ltspice® to ensure that the switching of the IGBT was satisfactory. Once the design from the simulations was satisfactory the circuit was built on a breadboard and tested in the Thevenin laboratory at 30 Vdc with the load represented by a 450 Ohm, 1W resistance. After testing the circuit was reconstructed on a stripboard and first tested at 30 Vdc in the Thevenin laboratory before being tested in the heavy current laboratory at 100 Vdc and 300 Vdc. The heavy current laboratory tests where first conducted with the test bench resistors acting as the circuit load, before finally being tested with the dc motor connected as the load. The circuit has a maximum duty cycle of 84.067 % where the mean voltage is 252.5 Vdc for an input of 300 Vdc, when the dc motor is connected as the load. The minimum duty cycle is 23.833% with a mean voltage of 71.5 Vdc for an input voltage of 300 Vdc with the dc motor connected as the load.

1 Introduction

The purpose of this practical is to design and build a low side switch to control the speed of a shunt dc motor loaded by a synchronous generator.

1.1 Background to system (type of converter) being investigated

A switch mode dc to dc converter is investigated to digitally control a shunt dc motor. Switch mode dc-dc converters are often used in sustainable energy by converting the voltage and current from one level dc to the desired level dc [1]. The dc-dc converter is also often used for electric and electronic circuit switching-mode power supplies as well as control of dc motor drive systems [2].In this practical a step-down (buck) converter is used to step down the input voltage to a lower output voltage to control a dc motor. PWM is used to regulate the dc-dc converter output voltage [1]. The PWM pulses the output voltage but the output current remains continuous due to the load inductance [3].

Gate controlled semiconductors such as IGBTs and MOSFETs are implemented to operate as switches in the dc-dc converter [2]. A pulse is applied to the IGBT or MOSFET's gate to switch the semiconductor into a conduction mode for the gate pulse interval, the semiconductor will then switch into a block mode [2].

2 Design Process

The circuit consists of the following parameters, the signal generator, Optoisolator, MOSFET driver, IGBT, load and the voltage sources. The exact components used in the design where [4]:

- STGP20V60F IGBT (characteristics found in [5]
- 600V 1 A, Diode, FR105G-K R0G (IGBT anti-parallel diode)
- 650V 30 A, Diode, IDP15E65D1XKSA1 (motor load free-wheel diode)
- 4N25
- TC1412 (characteristics from [6])

The signal generator produces the pulse that will be produced by the control section of the practical. The pulse is what is used to switch the circuit. The signal is the input of the optocoupler, the optocoupler is used to protect the Arduino against noise. The output of the optocoupler is connected to the input of the MOSFET driver. The MOSFET driver is used to trigger the IGBT by ensuring that the output to the IGBT is a perfect block form. The output of the MOSFET driver is connected to the IGBT input. The IGBT switches the circuit as controlled by the input.

The first step in the design process was the calculation and design of the basic circuit for the low side switch. The calculations are documented in sub-practical B and where done using the equations shown in [7] and [1]. The circuit was then refined and simulated in LTspice® where the load was represented by a 450 Ohm resistor. From the simulations the next step was building the circuit onto a bread board and testing it in the Thevenin laboratory. Appropriate changes were made to the design until the circuit worked satisfactory. The circuit was then soldered onto a strip board and tested in the Thevenin laboratory to ensure no errors were made during the building process. Finally, the circuit was testing in the heavy current laboratory with the dc motor set up as the load, once the circuit proved switch satisfactory.

3 Simulations

The low side switch circuit was simulated in Ltspice®. For the simulation an input frequency of 10kHz was applied as a square pulse by the signal generator V1 in the circuit shown in Figure 1 below. For the simulations in Ltspice® the STGP20V60F.lib module was used represent the IGBT. To simulate the free-wheel diode for the motor the rapid1b_e65d.lib diode model was used.

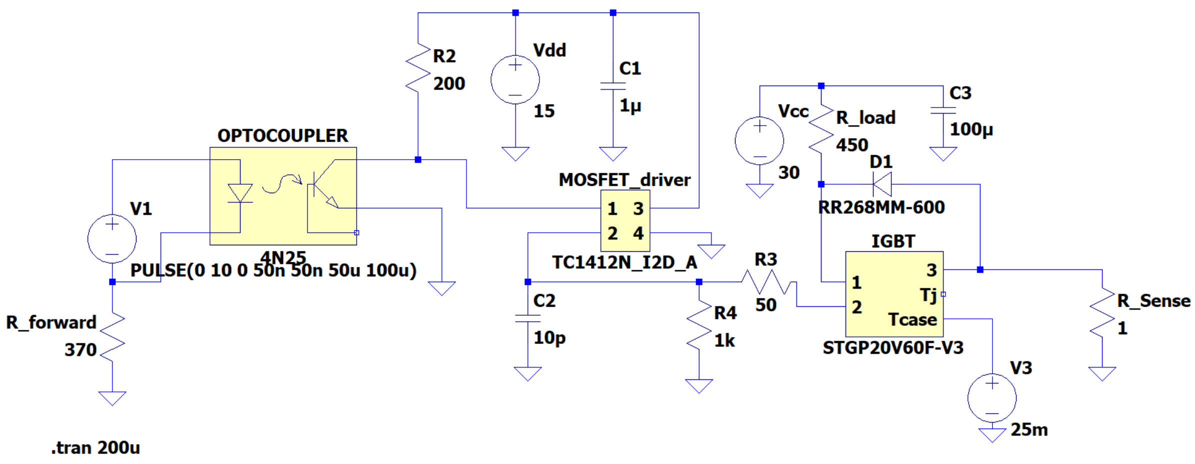

Figure 1: Low side switch Ltspice® circuit

The circuit was designed for a rise and fall time of 50ns respectively, where the signal generator is the input of the 4N25 optocoupler. The optocoupler is connected to the MOSFET driver input and 15V power supply. The MOSFET output is connected to the gate of the IGBT. The IGBT has an anti-parallel resistor connected to it as the IGBT that will be used in the practical does not have one in its package. The IGBT is connect to the load and the sensing resistor, that will be used to measure the output during the practical. The 450 Ohm load is a representation of the motor that will be used in the real circuit.

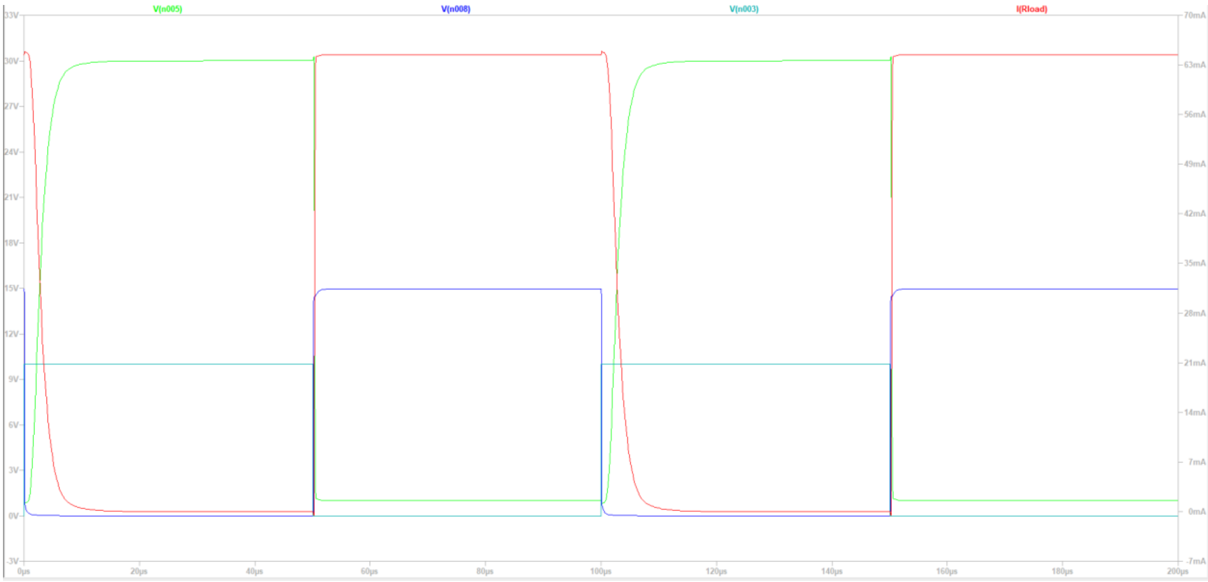

Figure 2: Ltspice® simulation results of circuit

From the simulation the follow parameters can be seen as shown in Table 1 below. In the simulation shown in Figure 2 above the red function shows the load current. The load voltage is depicted with a green graph and the dark blue line represents the MOSFET driver voltage output. The signal generator input is displayed with the light blue function.

Table 1: Simulation parameters of low side switch

Parameter	Value	Unit	Graph function colour
Load current	66	mA	Red
Load voltage	30	V	Green
MOSFET driver voltage	15	V	Dark Blue

From the simulation it is clear that the switching delay is very small as required for the circuit in order to properly switch the IGBT on and off.

4 Practical Results

The circuit was tested in several phases. The first phase was to built the circuit on a bread board in the Thevenin laboratory and testing the circuit with the oscilloscope. Once the design was satisfactory the circuit was rebuilt onto a strip board. The new circuit was then tested in the Thevenin laboratory as well at 30 V in order to ensure that there were no mistakes on the circuit board. Next the circuit was tested in the heavy current laboratory at 100 V and using the bench resistors as a load. Once the circuit proved to operate correctly at 100 V the voltage was increased to 300 V with the load resistance connected. If operation of the circuit was satisfactory the test bench resistors were disconnected and the dc motor was connected as the load for the circuit. The circuit was then tested at 30 V then 100V and finally 300V when each phased proved satisfactory.

To test and confirm that everything is working correctly in the circuit the input, shown in Figure 6 Appendix A, and output of the optocoupler, shown in Figure 7 in appendix A, was measured with the oscilloscope in the Thevenin laboratory. This was done to see that there was less than a 3ns delay in the rise and fall time. The output of the optocoupler was also measured to that no more than 16V was applied to the optocoupler to ensure that the optocoupler did not become damaged. The IGBT measurements can be seen in Figure 3 for 30V input, the delay in the rise and fall time is also required to be less than 3ns. Thither more the sensing resistor was used in the bread board circuit to ensure that the current for the 50% duty cycle was approximately 33mA as required by the design.

The bread board circuit was changed in order to shorten the delay in the rise and fall of the switching The IGBT output at 30V can be seen in Figure 3 below at channel 2 and the signal generator output can be seen at channel 1. The measurements were taken in the Thevenin laboratory with a 450 Ohm, 1W resistance applied as the load in place of the dc motor.

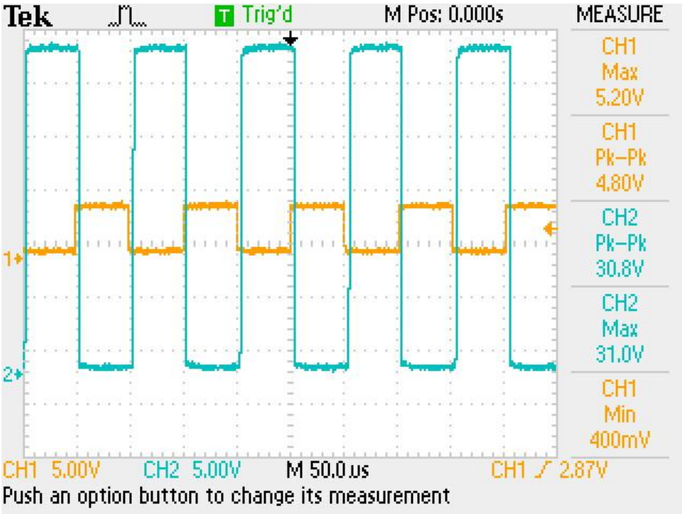

Figure 3: Bread board circuit, IGBT switching at 30V

The strip board circuit can be seen in Figure 11 in appendix A. Changes made from the bread board to the strip board circuit is the replacement of the capacitor with a WIMA 47µF capacitor at the IGBT. A heat sink was added to the IGBT to dissipate the heat in order to prevent heat damage to the IGBT. The signal generator ground was separated from the 15V input at the MOSFET driver input and the IGBT voltage, going as high as 300V. The signal generator ground is connected to a different ground in order to protect the signal generator. The rest of the circuit is connected to a common ground.

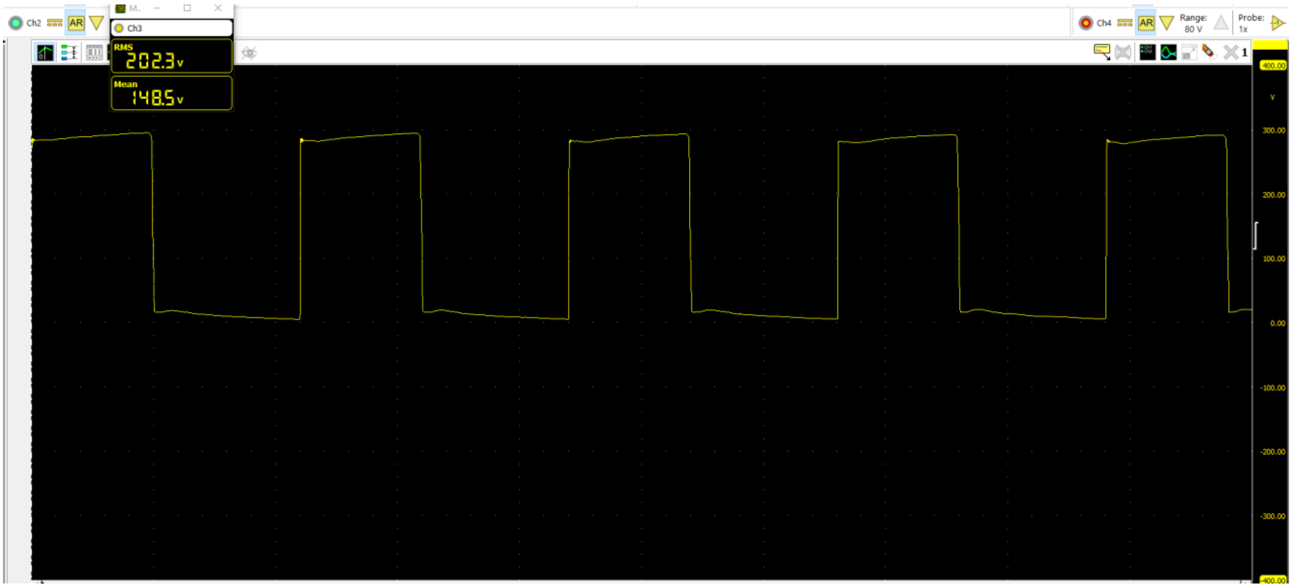

Figure 4: 300V low side switch for dc motor 50% duty cycle

The minimum and maximum duty cycle can be seen in appendix A. For the maximum duty cycle mean voltage is 252.5V which can be seen in Figure 14 in appendix A. The minimum duty cycle mean voltage is 71.5V as can be seen in Figure 13.

Table 2: Duty cycle results at 300V input with dc motor load in heavy current laboratory

Duty Cycle at 300V input	Duty Cycle [%]	Mean Voltage [V]
50%	50	150
Maximum	84.067	252.5
Minimum	23.833	71.5

It is clear from the tests in the heavy current laboratory that the IGBT is switched on and off properly for a 5V signal square pulse input at 300V when the dc motor is connected as the load of the converter. No components overheated during the test and evaluation as the circuit was built compactly in order to minimize the wire interference in the circuit. Other measures taken to protect the circuit was attaching a heat sink to the IGBT and connecting a WIMA and large electrolytic capacitor over at the 300 Vdc input.

5 Discussion

During the design I learnt that an important aspect of design is to design and build a circuit in phases in order to ensure that each module of the circuit is designed and built properly before moving on to the rest of the circuit. The importance of building a circuit as concise as possible was shown in this practical as the effect of the wires between connections was apparent in the design. As well as the importance to draw a schematic of the circuit with the packaging and pins to simplify the building process as can be seen in the schematic of the circuit shown in Figure 10 in appendix A. I learnt the importance of implementing capacitors in the circuit to combat the inductance caused by the wire's connection the components of the circuit. As well as the importance of placing diodes as a safety measure in a circuit.

6 Conclusions

A switch mode dc-dc converter to control a dc motor was designed, simulated, built and tested in this practical. The converter was designed from the calculations done in sub-practical-A. The circuit was simulated in Ltspice®, the simulation results are shown in Figure 2 above. From the simulations we can see that the load current is 66mA and the rise and fall time delay is very small. The circuit was first built on a breadboard to test the circuit the results can be seen in Figure 3, Figure 6 and Figure 7. The switching delay in the rise and fall time is less than 3ns and therefore is satisfactory for the control of the dc motor. The circuit was then rebuilt on a stripboard and, the circuit was tested in the heavy current lab to up to 300 Vdc input. From the tests it is clear that the switching was satisfactory and none of the components started to heat up as the IGBT had a heat sink to prevent overheating.

An important factor to consider for the dc-dc converter is the influence of parasitic inductance. The parasitic inductance can cause the circuit not to operate correctly and therefore cause damage to components such as the IGBT in the circuit. To minimize the parasitic inductance in the circuit the components where built as close as possible together to minimize the impact of the wiring of the circuit, a WIMA and electrolytic capacitor was also placed at the 300 Vdc source to minimize the effects.

7 Recommendations

The circuit could be improved by switching the existing resistors with a smaller tolerance and larger power allowance to minimize the effect of the heat on the circuit. The component layout can also be improved to lessen the effect of the wires on the circuit. The strip board used to solder the components on was not copper and therefore may be changed to copper for better conduction as well as using thicker wire with lower resistance to connect the components in the circuit. To ensure that no damage is done to the IGBT as a result of overheating a larger heat sink may be attached to the IGBT to dissipate the heat better.

8 Appendix A

8.1 Bread board circuit

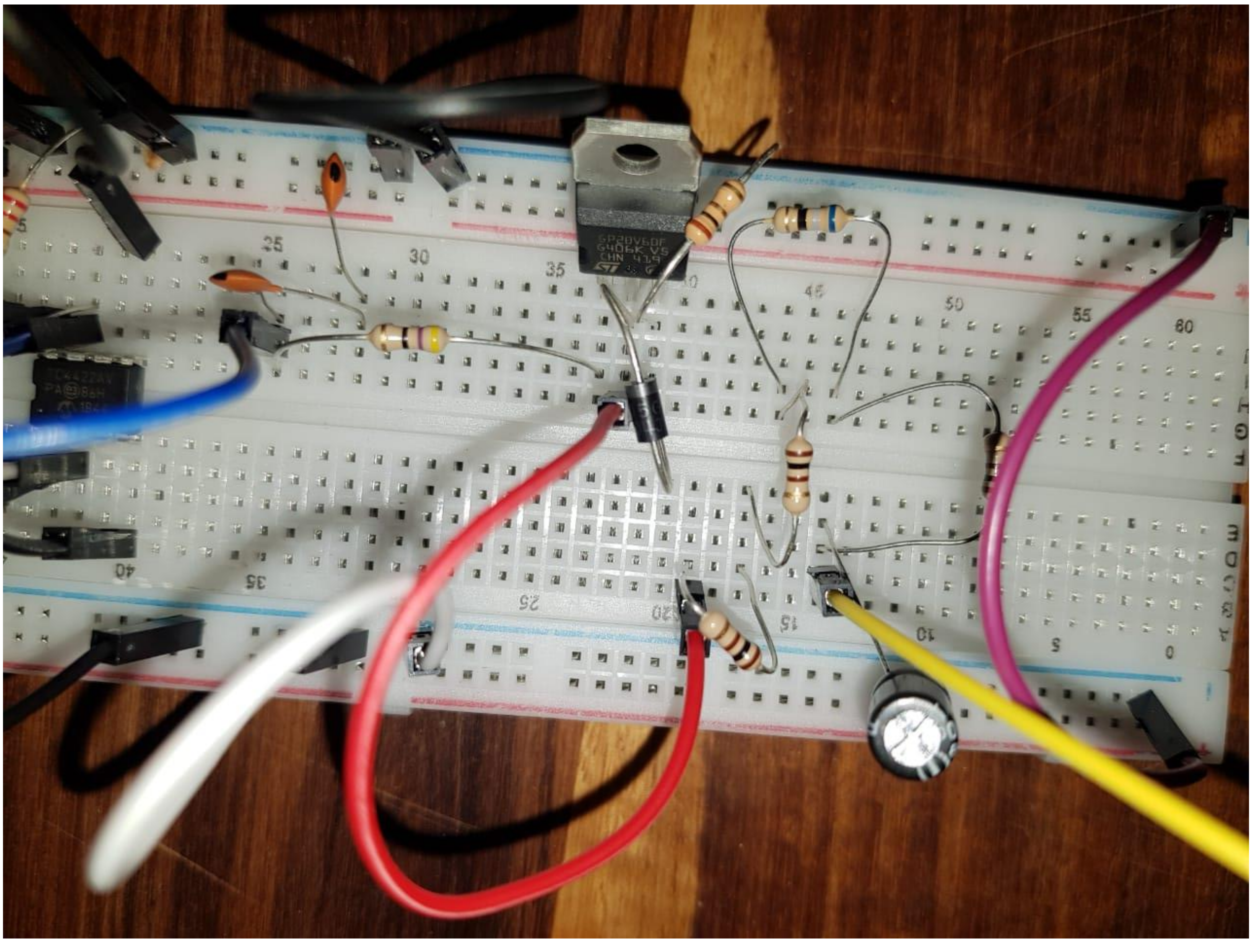

Figure 5: bread board circuit

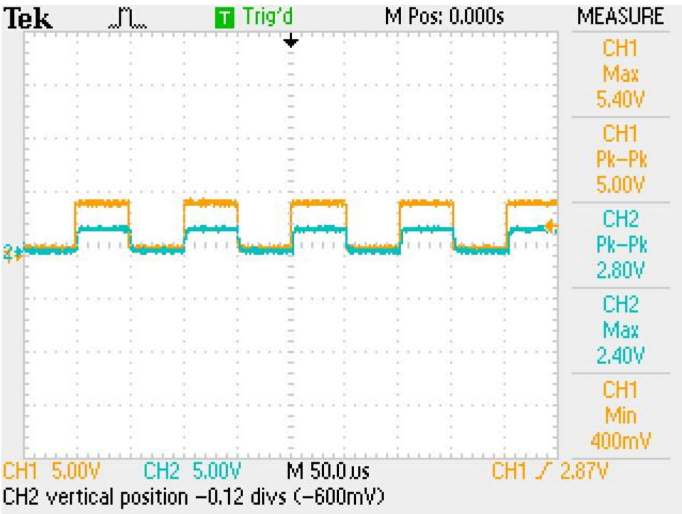

Figure 6: Bread board results, optocoupler input at 50% duty cycle

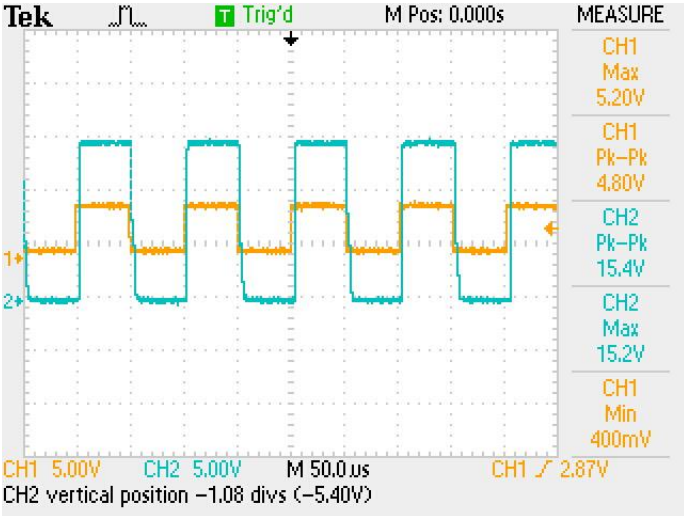

Figure 7: Bread board circuit results optocoupler output at 50% duty cycle

8.2 Strip board circuit

8.2.1 Heavy current laboratory setup

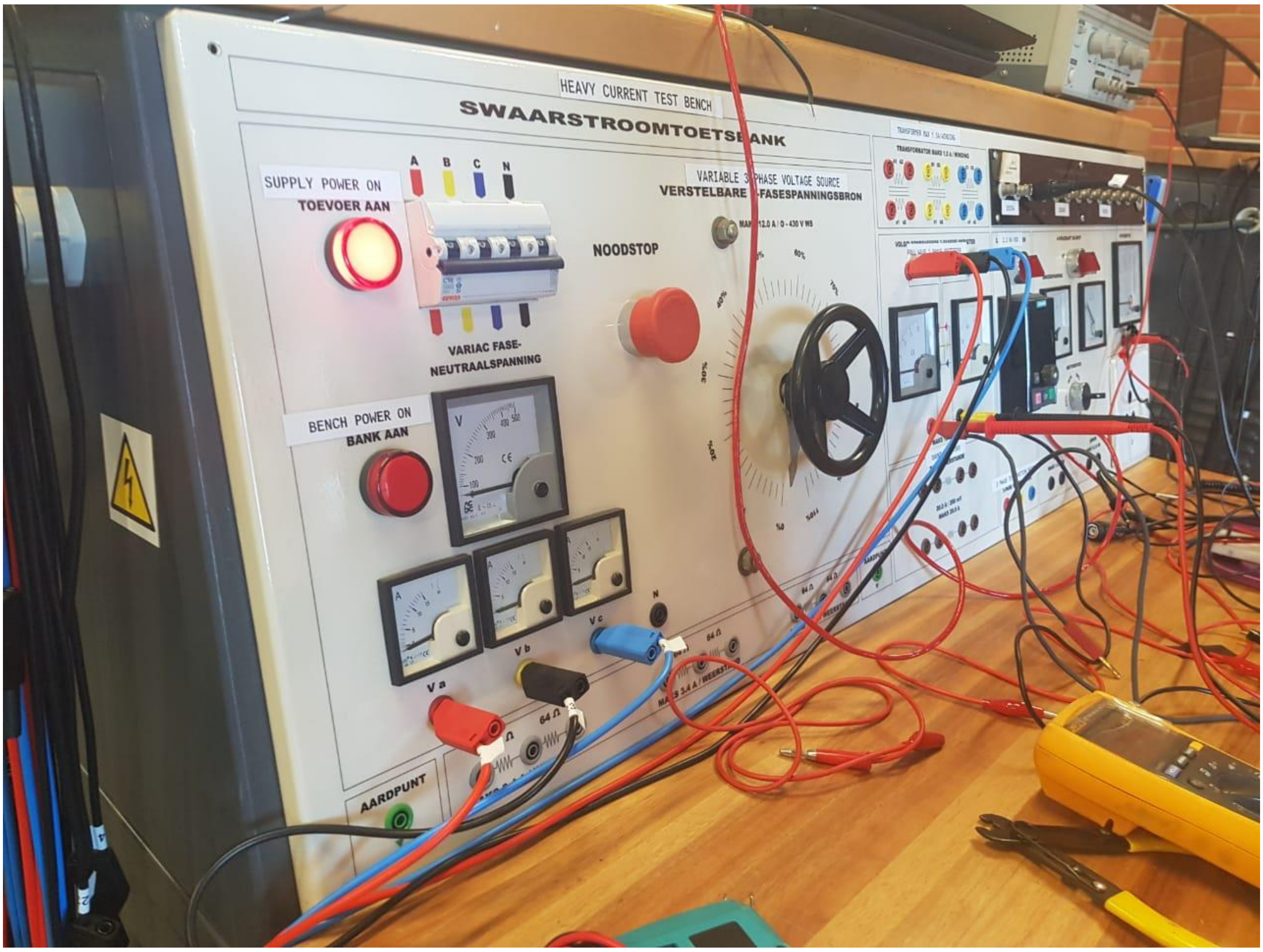

Figure 8: heavy current laboratory test bench

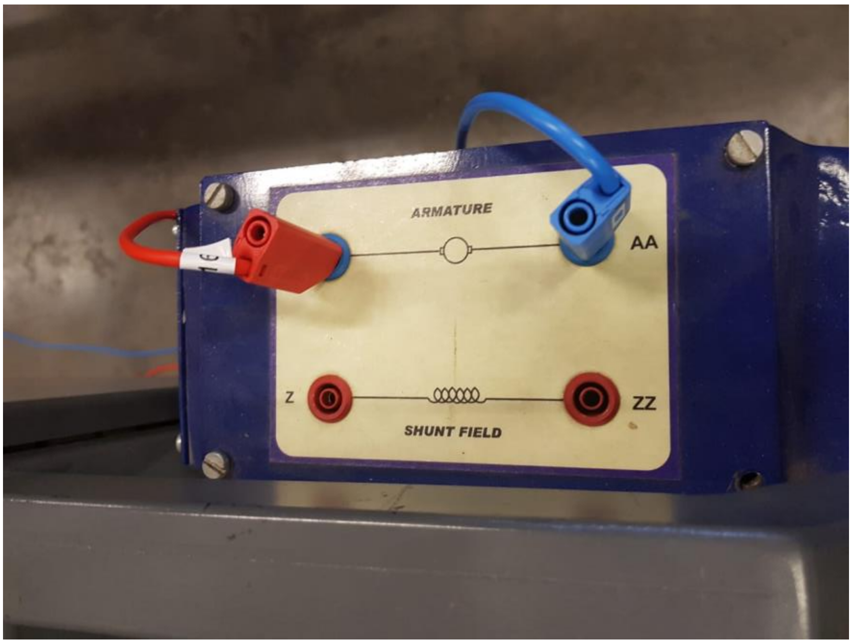

Figure 9: dc motor

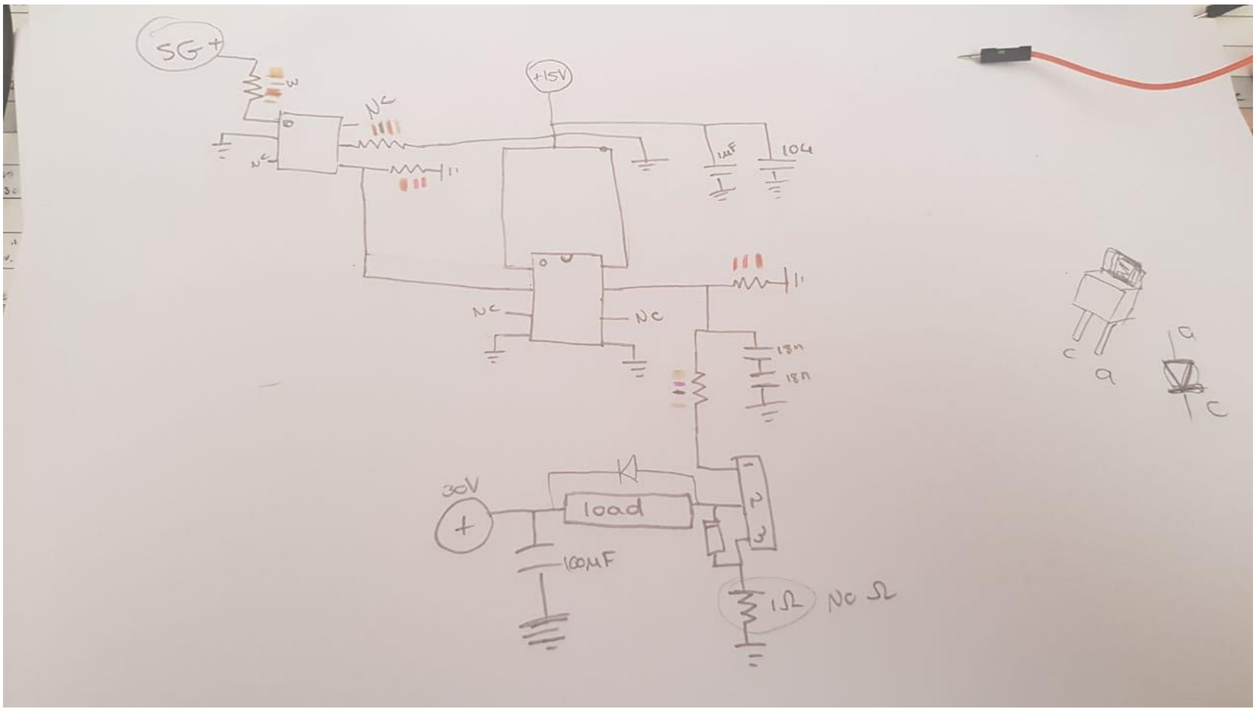

Figure 10: Circuit schematic to built the strip board.

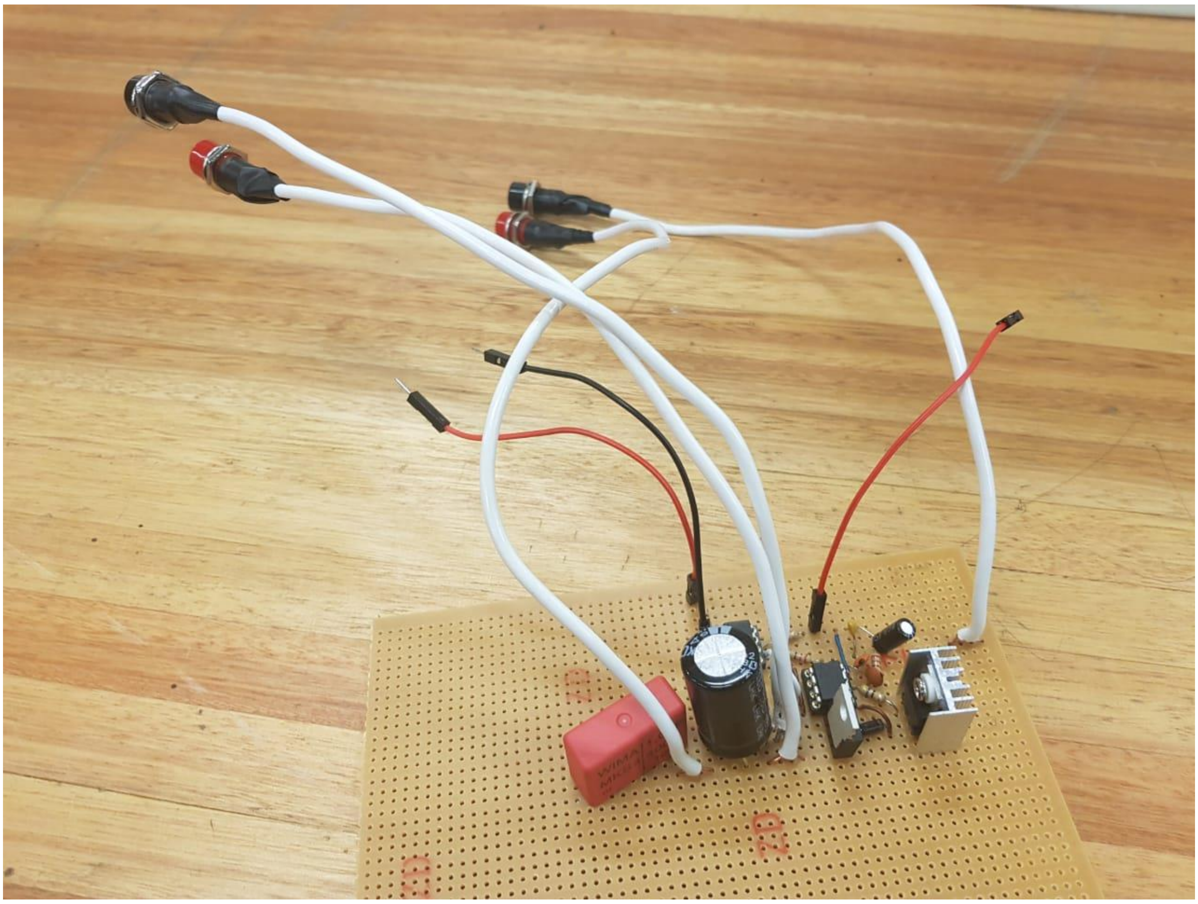

Figure 11: strip board final circuit

8.2.2 Heavy current laboratory results

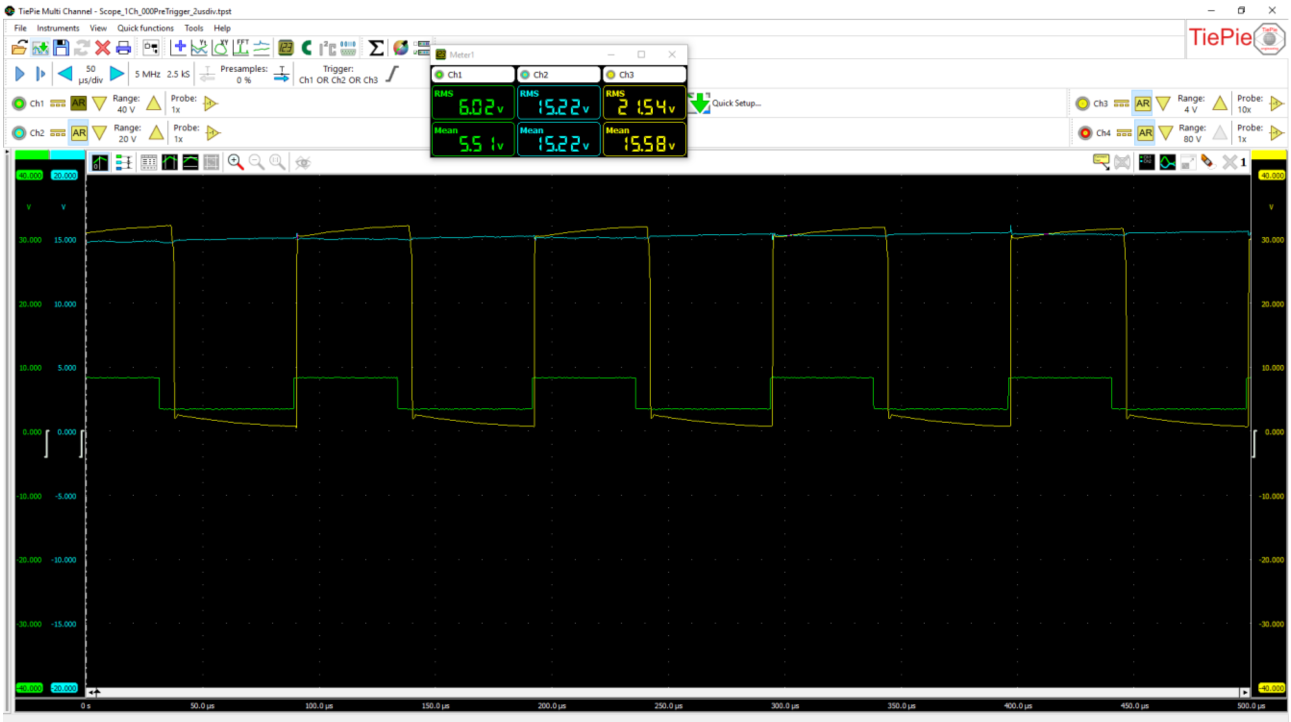

Figure 12: Strip board circuit 30V switching at 50% duty cycle, TiePie results

Figure 13: Heavy current laboratory minimum duty cycle with dc motor load

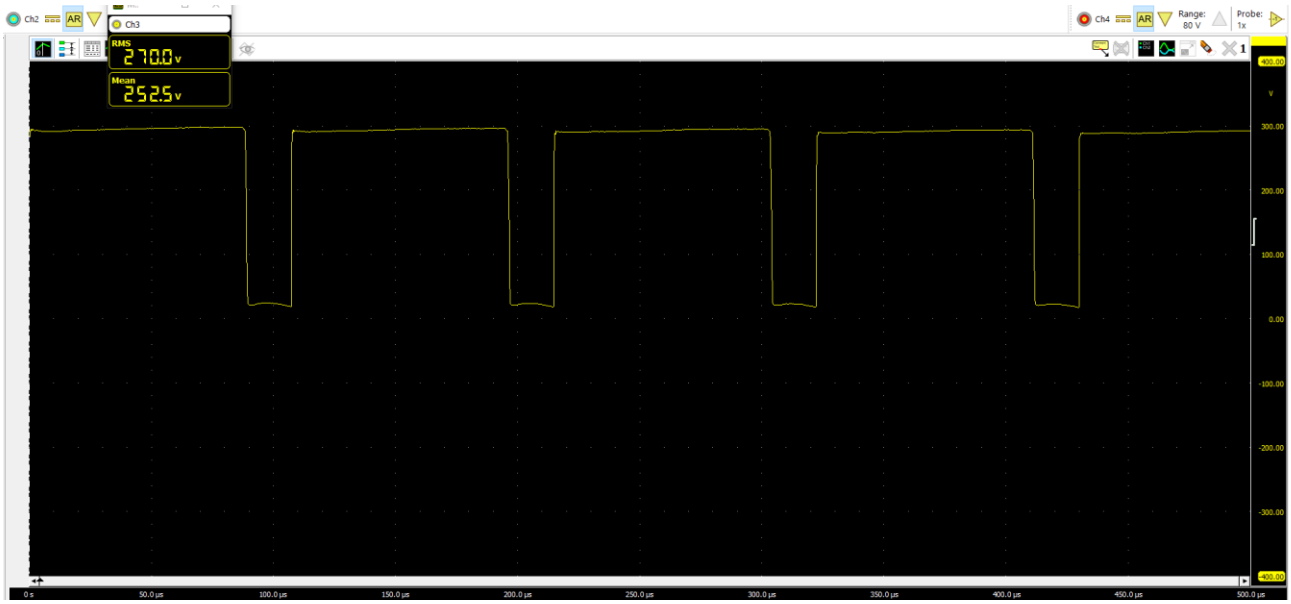

Figure 14: Heavy current laboratory maximum duty cycle with dc motor load

9 References

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