



**FAKULTI KEJURUTERAAN ELEKTRIK
UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**LAPORAN PROJEK
SARJANA MUDA**

**DESIGN AND SIMULATION OF DC-DC SWITCHING BOOST CONVERTER FOR
CURRENT RIPPLE REDUCTION**

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Bachelor of Electrical Engineering

June 2013

“I hereby declare that I have read through this report entitle “Design and Simulation of a DC-DC Switching Boost Converter For Current Ripple Reduction” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”

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**DESIGN AND SIMULATION OF DC-DC SWITCHING BOOST CONVERTER FOR
CURRENT RIPPLE REDUCTION**

NUR ANI BINTI NASRUDIN

**A report submitted in partial fulfilment of the requirements for the degree of Electrical
Engineering (Industrial Power)**

**Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

2013

I declare that this report entitle “Design and Simulation of a DC-DC Switching Boost Converter for Current Ripple Reduction” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name :

Date :

To my beloved family,

Abah

Mama

Along

Ana

Apit

Baby

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First and foremost, I would like to express my greatest gratitude to god the Almighty without his blessings I would never be able to complete this Final Year Project.

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ABSTRACT

This project is to simulate and to design a DC-DC switching boost converter for current ripple reduction. Step up converter is also referred to boost converter where its characteristic is to have a voltage at the output that is larger than the voltage at the input. The converter operates by opening and closing an electronic switch such as a power MOSFET, IGBT's or thyristors periodically. Ripple exist during the switching process in the DC-DC converter where the change or switching from the ON state and OFF state produces current ripple in the inductor. By reducing the current ripple in the DC-DC switching boost converter, the efficiency of the DC-DC switching boost converter will increase. Methods that is available for current ripple reduction includes by increasing the value of the inductor, by using soft-switching techniques and also by the adaptation of interleaving technologies. The method of varying the value of inductance to reduce the current ripple in the DC-DC boost converter is presented in this paper.

Keywords: DC-DC converter, boost converter, current ripple, reduction

ABSTRAK

Projek ini adalah bertujuan untuk mensimulasi dan mereka bentuk satu arus terus peningkatan pensuisan arus terus penukar untuk pengurangan riak arus. Meningkatkan penukar juga dirujuk kepada peningkatan penukar di mana biasanya mempunyai nilai voltan di output yang lebih besar daripada nilai voltan di input. Penukar beroperasi dengan kondisi di mana suis elektronik di buka dan di tutup secara berkala oleh suis elektronik seperti MOSFET, IGBT atau thyristor. Gelombang atau riak ini wujud dalam proses pensuisan dalam arus terus penukar di mana perubahan dari kondisi buka kepada kondisi tutup menghasilkan riak dalam pengaruh. Dengan mengurangkan riak arus dalam arus terus peningkatan pensuisan arus terus penukar, kecekapan arus terus peningkatan pensuisan arus terus penukar dapat ditingkatkan. Cara yang tersedia ada untuk mengurangkan riak arus terus termasuklah dengan menambahkan nilai pengarus, dengan menggunakan teknik penukar lembut dan juga oleh penyesuaian pengantara lembaran teknologi. Kaedah mempelbagaikan nilai aruhan untuk mengurangkan riak arus dalam arus terus peningkatan arus terus ini akan dibentangkan di dalam kertas tulis ini.

Kata kunci: Dc penukar DC, penukar peningkatan, riak arus, pengurangan

TABLE OF CONTENT

CHAPTER	TITLE	PAGE
	ABSTRAK	i
	ABSTRACT	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	TABLE OF CONTENT	v
	LIST OF TABLES	vii
	LIST OF FIGURES	viii
	LIST ABBREVIATIONS	ix
	LIST OF APPENDICES	
1	INTRODUCTION	
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 Objectives	2
	1.4 Scope of Project	3
	1.5 Chapter Summary	3
2	LITERATURE REVIEW	
	2.1 Chapter Introduction	4
	2.2 Common Method for Current Ripple Reduction	4
	2.2.1 By increasing the value of the inductance	4
	2.2.2 Frequency control	5
	2.2.3 Interleaved technologies	5

2.3	Overview of boost converter	6
2.4	Boost Converter Topology	7
2.5	Insulated-Gate Bipolar Transistor (IGBT)	11
2.6	MATLAB Simulink	12
2.7	DSP TMS320F2812	13
2.8	Chapter Summary	13
3	METHODOLOGY	
3.1	Introduction	14
3.2	Project Flow Chart	15
3.3	MATLAB Simulink	16
3.4	Code Composer Studio DSP TMS320F2812	18
	3.4.1 Flow chart using Code Composer Studio (CCS)	19
3.5	Program testing	20
3.6	Schematic Design Using Proteus 8 Professional	20
3.7	PCB Etching	22
3.8	Hardware testing	26
3.9	Chapter Summary	26
4	RESULTS	
4.1	Introduction	27
4.2	Calculation Results	28
	4.2.1 Case 1: The effect towards current ripple when the value of frequency is varied	29
	4.2.2 Case 2: The effect towards current ripple when the value of duty cycle is varied	31
4.3	Simulation Results	33
	4.3.1 Case 1: The effect towards current ripple when the value of frequency is varied	33
	4.3.2 Case 2: The effect towards current ripple	

	when the value of Duty Cycle Is Varied	40
4.4	Experimental Results	47
4.4.1	Case 1: The effect towards current ripple when the value of frequency is varies	47
4.4.2	Case 2: The effect towards current ripple when the value of duty cycle is varied	57
4.5	Chapter Summary	62
5	ANALYSIS AND DISCUSSION	
5.1	Chapter introduction	63
5.2	Analysis	63
5.2.1	Analysis on the effect towards the current ripple when varying the value of frequency	63
5.2.2	Analysis on the effect towards the current ripple when varying the value of duty cycle	67
5.3	Chapter Summary	70
6	CONCLUSION AND RECOMMENDATION	
6.1	Chapter introduction	71
6.2	Conclusion	71
6.3	Recommendation	72
	REFERENCES	73
	APPENDICES	76

LIST OF TABLES

4.1	Parameters of a boost circuit (frequency is varied)	29
4.2	Current ripple, Δi_L when the value of frequency is varied	30
4.3	Parameters of a boost circuit (duty cycle is varied)	31
4.4	Current ripple, Δi_L when the value of duty cycle is varied	32
5.1	Δi_L (A) for calculation, simulation and experimental when varying the value of frequency	64
5.2	Varying the value of duty cycle	68

LIST OF FIGURES

2.1	Boost converter	6
2.2	Equivalent circuit for switch closed	7
2.3	Equivalent circuit for switch open	8
2.4	Inductor current in continuous current mode	9
2.5	Inductor current discontinuous current mode	10
2.6	IGBT device symbol	11
2.7	Matlab simulink	12
2.8	DSP TMS 320F 2812	13
3.1	Project progress flow chart	15
3.2	Matlab Simulink	16
3.3	Model of a boost circuit	17
3.4	Creating a project	18
3.5	Progress flow chart for Code composer studio (CCS)	19
3.6	Proteus 8 professional	20
3.7	Isis schematic capture	21
3.8	ARES PCB layout	22
3.9	Positive acting PCB	23
3.10	Developing the PCB	23
3.11	Etching the PCB	24
3.12	(a) Drilling process (b) Boost converter box	25
3.13	Hardware testing	26
4.1	DC-DC boost circuit	28
4.2	Graph of pulse with a frequency, f of 10 kHz and the current ripple, Δi_L	

	at the inductor	33
4.3	Graph of pulse with a frequency, f of 20 kHz and the current ripple, Δi_L at the inductor	34
4.4	Graph of pulse with a frequency, f of 30 kHz and the current ripple, Δi_L at the inductor	35
4.5	Graph of pulse with a frequency, f of 40 kHz and the current ripple, Δi_L at the inductor	36
4.6	Graph of pulse with a frequency, f of 50 kHz and the current ripple, Δi_L at the inductor	36
4.7	Graph of pulse with a frequency, f of 60 kHz and the current ripple, Δi_L at the inductor	37
4.8	Graph of pulse with a frequency, f of 70 kHz and the current ripple, Δi_L at the inductor	38
4.9	Graph of pulse with a frequency, f of 80 kHz and the current ripple, Δi_L at the inductor	39
4.10	Graph of pulse with a duty cycle, D of 10% and the current ripple, Δi_L at the inductor	40
4.1	Graph of pulse with a duty cycle, D of 20% and the current ripple, Δi_L at the inductor	41
4.12	Graph of pulse with a duty cycle, D of 30% and the current ripple, Δi_L at the inductor	41
4.13	Graph of pulse with a duty cycle, D of 40% and the current ripple, Δi_L at the inductor	42
4.14	Graph of pulse with a duty cycle, D of 50% and the current ripple, Δi_L at the inductor	43
4.15	Graph of pulse with a duty cycle, D of 60% and the current ripple, Δi_L at the inductor	44
4.16	Graph of pulse with a duty cycle, D of 70% and the current ripple, Δi_L at the inductor	44

4.17	Graph of pulse with a duty cycle, D of 80% and the current ripple, Δi_L at the inductor	45
4.18	Graph of pulse with a duty cycle, D of 90% and the current ripple, Δi_L at the inductor	46
4.19	Setup of the boost circuit	47
4.20	Output window	48
4.21	Relationship of T1PR command and T1CMPR command	49
4.22	Current ripple	50
4.23	Pulse with a frequency, f of 10 kHz and the current ripple, i_L at the inductor	51
4.24	Pulse with a frequency, f of 20 kHz and the current ripple, i_L at the inductor	52
4.25	Pulse with a frequency, f of 30 kHz and the current ripple, i_L at the inductor	53
4.26	Pulse with a frequency, f of 40 kHz and the current ripple, i_L at the inductor	54
4.27	Pulse with a frequency, f of 50 kHz and the current ripple, i_L at the inductor	55
4.28	Pulse with a frequency, f of 60 kHz and the current ripple, i_L at the inductor	56
4.29	Pulse with a frequency, f of 70 kHz and the current ripple, i_L at the inductor	56
4.30	Pulse with a duty cycle, D of 10% and the current ripple, i_L at the Inductor	57
4.31	Pulse with a duty cycle, D of 20% and the current ripple, i_L at the Inductor	58
4.32	Pulse with a duty cycle, D of 30% and the current ripple, i_L at the Inductor	58
4.33	Pulse with a duty cycle, D of 40% and the current ripple, i_L at the Inductor	59
4.34	Pulse with a duty cycle, D of 50% and the current ripple, i_L at the	

	Inductor	60
4.35	Pulse with a duty cycle, D of 60% and the current ripple, i_L at the Inductor	60
4.36	Pulse with a duty cycle, D of 70% and the current ripple, i_L at the Inductor	61
4.37	Pulse with a duty cycle, D of 80% and the current ripple, i_L at the Inductor	61
5.1	Obtaining the result from graph	65
5.2	Graph of current ripple reduction by varying the value of frequency	67
5.3	Graph of performance of the current ripple by varying the value of duty cycle, D	69
5.4	Graph of duty cycle, D versus output voltage, V_o	70

LIST OF ABBREVIATIONS

AC	-	Alternating Current
DC	-	Direct Current
SEPIC	-	Single Inductance Converter
IGBT	-	Insulated Gate Bipolar Transistor
DSP	-	Digital Signal Processing
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
CCM	-	Continuous Current Mode
DCM	-	Discontinuous Current Mode
L_{min}	-	Minimum Inductance
V	-	Voltage
V_s	-	Voltage source
D	-	Duty cycle
f	-	Frequency
R	-	Resistance
CCS	-	Code Composer Studio
PCB	-	Printed Circuit Board

LIST OF APPENDICES

PAGES	TITLE	
A	Gantt Chart	76
B	Boost converter layout	77
C	Boost converter schematic	78
D	Input/ output connector and signal description	79
E	PWM coding using DSP TMS320F2812	80
F	Current transducer LA 100-P	84
G	Experimental Setup	85
H	Turnitin	86

CHAPTER 1

INTRODUCTION

1.1 Background

As the world evolves to an era where the parameters of a device or component in terms of size, weight, and performance of technologies are concerned, the power electronic industry escalates to rise. With the advantage of having a compact system with low losses, high efficiency, availability, and reliability, new switching circuit topologies, high speed of response, power electronic operates with digital or analog electronic control circuits with the conjunction of semiconductor device circuit. Power electronics is the combination of three important elements which are power, electronics and control. Power electronic device allows the conversion of voltage and current to a specified output without the need of a transformer. There are six types of power electronic circuits which includes diode rectifier, AC-DC converters (controlled rectifier), AC-AC converters (AC voltage controller), DC-DC converters (DC choppers or switching regulator), and static switches. Each type can be divided into a broader range of implementation depending on its function. In line with the topic of the project, the scope is directly focused to the DC-DC converter. Based on the industrial demand, fixed voltage DC source are required to be converted into a DC voltage source that is variable while maintaining the system to have acceleration control that is smooth, high efficiency and also to have fast dynamic response. The types of converters can be divided to buck converter (also known as the step down converter), boost converter (as step up converter), buck-boost converter, cuk converter, single inductance converter (SEPIC) and also interleaved converter (multiphasing). The boost converter or also known as the step up converter is a switching converter that uses semiconductor devices such as diode, thyristor, IGBT and transistor as switches that is periodically open and closes.

The boost converter has the characteristic of having an output voltage higher than the input voltage. A problem exists in the converter as it is a switching converter. The interrelation between the ON and OFF state of the semiconductor devices as switches (diode, thyristor, and transistor) causes current ripple at the inductor. This project consist of the pulse generated from a program from the digital signal processing (DSP), a gate drive to drive the IGBT of the boost circuit, and the boost circuit itself.

1.2 Problem Statement

Current ripple reduction in a DC-DC boost converter is crucial in order to cater the escalating demand of electronic devices that faces challenges in designing in terms of battery life, power dissipation and many more. Ripple exist during the switching process in the DC-DC converter. The change or switching from the ON state and OFF state produces current ripple in the inductor. The converter will suffer from efficiency reduction as the higher the switching frequency, the more losses it would have. By reducing the current ripple of the DC-DC boost converter; it would overcome the problem faced as the DC-DC converter will improve its efficiency, dynamic response and provides smooth acceleration control. Therefore, this project simulates and designs the DC-DC switching boost converter for current ripple reduction.

1.2 Objectives

The objectives of the project includes

1. To design and to obtain the correct parameters of a DC-DC switching boost converter for current ripple reduction
2. To understand the effect of switching to current ripple
3. To model, simulate and analyze the DC-DC switching boost converter for current reduction designed using MATLAB software
4. To develop a hardware prototype of the DC-DC converter

1.4 Scope of Project

The scope is limited to simulate, design and to analyze an open loop DC-DC switching boost converter with a continuous current mode operation. MATLAB is used to simulate the DC-DC switching boost converter in terms of the relationship of related parameters that would affect the current ripple in the DC-DC switching boost converter which includes by varying the value of frequency and by varying the value of duty cycle. The pulse width for the switching controller is generated by using programming developed by DSP TMS320F2812. And the hardware implementation of the DC-DC switching boost converter is based on the simulation done in the MATLAB software.

1.5 Chapter summary

This chapter states the background or motivation of this project, the problem statement, the objectives that are identified that needs to be accomplish throughout the project and the scope that is to limit the research area and what to focus on. The next chapter which is chapter 2 will discuss regarding the literature to show a brief overview regarding the projec

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter describes the general overview of components and criteria's or software involved in the process of developing this project. The literature review part is to provide a general overview regarding the DC-DC boost converter. It is also to supports theoretically regarding the implementation of this project.

2.2 Common Methods for Current Ripple Reduction

2.2.1 By increasing the value of the inductance

As stated in [4] the value of the inductance used in a converter holds a huge significance to the existence of current ripple in a circuit thus affecting the efficiency or performance of the circuit. [4] States that if the load current in the converter increases, the inductance reduces as it is forced towards saturation. In [11] states that the higher the value of the inductor, the slower the start up time. [11] Describes that the inductance that is to be used in the circuit must be based on the maximum current ripple that is allowed during the minimum duty cycle, D at the maximum input voltage.

2.2.2 Frequency control

Micro-technology forces manufacturers to produce miniature products. The voltage needed for a microprocessor requires low voltage but increasing current rating. With little amount of inductance in the circuit, large current ripple will result during the switching process. Research in [8] states that the peak to peak current and conduction mode of the converter will be affected by the changes of switches.

2.2.3 Interleaved technologies

In an interleaved boost converter, the phase number, the size of inductance, the amplitude of switching frequency, the input voltage, the desired output voltage and the load that is connected to the circuit effects the current ripple in the circuit of the DC-DC boost converter. Based on research [7] that uses the method of interleaved DC-DC boost converter, the research that is conducted results that the inappropriate usage of components (inductors, input voltage source and MOSFET) would cause effect to the input current amplitude during the interval of the switching process, the current in the inductor is not equal to zero as resonance exist in the circuit. Research [7] includes optimal control, components selection and input filter as techniques to reduce the input current ripple. For optimal control high consideration are given upon selecting optimal base angle and phase shift angle. The input current ripple will be minimized as the switching frequency increases but the downside is that it would produce high power dissipation. The second technique introduced in [7] includes components selections (MOSFET and inductance). High inductance causes smaller current ripple but it would impact the speed response, power density and also efficiency. [7] States that other parameters such as the temperature rise, saturation current and magnetic core material characteristic should be taken into consideration. The third technique introduced by [7] is the input filter. To minimize the input current ripple, a series of damped filter (output impedance of the input filter must be less than input impedance of the converter) is attached to the circuit thus causing it to affect its stability to be better.

2.3 Overview of Boost Converter

DC-DC converters are invented to cater the need of industrial application as the demand of a variable voltage source is needed. DC-DC boost converter or also known as step-up converters are converters where the output voltage is higher than the voltage at its input. It operates by periodically opening and closing an electronic switch. The information and details on the DC-DC switching boost convert includes the discussion on its mode of operation, the Figure 2.1: illustrates the basic structure of a DC-DC boost converter.

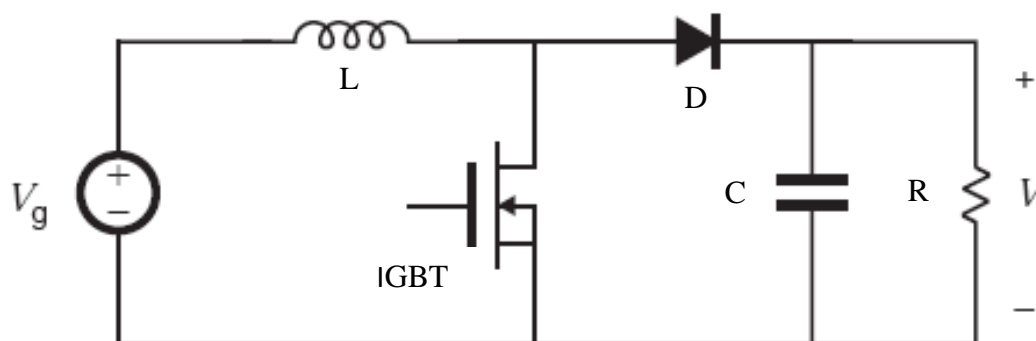


Figure 2.1: Boost converter [4]

The basic component of a DC-DC boost converter is a voltage source, inductor, diode, capacitor, resistor and a switching device which can be any semiconductor device such as MOSFET, IGBT or thyristor as can be seen in figure 2.1 above. Based on research conducted by previous researchers, current ripple can be reduced by several methods which includes by increasing the value of inductance, through frequency control, by varying the value of inductance and by using interleaving technologies. In this project only two methods are implemented which is through varying the value of frequency and by varying the value of its duty cycle.

2.4 Boost Converter Topology

There are two states in the operation of the boost circuit which is the ON-state and the OFF-state. The ON and OFF state refers to the switching of an electronic switch that operates by periodically opens or closes the switch. Figure 2.2 below shows an equivalent circuit of a boost converter when the switch is closed.

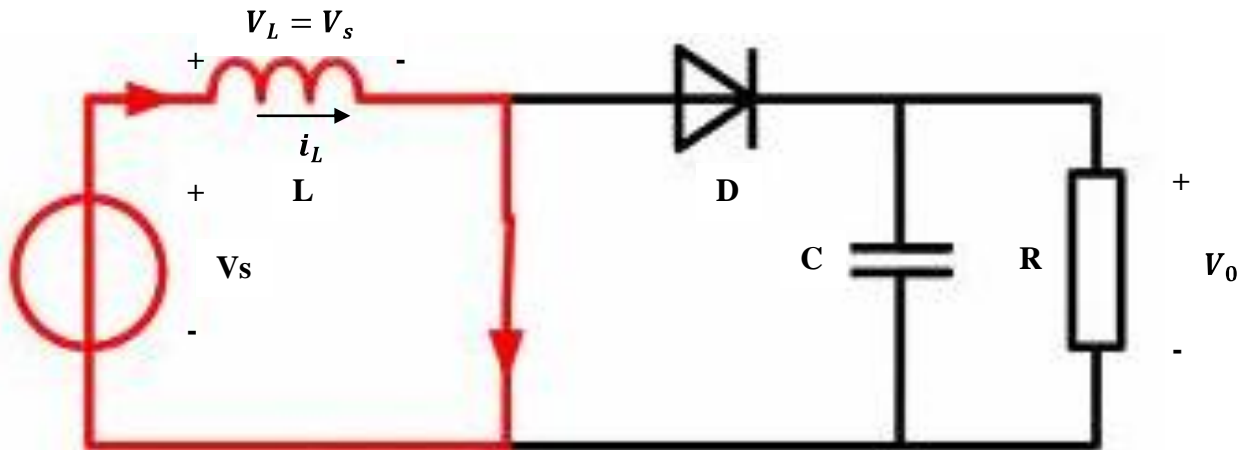


Figure 2.2: Equivalent circuit for switch closed [2]

As illustrated in figure 2.2 above, the circuit shows where the voltage flows (in red) when the switch is closed. As can be seen, when the switch is closed, the diode is reverse biased. The current that flows in the inductor causes the inductor to charge linearly. The change of current in the inductor can be computed from equation Eq. (2.1) [2]

$$(\Delta i_L)_{closed} = \frac{V_s D T}{L} \quad (2-1)$$

Where D is duty cycle, the switching period is T, and L the inductance. Based on Eq. 2-1, the illustration of the process where the current increases linearly (charged) as the switch is turned on can be seen in figure 2.4 below. In figure 2.3 below is the equivalent circuit when the switch is open.

As can be seen in figure 2.3, the voltage flows through the diode (in red) as the diode is forward biased for the inductor current to flow through [2]. The current in the inductor would decrease linearly (discharged) as can be seen in figure 2.3 below.

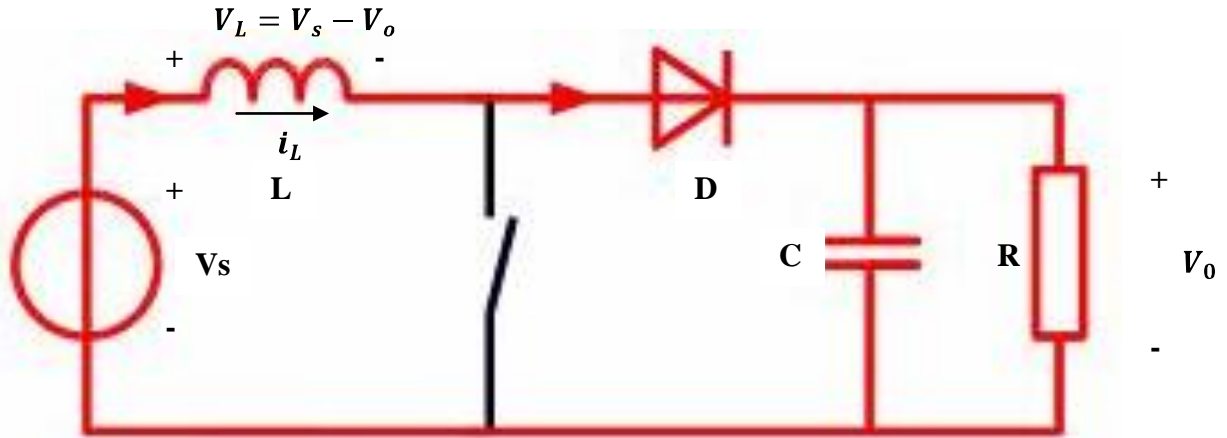


Figure 2.3 Equivalent circuit for switch open [2]

The change of current in the inductor for switch open can be computed from equation Eq. (2.2), the current ripple, Δ_{iL} and the output voltage, V_o can be computed as in Eq. (2.3)

$$(\Delta_{iL})_{open} = \frac{(V_s - V_o)(1 - D)T}{L} \quad (2-2)$$

$$V_o = \frac{V_s}{1 - D} \quad (2-3)$$

The boost converter has two operation which include continuous-current operation (CCM) and discontinuous current operation (DCM). Continuous current is referred to a state in the inductor where the current that flows remains positive (above zero) throughout the entire switching period [2]. Boost converters using a current continuous mode are usually used as the front-end converters active input current shaping [13].

Figure 2.4 below shows a CCM whereby the current is above zero (positive). The inductor used for the simulation is higher than the minimum inductance required.

To obtain a continuous current operation (CCM) the value of the inductor used must be higher than the minimum inductance, L_{min} . The conduction mode depends on the value of duty cycle, D load, R and frequency, f set. The equation is as Eq. (2.4);

$$L_{min} = \frac{(D(1 - D))^2 R}{2f} \quad (2-4)$$

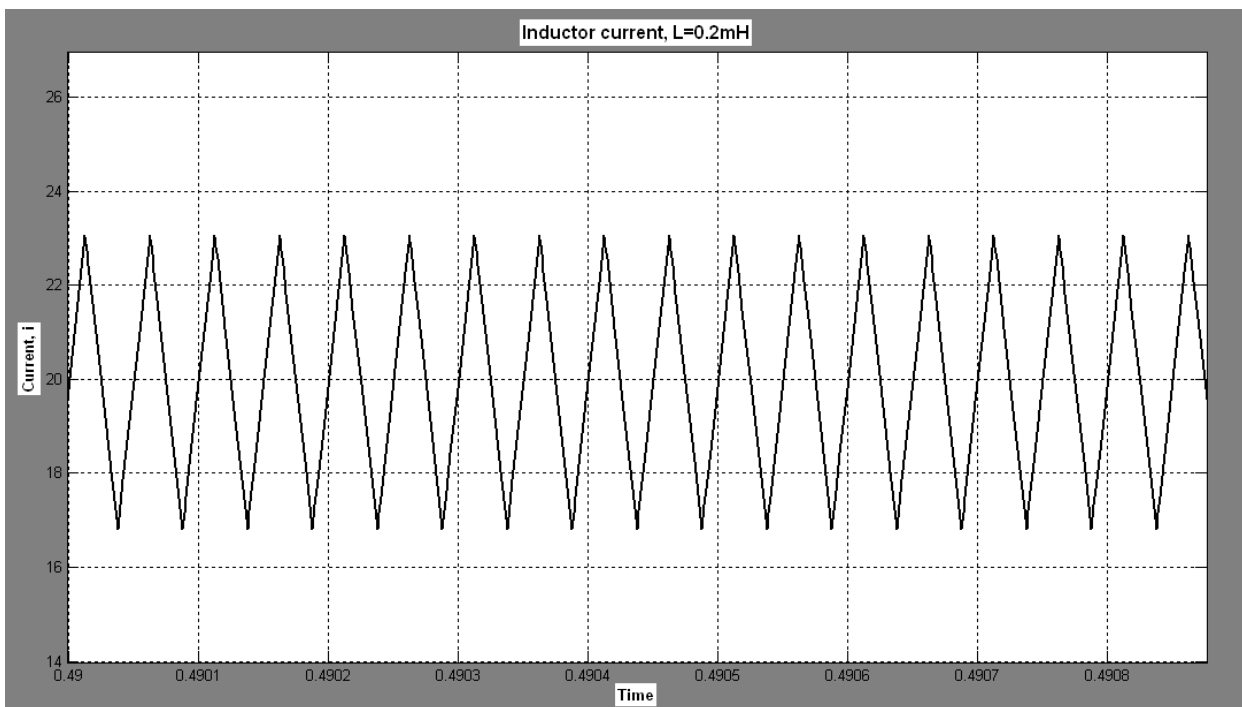


Figure 2.4 Inductor current in continuous current mode

As for the discontinuous current mode (DCM), it is usually desired for control reasons in cases that include a regulated output. The discontinuous current mode, DCM can be obtained when the minimum inductor selected is lower than the minimum inductor as in Eq. (2.1) above.

Based on research conducted by [12], in a discontinuous current mode, the maximum current or peak value at the inductor becomes high while the rating of the switching device becomes large. A discontinuous current mode is shown in figure 2.5 below.

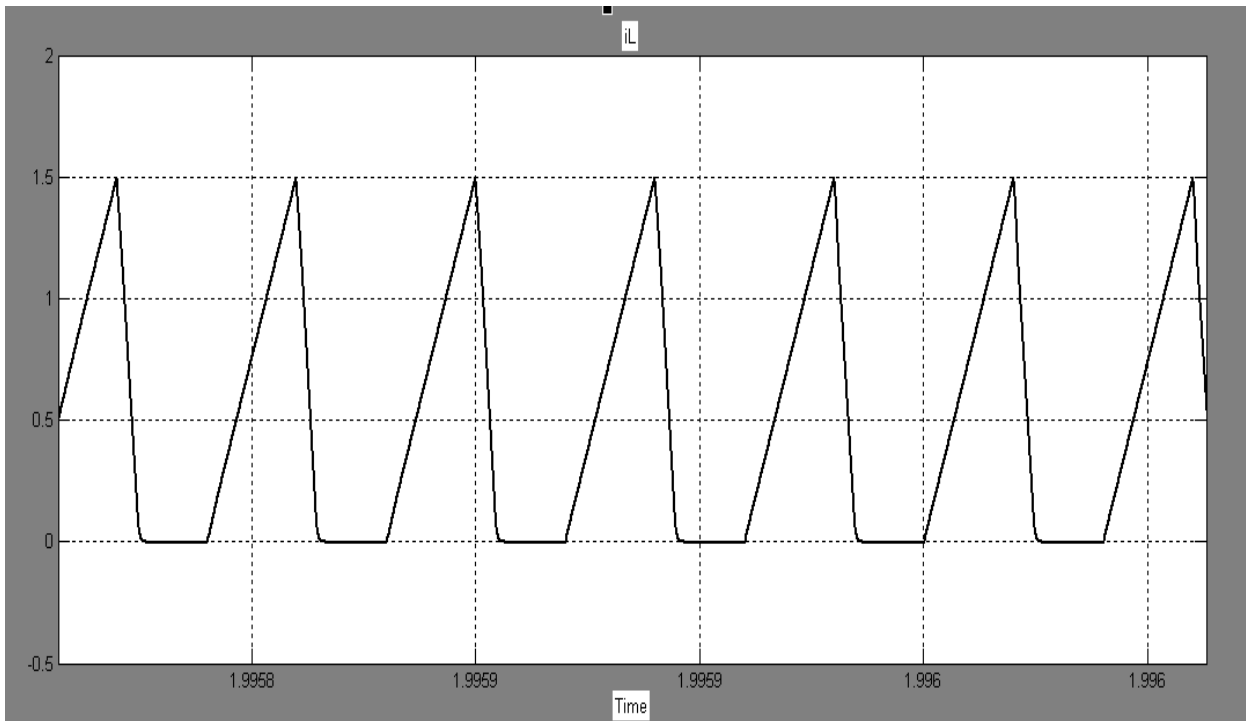


Figure 2.5: Inductor current discontinuous current mode

An inductor, L which is less than the minimum inductor from (Eq. 2.4) above is used in the simulation using MATLAB Simulink. As can be seen in figure 2.5 above, the result or behavior of an inductor current mode the inductor current is positive when the switch is off. The current at the inductor decreases when the current starts to discharge during the time off period until the inductor current reaches to zero. The inductor current won't go below zero as it has been prevented by the diode. When the switch is on, the current will continue to recharge [2]. In this project, only a continuous current mode is considered as the value of inductor is set to be above the value of the minimum inductance required for it to be in a continuous current mode. For the boost converter to be in continuous or discontinuous mode, it is depending on the parameters that are selected.

2.5 Insulated-Gate Bipolar Transistor (IGBT)

The IGBT or insulated-gate bipolar transistor is a type of power semiconductor that has three terminals which is usually used for the combination of high efficiency and fast switching. The IGBT can be controlled easily current controlled devices such as thyristors or BJT. The terminal includes the collector, gate and emitter as can be shown in figure 2.6: IGBT device symbol below. The IGBT combines the gate drive characteristic of the MOSFET with the high-current and low saturation capability of bipolar transistors by combining an isolated gate FET (Field effect transistor for the control input and a bipolar power transistor as a switch in a single device [16]. The IGBT has is high in reliability and high switching frequency which requires simple drive circuits [16]. A gate drive circuit is used to step up the output pulse from the DSP (pulse signal) up to 15V in order for the IGBT to receive the pulse signal and is able to perform its switching characteristic. The life period and the durable intensity of the IGBT is directly related to the IGBT gate drive as it brings impact to the on-state voltage drop, switching time, switching losses and other parameters[16]. In this project, the switching signal is from the program developed in the code composer studio (CCS) of the digital signal processing TMS320F2812.

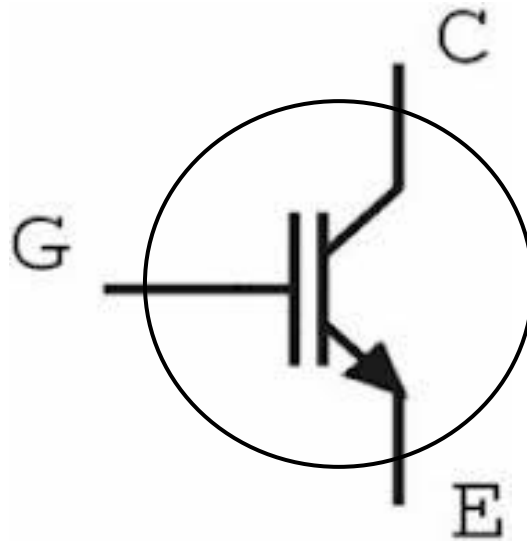


Figure 2.6: IGBT device symbol [2]

2.6 MATLAB Simulink

The simulation software used in this project is MATLAB simulink by MathWorks as shown in figure 2.7 below. MATLAB Simulink is used for the boost converter simulation in order to model and to analyze the DC-DC boost converter for current ripple reduction. Based on [11], the software allows user to analyze and to obtain results for further investigation, as it helps to identify trends and uncertainty as well as to test hypothesis. The boost converter circuit is drawn in the work place and is simulated. The components are varied according to the specification that is set which includes by varying the frequency and by varying the duty cycle. The results are obtained by tapping a scope to wherever output desired.



Figure 2.7: Matlab simulink [10]

2.7 DSP TMS320F2812

DSP or digital signal processing is used in the hardware part for the development of the switching controller for the IGBT used in the DC-DC boost converter as shown in figure 2.8 below. The digital signal processing or DSP is one type of microprocessor with real time data processing [14]. The programming code will be developed in the Code Composer Studio (CCS). The 32-bit DSP controller speed is up to 150MHz peripherals which includes 12-bit analog to digital converter with a conversion speed up to 80nSec, 32x32-bit MAC (multiplication and accumulation), 32-bit timers and real-time code debugging capability brings advantage of digital control and allows implementation of more functional control schemes, and the capability of fast designing and modification desired [15].



Figure 2.8: DSP TMS 320F 2812 [14]

2.8 Chapter Summary

In summary, chapter 2 includes the general overview on parameters, criteria's or components involved throughout the project. The literature review done is based on research and findings of previous researchers as cited above.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Chapter 3 discusses the methodology used in this project. The methodology of this project can be divided into four stages which include stage 1 which are setting objectives, information gathering, and case study on related materials which involves DC-DC converters, boost converter, and current ripple due to the switching phenomena. Stage 2 of the project is to design and model a DC-DC switching boost converter for current ripple reduction using MATLAB simulink software. The analysis includes the change of duty cycle, and the change of frequency. In stage 3, the hardware implementation of the DC-DC switching boost converter is developed. The design can be divided into two parts which is part A: Development of switching (pulse) using DSP TMS 320F 2812 and part B: System integration, testing and modification of the circuit of DC-DC switching boost converter for current ripple reduction. The last stage is stage 4 which is the result and analysis of calculation, simulation and hardware are taken into consideration. The gantt chart of the project is attached in Appendix A. The methods are compared to see either the implementation of hardware fulfils the result obtained from simulation and calculation.

3.2 Project flow chart

Figure 3.1 below is the flow chart of the project (DC-DC switching boost converter). As can be seen in the figure below, the project is split into three main stages before all the results is analyzed and compared in last stage which is to troubleshoot and analyze the results

obtained. The parameters in the flowchart are discussed in detail regarding the steps further in this chapter.

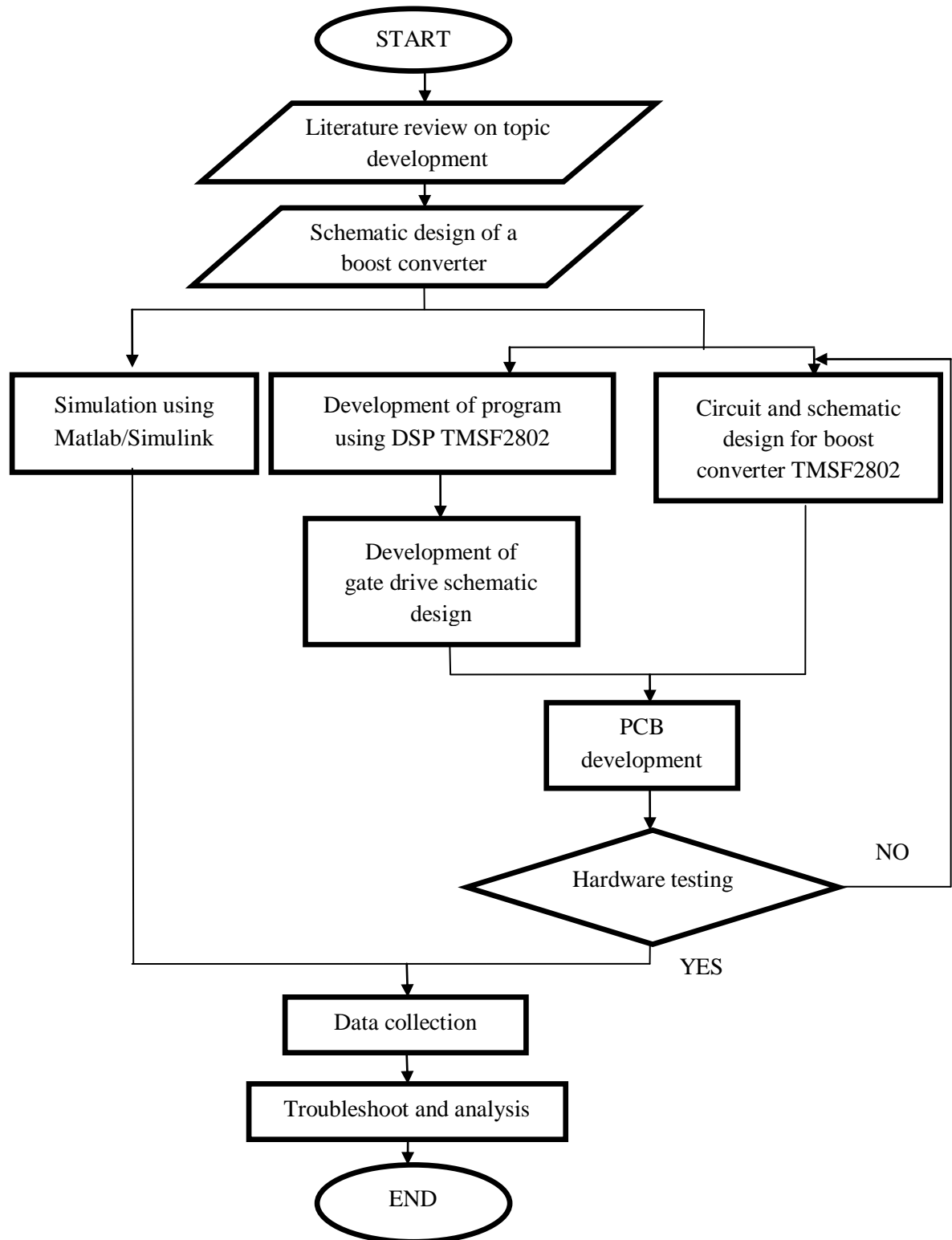


Figure 3.1: Project progress flow chart

3.3 MATLAB Simulink

For simulation base, the simulation of the boost converter is done in the MATLAB simulink as shown in figure 3.2 below. The components to build the boost circuit is obtain by keyying in powerlib at the command window. Once the circuit is saved and build, if errors or warnings appear at the command window, the errors and commands are solved according to the system's recommendation.

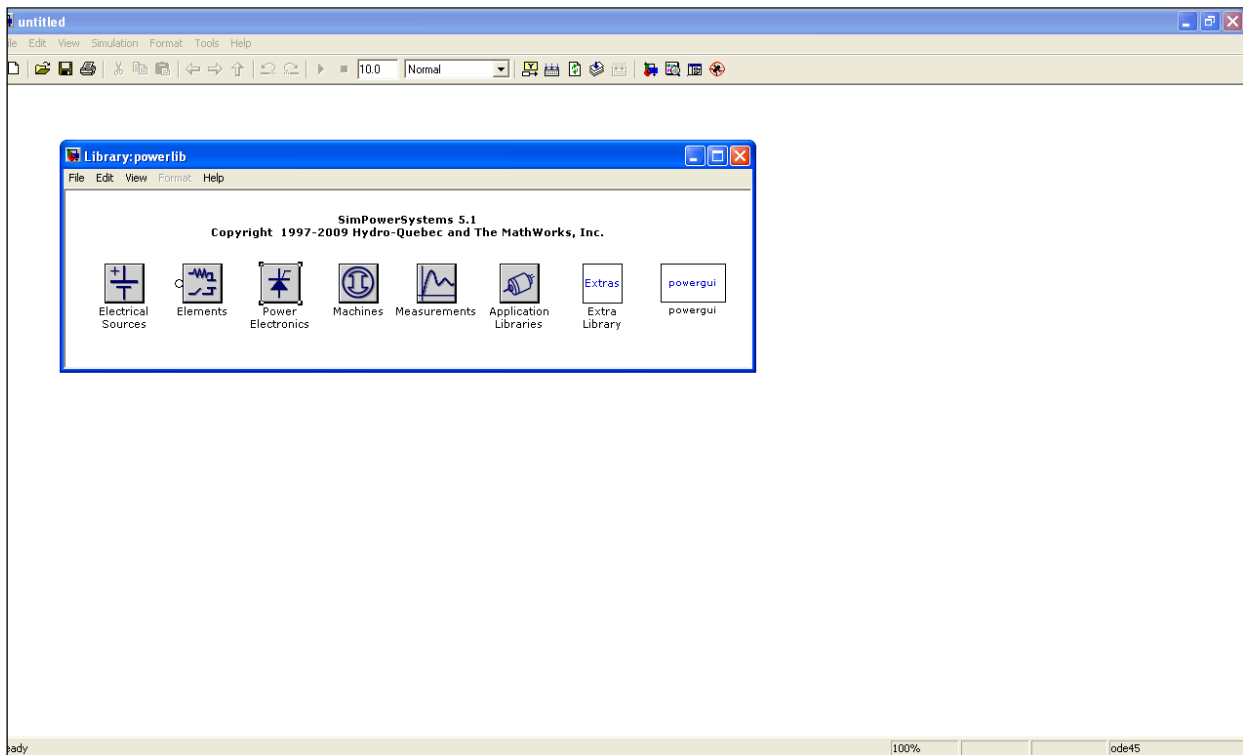


Figure 3.2 Matlab Simulink

The boost circuit is drawn by adding components from the library to the and the output can be seen at the scope model as in figure 3.3 on the next page. The output voltage is checked first to determine either does the boost circuit created steps up the input voltage accordingly or not. The output voltage of a boost converter shows that from an input voltage of 12V, with a duty cycle of 50%, the output voltage is 24V which is proven theoretically from calculation.

From Eq. (2.3);

$$V_o = \frac{V_s}{1 - D}$$

(2.3)

$$V_o = \frac{12}{1 - 0.5} = 24V$$

At the boost circuit's pulse generator, two cases are identified whereby the first case is to vary the frequency from 10kHz to 80kHz to determine the effect of varying the value of frequency towards the current ripple at the inductor and the second case is by varying the value of the duty cycle to see the effect of the current ripple towards the change of duty cycle. The graph result obtained from the scope is saved by opening the simplot function at the command video and is edited according to what is desired. The data's are recorded and analyzed.

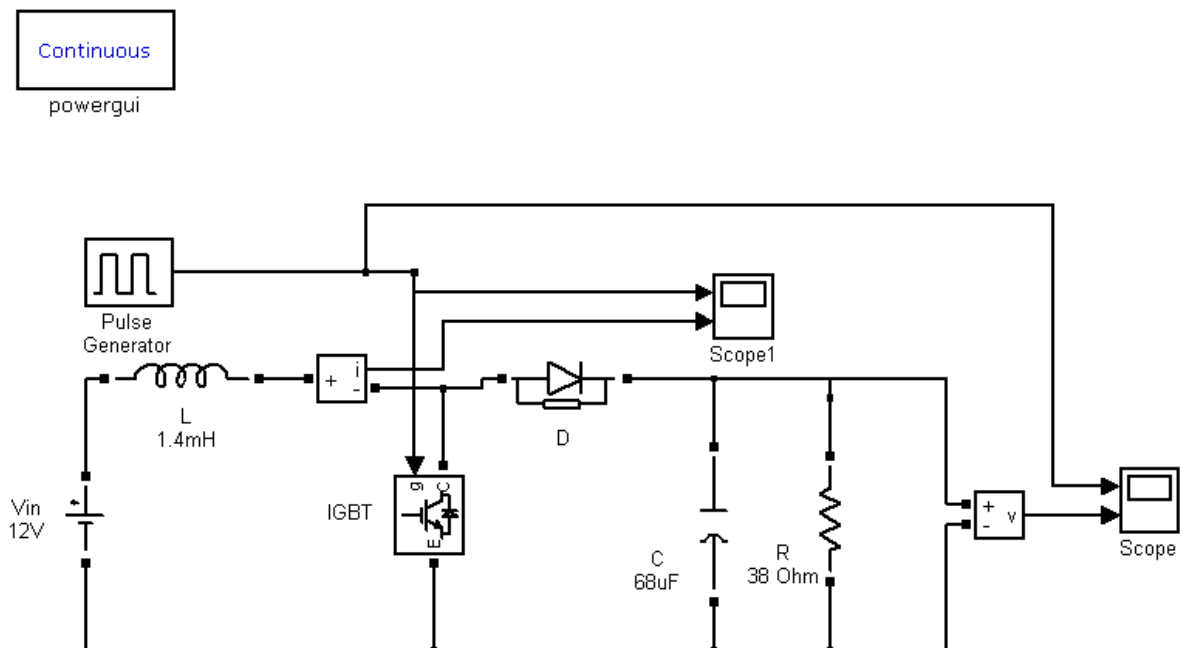


Figure 3.3: Model of a boost circuit [2]

3.4 Code composer studio DSP TMS320F2812

Composer Studio (CCS), the first step is to create a project as illustrated in figure 3.4.

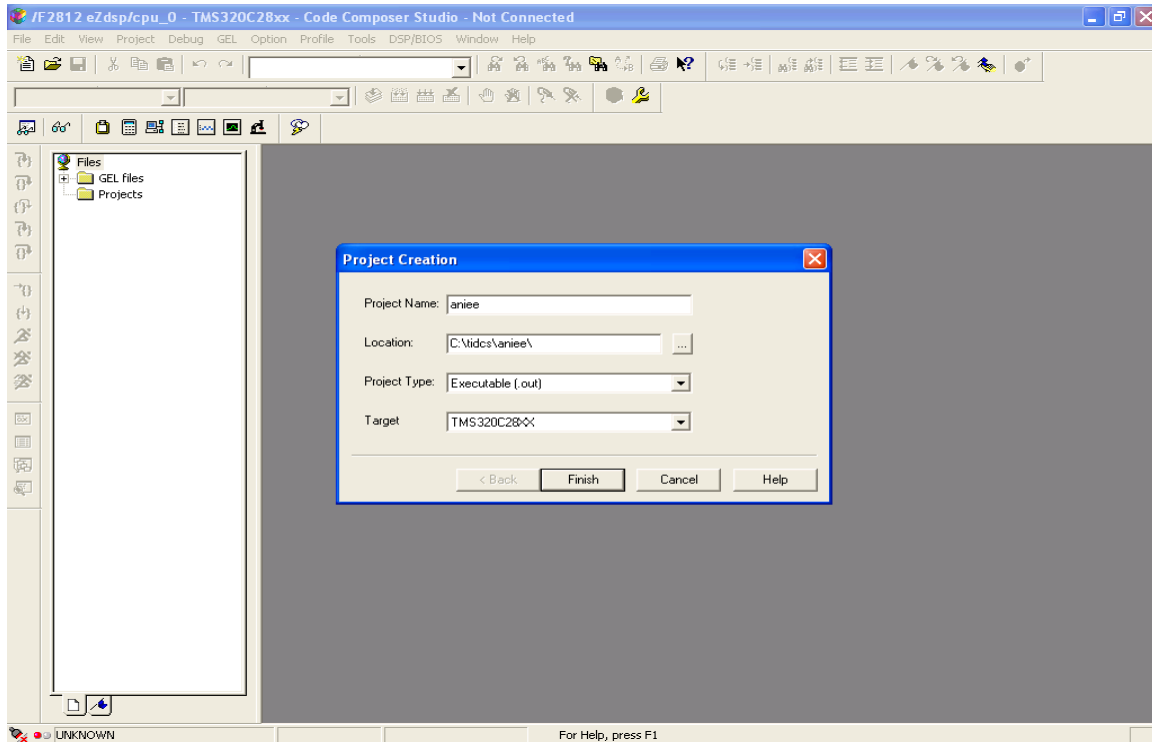


Figure 3.4: Creating a project

The project name is inserted as “aniece” and saved in C:\tidcs\aniece\. In the compiler tab, category: preprocessor, all the search paths are included. These search paths are necessary to be included in the project file so that when the program is written, the basic components are able to be detected in its library thus no missing path option would appear. To start a program, the most important thing to study the output desired. In this case, it’s to obtain a pulse for the switching of the IGBT. The function calls needs to be declared before using the functions in the program. A timer control register is used in the program therefore, all the related parameters like input clock pre-scale, count mode selection, emulation control bits and many others need to be clarified and declared in the program. The output of the program is set according to its signal description. The program created is done and checked according to figure 3.5: Progress flow chart for Code composer studio (CCS) below.

3.4.1 Flow chart using Code Composer Studio (CCS)

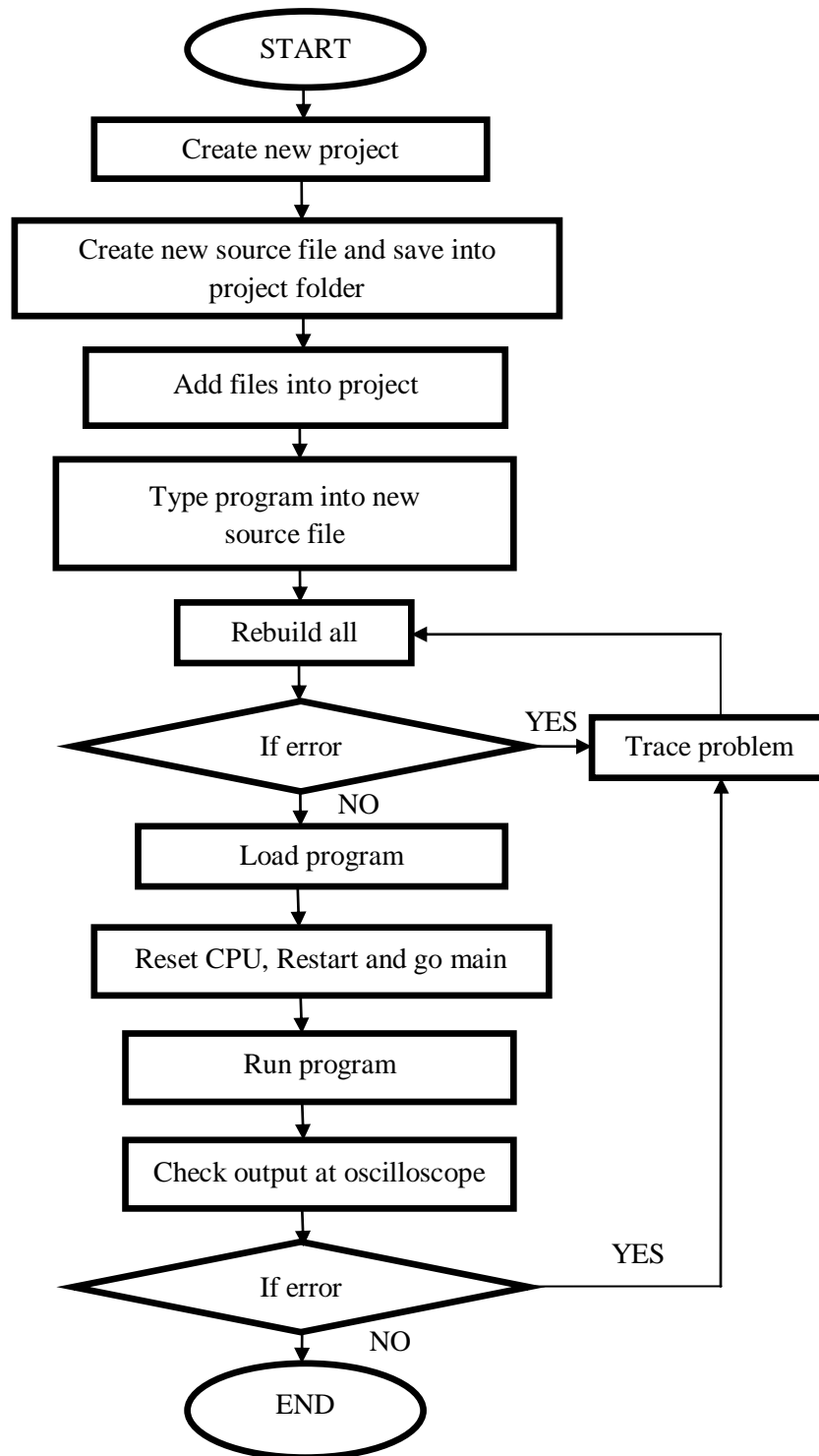


Figure 3.5: Progress flow chart for Code composer studio (CCS)

3.5 Program testing

Based on the steps in figure 3.5, the program is downloaded into the DSP for program testing. As has been set into the program, the output connector is P8 connector of pin 15. The oscilloscope probe is tapped at the output of pin 15 of connector P8. The output is checked at the oscilloscope

3.6 Schematic design using Proteus 8 professional

Proteus 8 professional is used to design the schematic and layout for the gate drive circuit and boost circuit as illustrated in figure 3.6: Proteus 8 professional below. Isis schematic capture is used to draw the circuit desired and it is then opened using the ARES PCB layout. In the ARES PCB layout, components are placed according to desired design and the routes are placed accordingly.

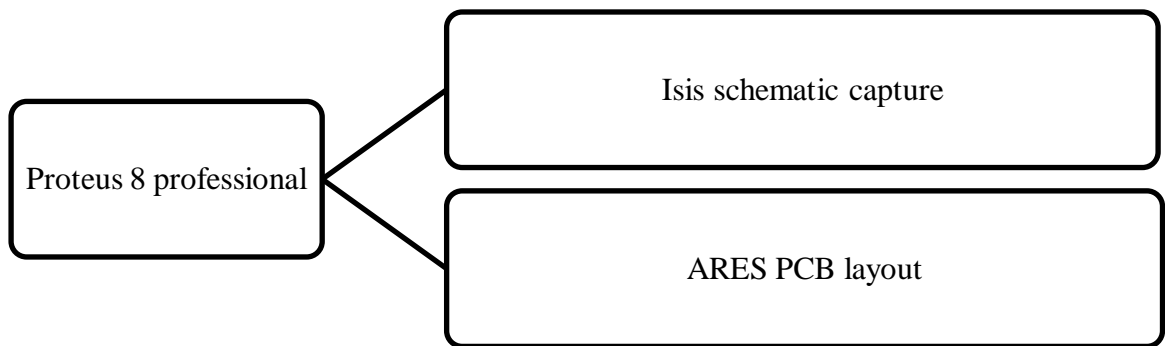


Figure 3.6: Proteus 8 professional

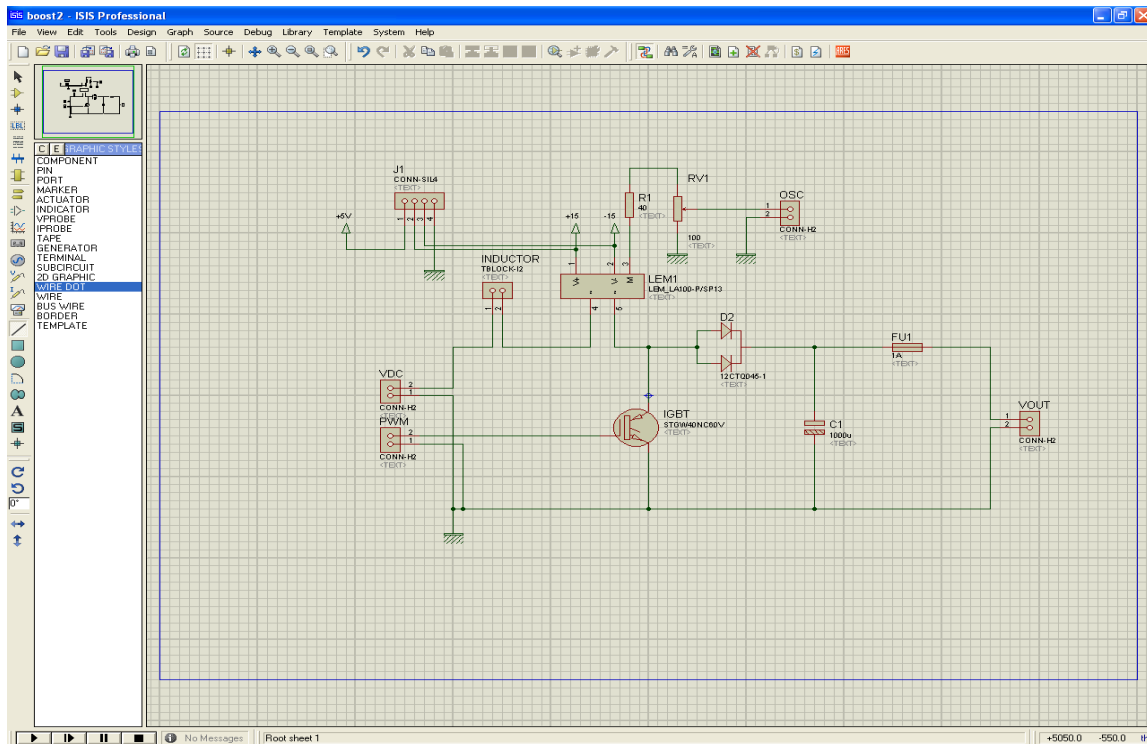


Figure 3.7: Isis schematic capture

Two circuit needs to be developed in order to create the boost converter which includes the gate drive which acts as the driver to the IGBT's gate where an input pulse (obtained from the output of the DSP) with a minimum of 15V is required to drive the IGBT at the boost circuit. As illustrated in figure 3.7: Isis schematic capture above, the components are obtained from the "place component" tab and if the component is not inside the library of the system, it can be created by manually creating the block of the component. The pins to the block are then assigned accordingly as required. The completed schematic design is opened using ARES PCB layout where the components are placed as desired and the route are connected accordingly. The layout created is single layer as can be shown in figure 3.8: ARES PCB layout below. The schematic of the boost converter is attached in appendix B, Appendix B: Boost converter schematic; and the boost converter layout is attached in Appendix C: Boost converter layout. The list of components is attached in appendix F.

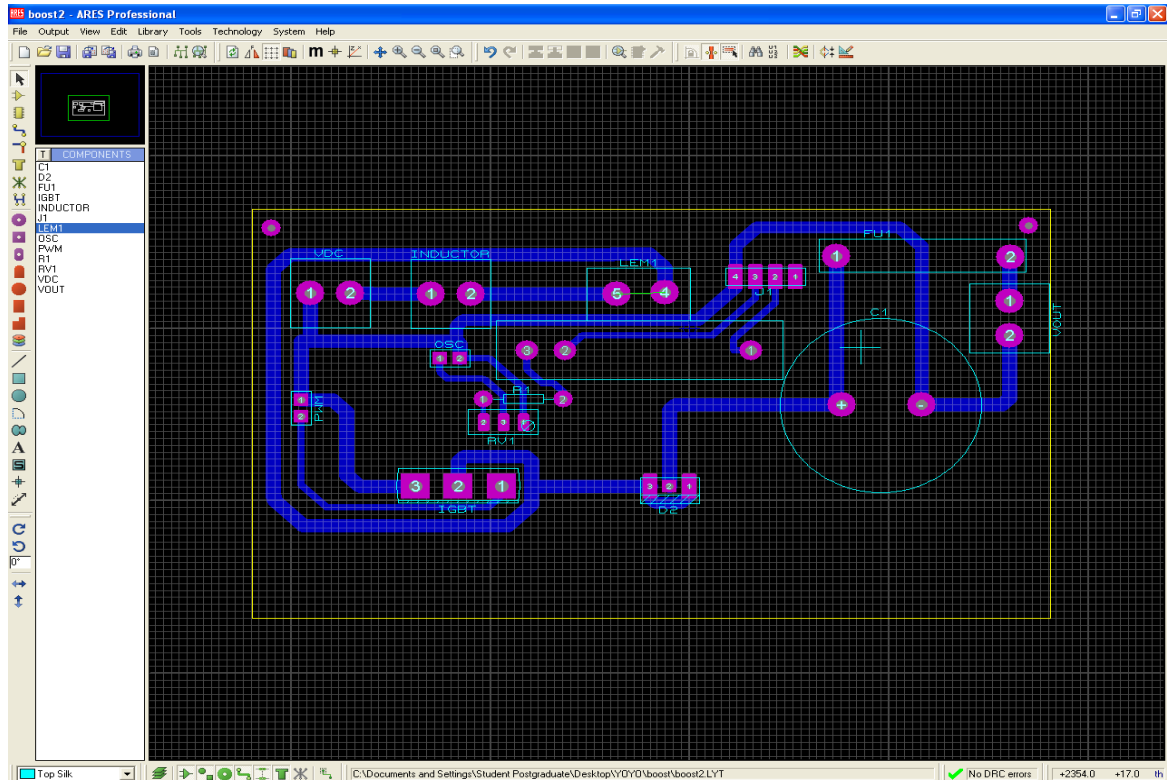


Figure 3.8: ARES PCB layout

3.7 PCB etching

The PCB layout is then printed onto a trace paper using high resolution mode (printer setting). The PCB used is a positive acting PCB. At a dark area, the trace paper is attached to the positive acting PCB and is sandwiched between two clear glasses. The PCB is then exposed to the sun where ultraviolet (UV) exist for approximately three minutes depending on the weather. This process is shown in figure 3.9 below. If the coating on the PCB is exposed to enough light, the copper layer can be rinsed away when it is dipped into the developer solution.

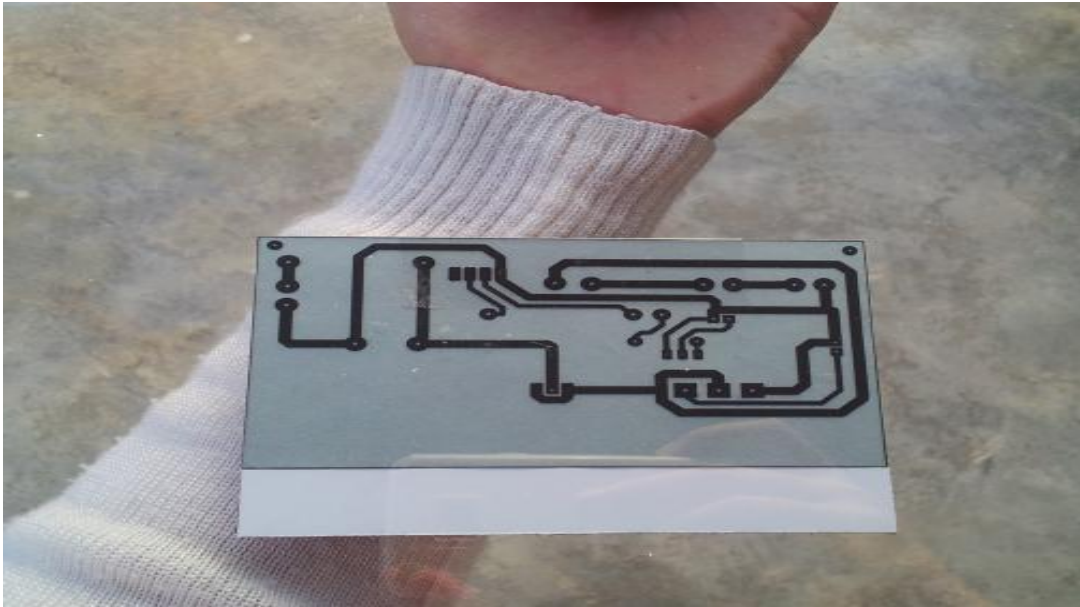


Figure 3.9: Positive acting PCB

The PCB is copper coated with a chemical that is sensitive to light (photoresist). When the PCB is soaked into the PCB developer, as illustrated in figure 3.10: Developing the PCB below, the photoresist will be removed by the developer leaving the copper beneath.



Figure 3.10: Developing the PCB

The PCB is developed using the PCB developer until a stage where the copper is exposed in areas that is to be etched (areas that are not the route of the circuit). The PCB will then undergo the etching process by using Ferric Chloride. Throughout the developing process, the PCB is monitored so that it is not over etched. Over etched would result in narrow traces and the pad diameters is somehow etched as well. The process is illustrated in figure 3.11: Etching the PCB below.



Figure 3.11: Etching the PCB

Once the PCB is completed, continuity is checked using a multimeter with buzzer mode. This process is done to check if there are places on the circuit that is not developed or etched properly short circuits the circuit in unwanted areas. The process in figure 3.12 (a): Drilling process is to drill the holes for the components at the PCB so that the components can be attached to the PCB according to its route. The size of the holes depends on the size of the component legs. Figure 3.12 (b): Boost converter box is the development of the converter's box. This is necessary so that the circuits would be in place. The box is made of acrylic.

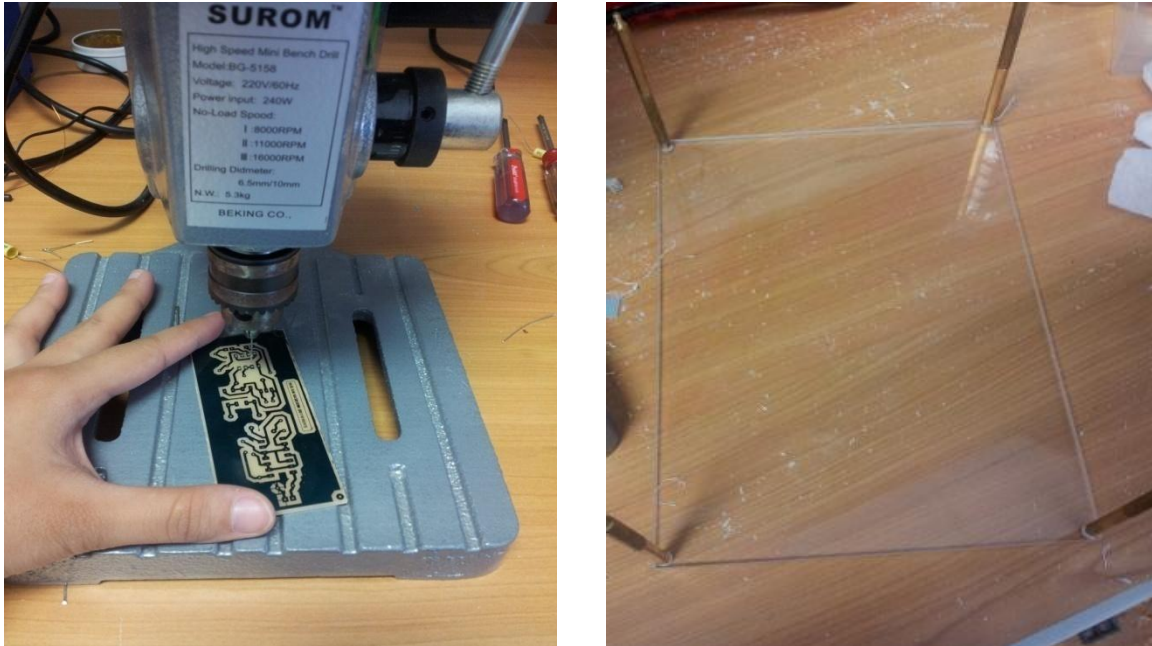


Figure 3.12 (a): Drilling process (b): Boost converter box

The components are placed into place and are soldered for both the components of the gate drive circuit and the boost circuit. The gate drive is checked if it functions or not by giving an input voltage of 5V to the circuit. By using a multimeter, the output of the HCPL 3120 (IGBT gate drive optocoupler) for the leg pin of 5 and 8 is checked to have an output of 15V. This is necessary because the requirement for the IGBT in the boost circuit to turn on is with a pulse with a minimum voltage of 12V and a maximum voltage of 20V (experimental base). Once everything is completed, the program is loaded into the DSP, and is connected to the gate drive circuit whereas the gate drive circuit is connected to the boost circuit, the converter is tested as illustrated in figure 3.13 below.

3.8 Hardware testing

The final part is to test the hardware to see either it is functioning or not. The output is checked through the multimeter and oscilloscope and is compared to the results obtained from the calculation and hardware.



Figure 3.13: Hardware testing

3.9 Chapter Summary

This chapter describes the methodology used in completing this project. The procedure of each step is described which includes the simulation using MATLAB simulink, the coding using the DSP CCS studio, the implementation of the experimental part (hardware) and also the hardware testing. Based on these procedures the data's for each results are collected and is stated in the next chapter.

CHAPTER 4

RESULTS

4.1 Introduction

Chapter 4 includes the results obtained from the project entitled simulation and design of the DC-DC switching boost converter. The first part of the chapter is calculation result. The second part is the simulation result of the boost converter by using MATLAB simulink software. The third part of this chapter is the hardware result of the DC-DC switching boost converter. The pulse for the switching of the IGBT in the experimental part is developed using the DSP TMS F2812. By using a prototype boost circuit developed, two cases are studied which includes case 1: Monitoring and analyzing the effect of the current ripple when the value of frequency is varied and case 2: Monitoring and analyzing the effect of the current ripple when the value of duty cycle is varied. These cases are applied for all three parts, calculation, simulation and hardware. All data's for calculation, simulation and hardware is then compared, discussed and analyzed. The current at the inductor, i_L is determined from Eq. (4-1) and the minimum and maximum current at i_L is determined from Eq. (4.2) and the Δi_L is from Eq. (4-3).

$$I_L = \frac{V_s}{(1-D)^2(R)} \quad (4-1)$$

$$\frac{\Delta i_L}{2} = \frac{V_s D T}{2L} \quad (4-2)$$

$$\Delta i_L = I_{max} - I_{min} \quad (4-3)$$

4.2 Calculation Results

Figure 4.1 below is the illustration of a boost circuit. The boost circuit consists of a voltage source, an inductor, a diode, a power semiconductor (IGBT), capacitor and a resistor. As stated in the introduction of this chapter, the calculation part is divided into two cases which includes case 1: Effect towards the current ripple when the value of frequency is varied and case 2: Effect towards the current ripple when the value of duty cycle is varied.

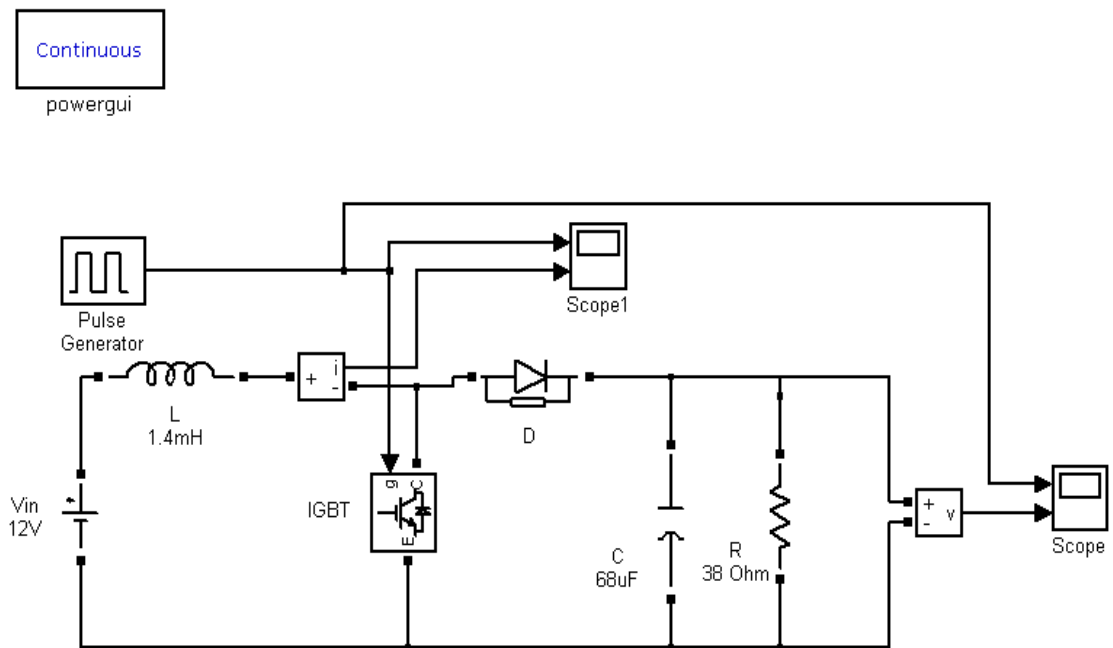


Figure 4.1: DC-DC boost circuit

4.2.1 Case 1: The effect towards current ripple when the value of frequency is varied

For case 1, the parameters of the boost circuit are stated in table 4.1 as shown below. As can be seen in table 4.1, the value of the frequency ranges from 10 kHz to 80 kHz while maintaining the duty cycle to be 50%.

Table 4.1: Parameters of a boost circuit (frequency is varied)

Parameters	Rating
V_{in}	12V
Resistor, R	38Ω
Capacitance, C	68 μ F
Inductance, L	1.4mH
Duty cycle, D	50%
Frequency, f	10kHz, 20 kHz, 30 kHz, 30 kHz, 50 kHz, 60 kHz, 70 kHz, 80kHz

As stated in table 4.1, the value of frequency is varied from 10 kHz up to 80 kHz. The value of the current ripple Δi_L is calculated based on Eq. (4-2) and is compared in table 4.2 below.

Table 4.2: Current ripple, Δi_L when the value of frequency is varied.

Frequency (kHz)	Δi_L (A): Calculation
10	$\Delta i_L = \frac{V_s DT}{2L} (2) = \frac{12(0.5)(1)}{2(1.4m)(10k)} (2)$ =0.428
20	$\Delta i_L = \frac{V_s DT}{2L} (2) = \frac{12(0.5)(1)}{2(1.4m)(20k)} (2)$ =0.214
30	$\Delta i_L = \frac{V_s DT}{2L} (2) = \frac{12(0.5)(1)}{2(1.4m)(30k)} (2)$ =0.143
40	$\Delta i_L = \frac{V_s DT}{2L} (2) = \frac{12(0.5)(1)}{2(1.4m)(40k)} (2)$ =0.107
50	$\Delta i_L = \frac{V_s DT}{2L} (2) = \frac{12(0.5)(1)}{2(1.4m)(50k)} (2)$ =0.0857
60	$\Delta i_L = \frac{V_s DT}{2L} (2) = \frac{12(0.5)(1)}{2(1.4m)(60k)} (2)$ =0.0714
70	$\Delta i_L = \frac{V_s DT}{2L} (2) = \frac{12(0.5)(1)}{2(1.4m)(70k)} (2)$ =0.0612
80	$\Delta i_L = \frac{V_s DT}{2L} (2) = \frac{12(0.5)(1)}{2(1.4m)(80k)} (2)$ =0.0535

4.2.2 Case 2: The effect towards current ripple when the value of duty cycle is varied

For case 2, it is to calculate the current ripple Δi_L , if the duty cycle is varied. This is to see the pattern of the on which state does the current ripple relates to the percentage of duty cycle applied. The parameters of the boost circuit are stated in table 4.3 as shown below. As can be seen in table 4.3 below, the value of the duty cycle ranges from 10% to 90% while maintaining the frequency to be 20 kHz.

Table 4.3: Parameters of a boost circuit (duty cycle is varied)

Parameters	Rating
V _{in}	12V
Resistor, R	38Ω
Capacitance, C	68uF
Inductance, L	1.4mH
Duty cycle, D	10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%
Frequency, f	20 kHz

As stated in table 4.3, the value of the duty cycle is varied from 10% up to 90%. The value of the current ripple Δi_L is calculated based on Eq. (4-2) and is compared in table 4.4 below.

Table 4.4: Current ripple, Δi_L when the value of duty cycle is varied

Duty cycle, D	Calculation	
	$\Delta i_L, = \frac{V_s D T}{2L} (2) \text{ (A)}$	Vout (V)
0.1	$= \frac{12(0.1)(1)}{2(1.4m)(60k)} (2)$ $= 0.0428$	13.33
0.2	$= \frac{12(0.2)(1)}{2(1.4m)(60k)} (2)$ $= 0.085714$	15
0.3	$= \frac{12(0.2)(1)}{2(1.4m)(60k)} (2)$ $= 0.1284$	17.14
0.4	$= \frac{12(0.2)(1)}{2(1.4m)(60k)} (2)$ $= 0.1714$	20
0.5	$= \frac{12(0.2)(1)}{2(1.4m)(60k)} (2)$ $= 0.214$	24
0.6	$= \frac{12(0.2)(1)}{2(1.4m)(60k)} (2)$ $= 0.25714$	30
0.7	$= \frac{12(0.2)(1)}{2(1.4m)(60k)} (2)$ $= 0.3$	40
0.8	$= \frac{12(0.2)(1)}{2(1.4m)(60k)} (2)$ $= 0.348$	60
0.9	$= \frac{12(0.2)(1)}{2(1.4m)(60k)} (2)$ $= 0.3857$	120

4.3 Simulation Results

4.3.1 Case 1: The effect towards current ripple when the value of frequency is varied

Figure 4.2 as shown below is the graph of pulse with a frequency of 10 kHz and the characteristic of the current ripple at the inductor obtained from the output of the scope that is tapped at the inductor as shown in figure 4. The parameters used for the circuit is referred to table 4.1. For a frequency of 10 kHz, a pulse is generated for every 0.1ms. The current ripple in the inductor for a frequency of 10 kHz based on the simulation done in the MATLAB simulink software, is shown in figure 4.2, the minimum current, I_{min} is 1.032A and the maximum current, I_{max} is 1.453A which result of a $\Delta i_L = I_{max} - I_{min}$ of $(1.453A - 1.032A) = 0.421A$.

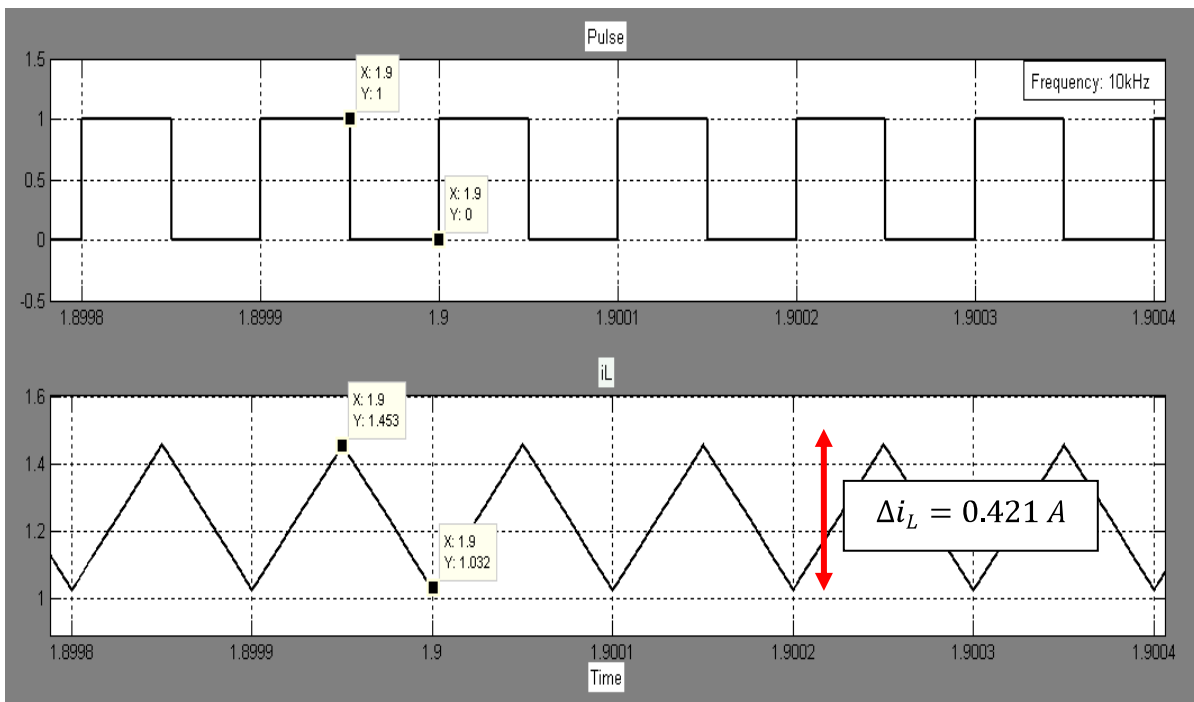


Figure 4.2: Graph of pulse with a frequency, f of 10 kHz and the current ripple, Δi_L at the inductor

For a frequency of 20 kHz, two pulses are generated for every 0.1ms. The current ripple in the inductor for a frequency of 20 kHz based on the simulation done in the MATLAB simulink software, is shown in figure 4.3, the minimum current, I_{min} is 1.141A and the maximum current, I_{max} is 1.1352A which result of a $\Delta i_L = I_{max} - I_{min}$ of (1.352A-1.141A)= 0.211A.

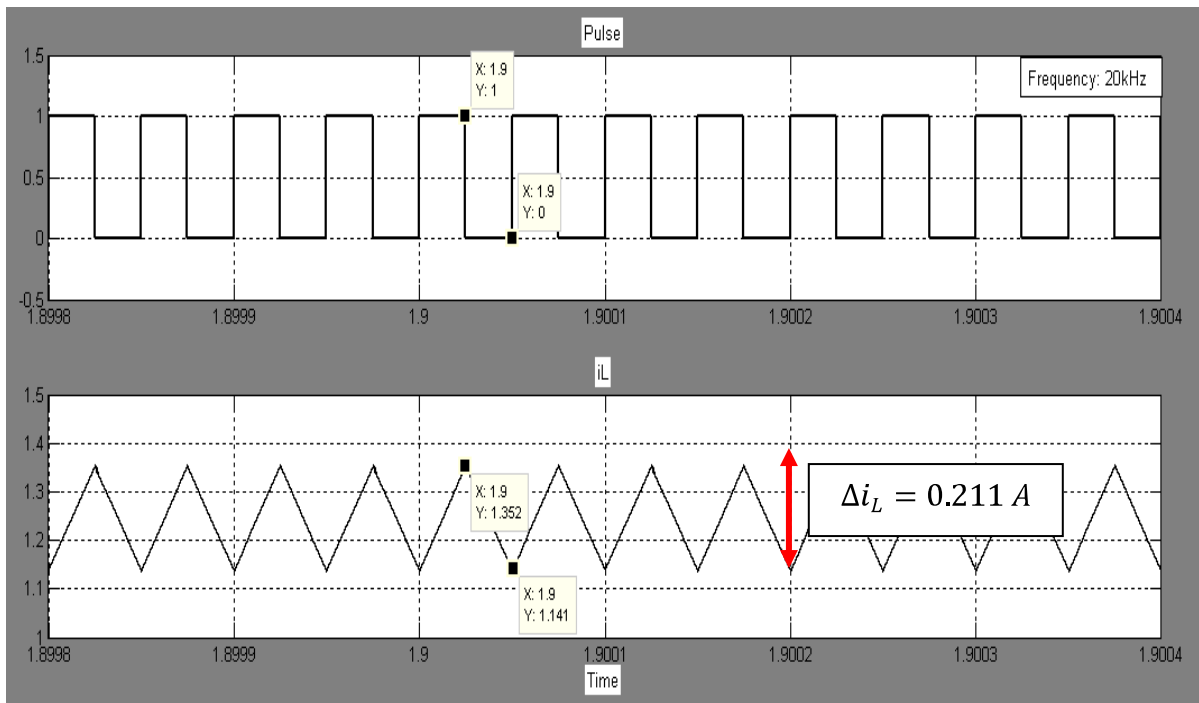


Figure 4.3: Graph of pulse with a frequency, f of 20 kHz and the current ripple, Δi_L at the inductor

Figure 4.4 below shows the result of a pulse with a frequency of 30 kHz. Three pulses are generated within 0.1ms. The current ripple obtained is $\Delta i_L = I_{max} - I_{min}$ of (1.316A-1.173A)= 0.143A.

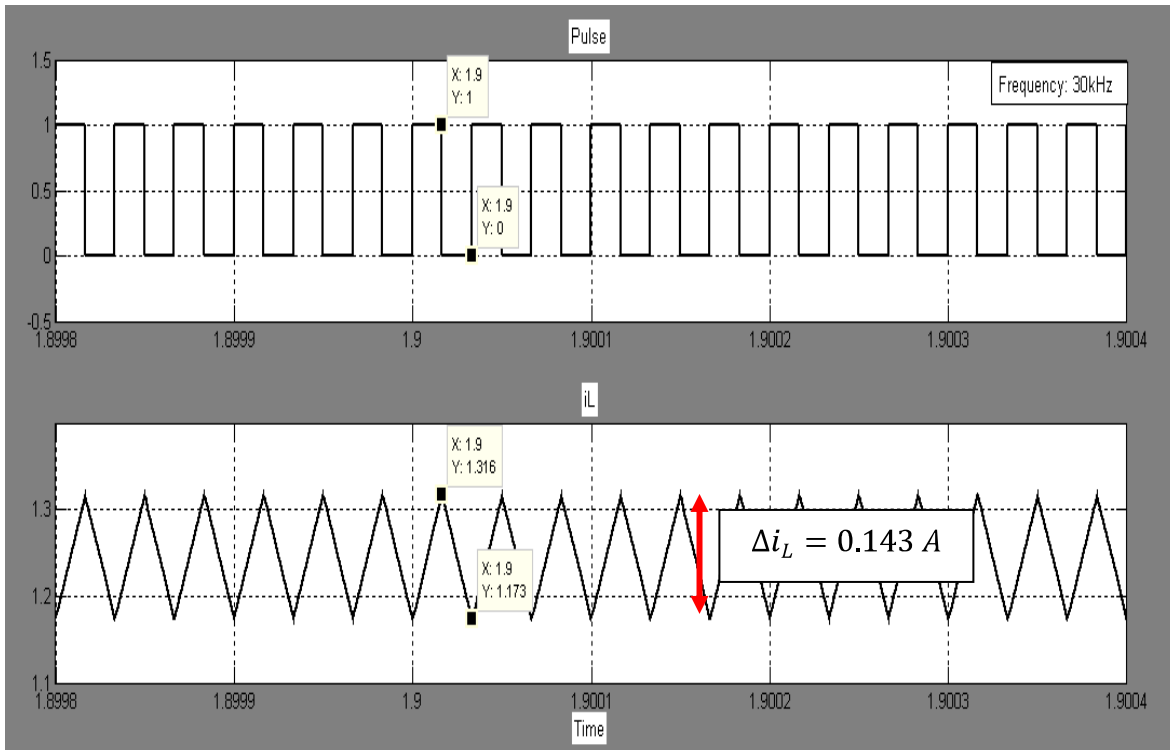


Figure 4.4: Graph of pulse with a frequency, f of 30 kHz and the current ripple, Δi_L at the inductor

Figure 4.5 below shows the result of the current ripple with a frequency of 40 kHz. The pattern of the current ripple up to frequency of 40 kHz shows that as the frequency increase, the current ripple Δi_L decreases. The current ripple obtained is $\Delta i_L = I_{max} - I_{min}$ of (1.299A-1.191A)= 0.108A. In every 0.1ms, four pulses occurs which means that as the higher the frequency is varied to, the faster the switching process occur.

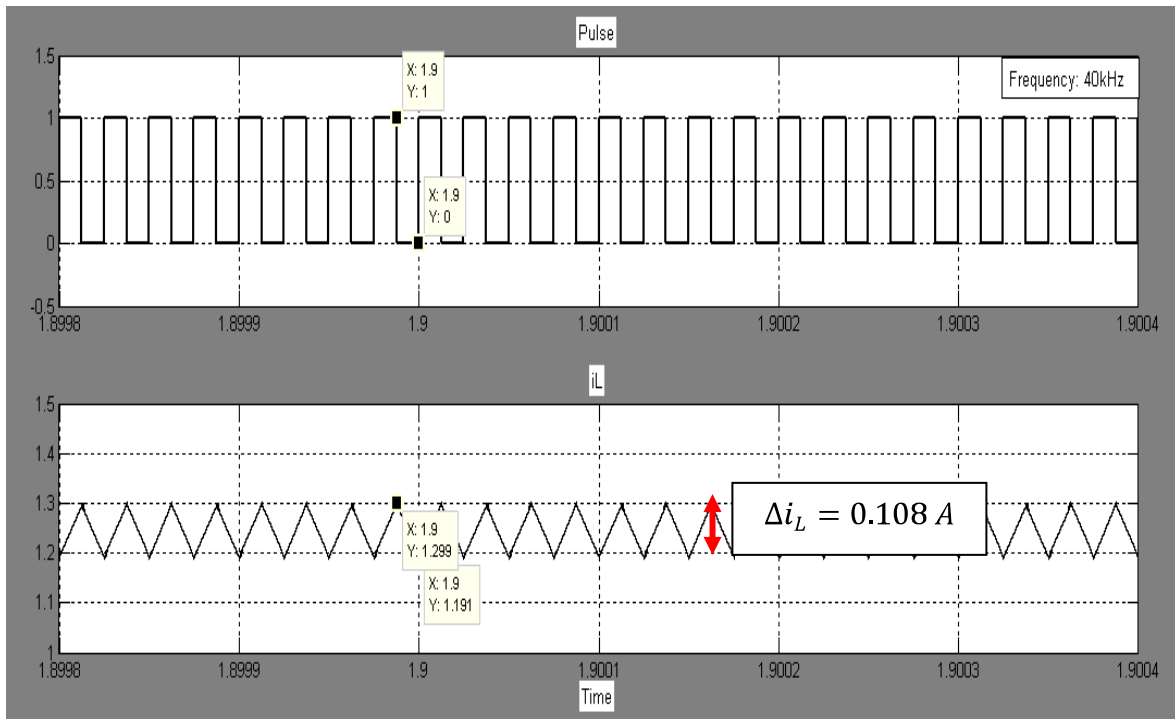


Figure 4.5: Graph of pulse with a frequency, f of 40 kHz and the current ripple, Δi_L at the inductor

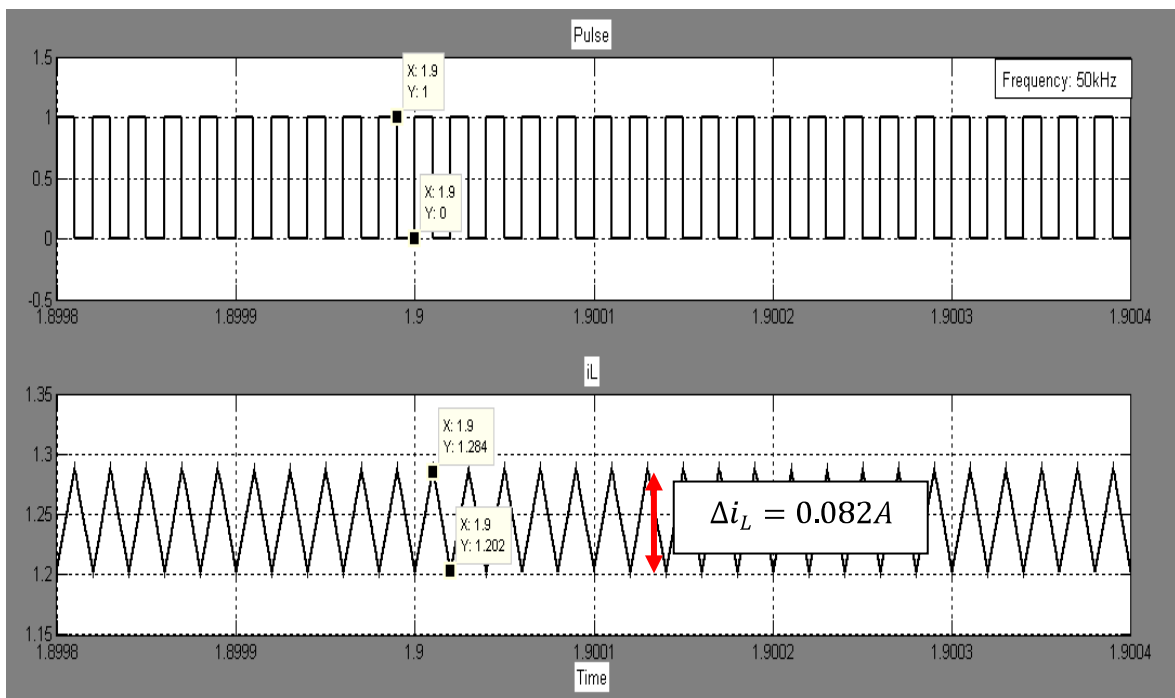


Figure 4.6: Graph of pulse with a frequency, f of 50 kHz and the current ripple, Δi_L at the inductor

Figure 4.6 above shows the switching frequency of 50 kHz. The current ripple obtained is $\Delta i_L = I_{max} - I_{min}$ of (1.284A-1.202A)= 0.082A and within 0.1ms, five pulses or switching occurs.

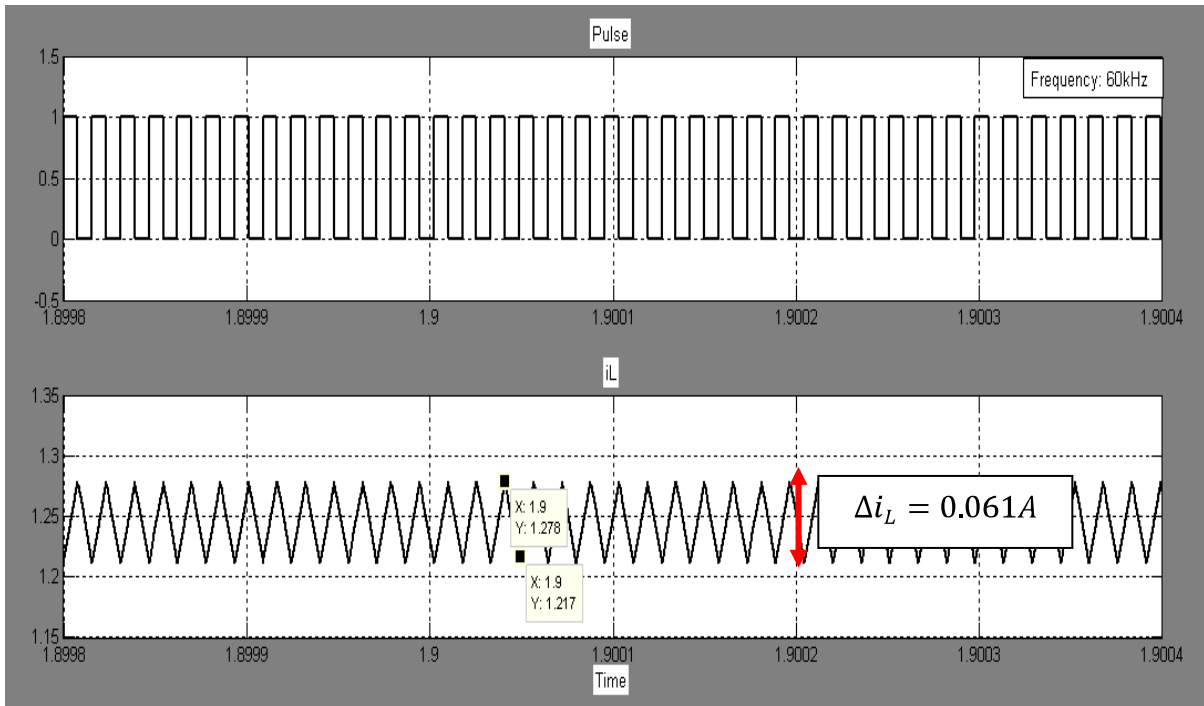


Figure 4.7: Graph of pulse with a frequency, f of 60 kHz and the current ripple, Δi_L at the inductor

For a frequency of 60 kHz, six pulses are generated for every 0.1ms. The current ripple in the inductor for a frequency of 60 kHz based on the simulation done, is shown in figure 4.7 above, the minimum current, I_{min} is 1.217A and the maximum current, I_{max} is 1.1.278A which result of a $\Delta i_L = I_{max} - I_{min}$ of (1.278A-1.217A) = 0.061A. As for figure 4.8 below, is with a result of $\Delta i_L = I_{max} - I_{min}$ of (1.276A-1.219A) = 0.057A

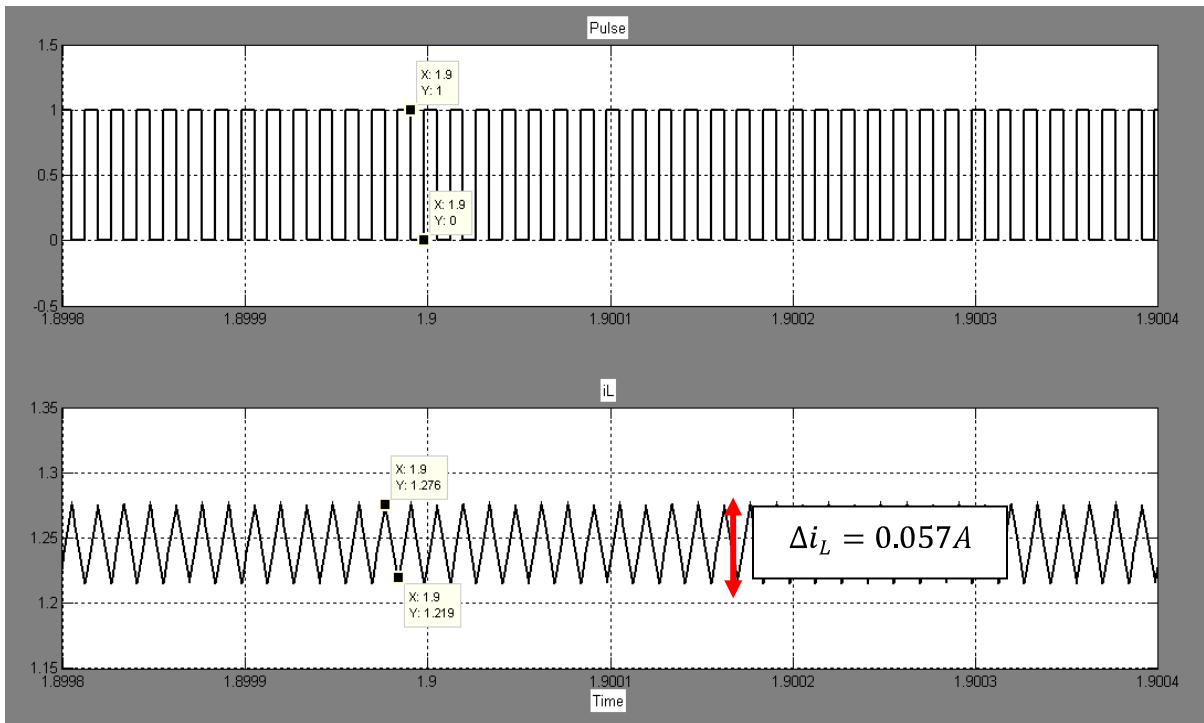


Figure 4.8: Graph of pulse with a frequency, f of 70 kHz and the current ripple, Δi_L at the inductor

Last but not least, for a frequency of 80 kHz, the simulation result is as illustrated in figure 4.9 below. The current ripple, Δi_L calculated is $\Delta i_L = I_{max} - I_{min}$ of $(1.272\text{A} - 1.219\text{A}) = 0.053\text{A}$

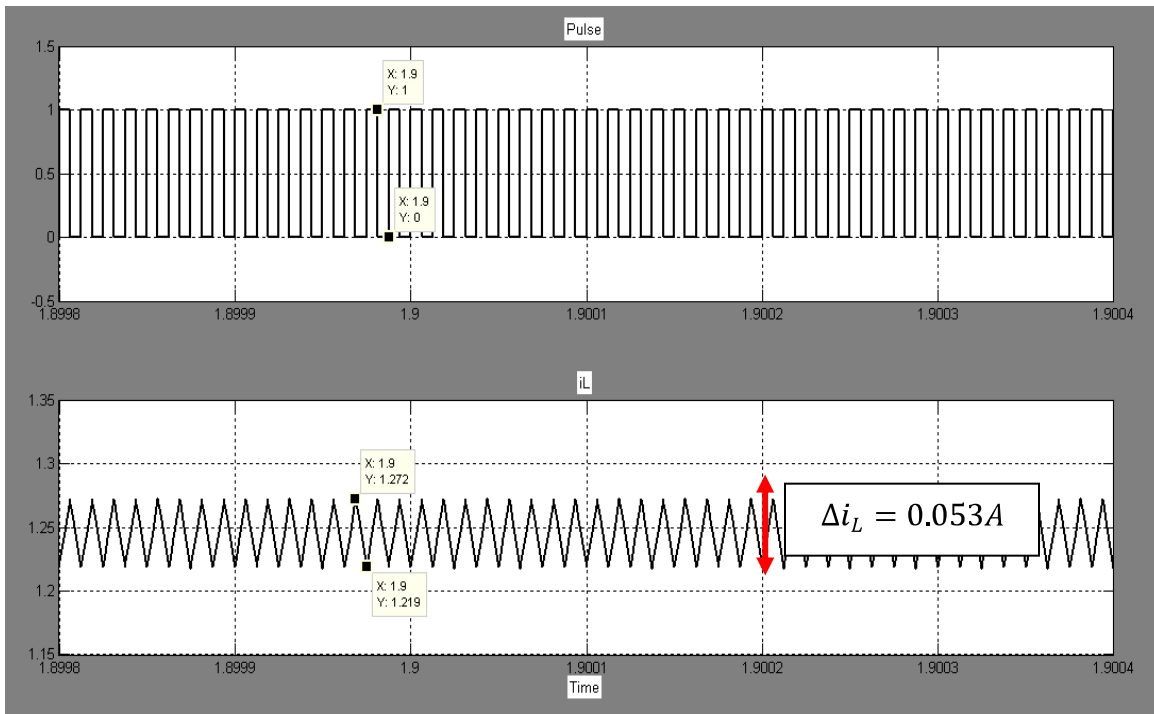


Figure 4.9: Graph of pulse with a frequency, f of 80 kHz and the current ripple, Δi_L at the inductor

4.3.2 Case 2: The effect towards current ripple when the value of duty cycle is varied

The next case is to see the effect of varying the duty cycle towards the current ripple. Table 4.3 is the parameters used in circuit figure 4.10 below. The parameters are remained constant as the previous case (varying the value of frequency) whereby only the duty cycle varies. This part will show the result of current ripple at the inductor, Δi_L (A) for duty cycle ranging from 10 % to 90%. Figure 4.10 as shown below is the graph of pulse with a duty cycle of 10% and the characteristic of the current ripple at the inductor obtained from the output of the scope that is tapped at the inductor as shown in figure 4.1 above. For a duty cycle of 10%, the time on of the pulse generated is only 10% of the total time or period of the pulse causing the current to charge at a short period and discharge at a longer period. The current ripple, Δi_L calculated is $\Delta i_L = I_{max} - I_{min}$ of $(0.3905 - 0.3487) = 0.0418A$

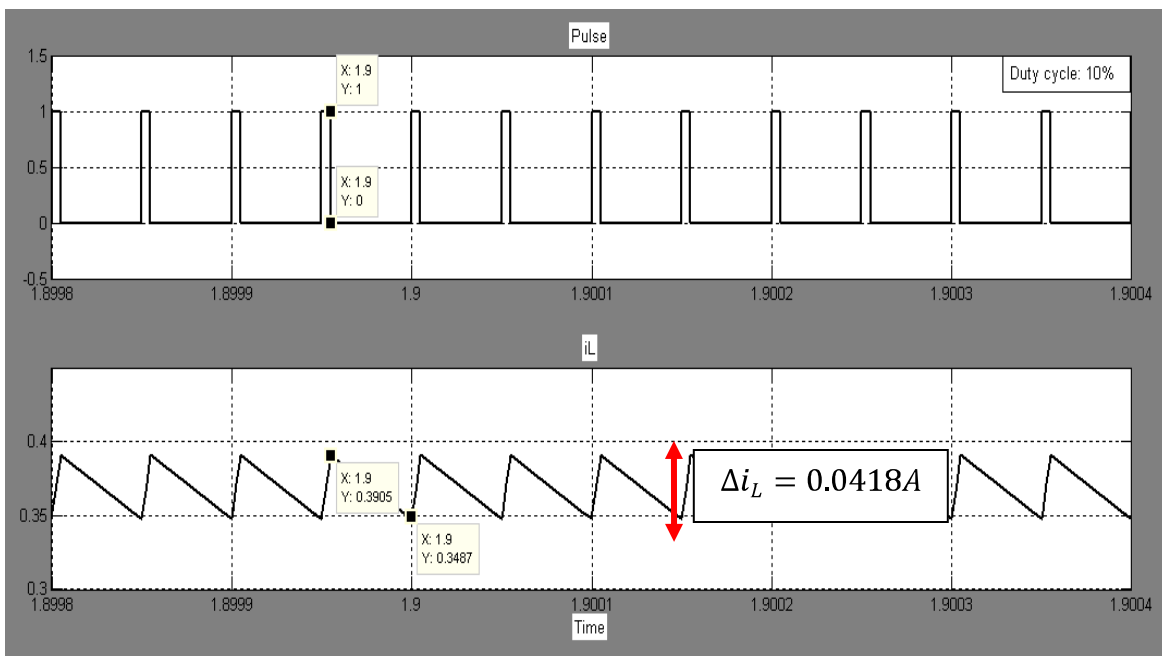


Figure 4.10: Graph of pulse with a duty cycle, D of 10% and the current ripple, Δi_L at the inductor

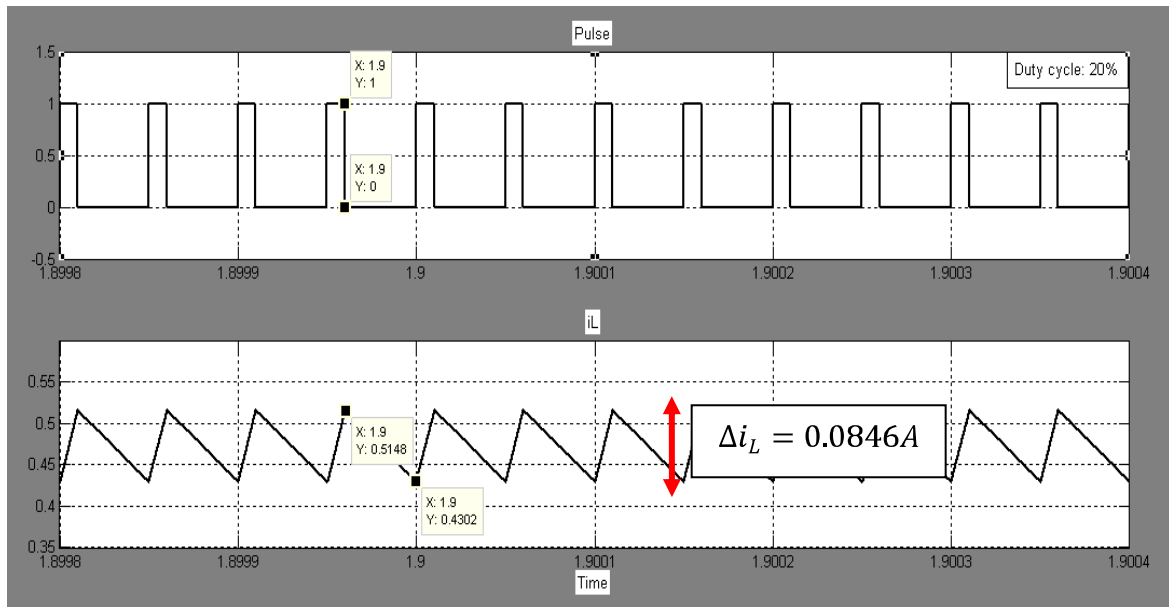


Figure 4.11: Graph of pulse with a duty cycle, D of 20% and the current ripple, Δi_L at the inductor

The current ripple, Δi_L calculated for figure 4.11 with a duty cycle of 20% above is $\Delta i_L = I_{max} - I_{min}$ of $(0.5148 - 0.4302) = 0.0846A$

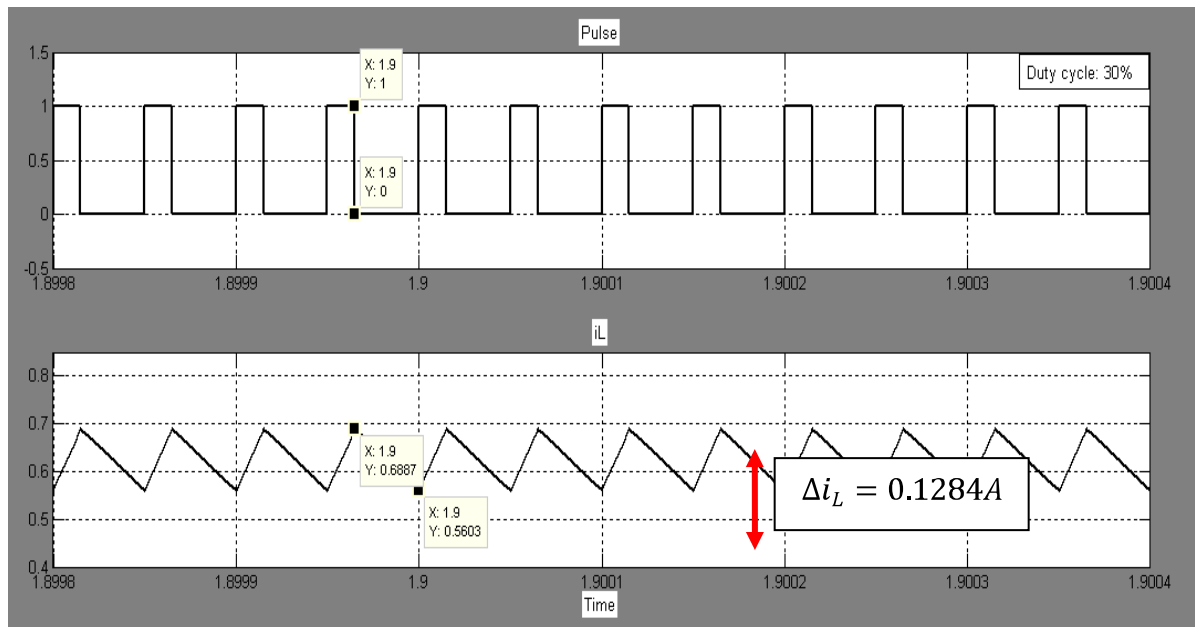


Figure 4.12: Graph of pulse with a duty cycle, D of 30% and the current ripple, Δi_L at the inductor

For a duty cycle of 30%, the current ripple in the inductor for a duty cycle of 30% based on the simulation done in the MATLAB simulink software, is shown in figure 4.12, the minimum current, I_{min} is 0.5603A and the maximum current, I_{max} is 0.6887A which result of a $\Delta i_L = I_{max} - I_{min}$ of (0.6887A-0.5603A) = 0.1284A. As for a duty cycle of 40% shown in figure 4.13 below, the $\Delta i_L = I_{max} - I_{min}$ of (0.9435A-0.776A) = 0.1675A

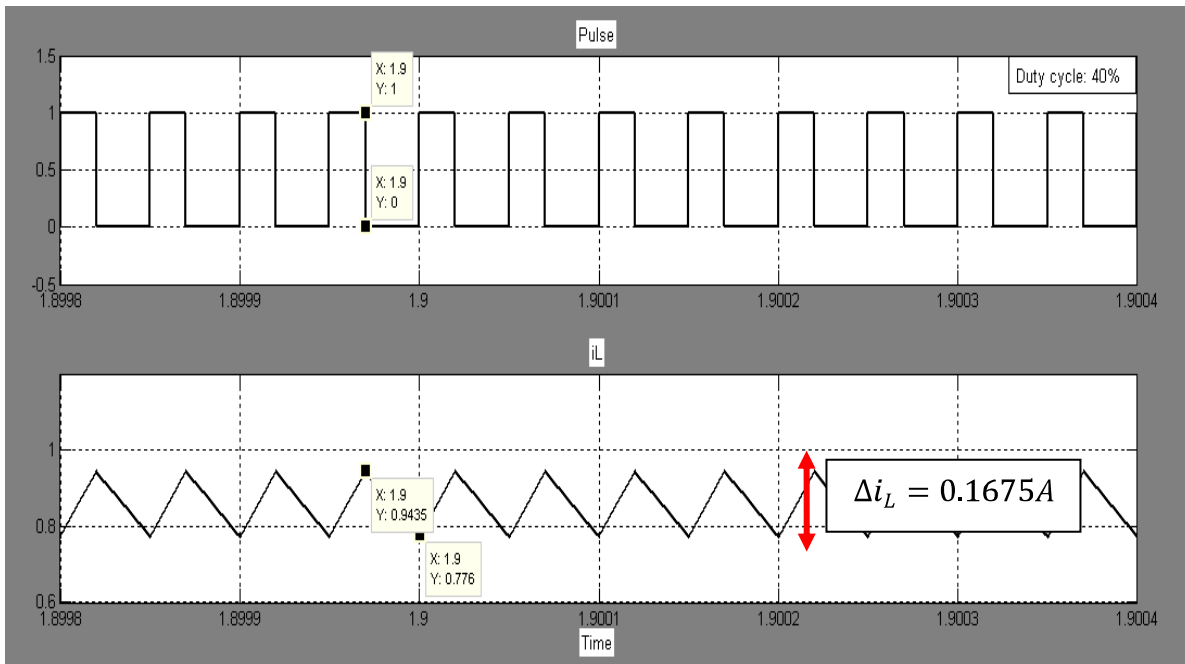


Figure 4.13: Graph of pulse with a duty cycle, D of 40% and the current ripple, Δi_L at the inductor

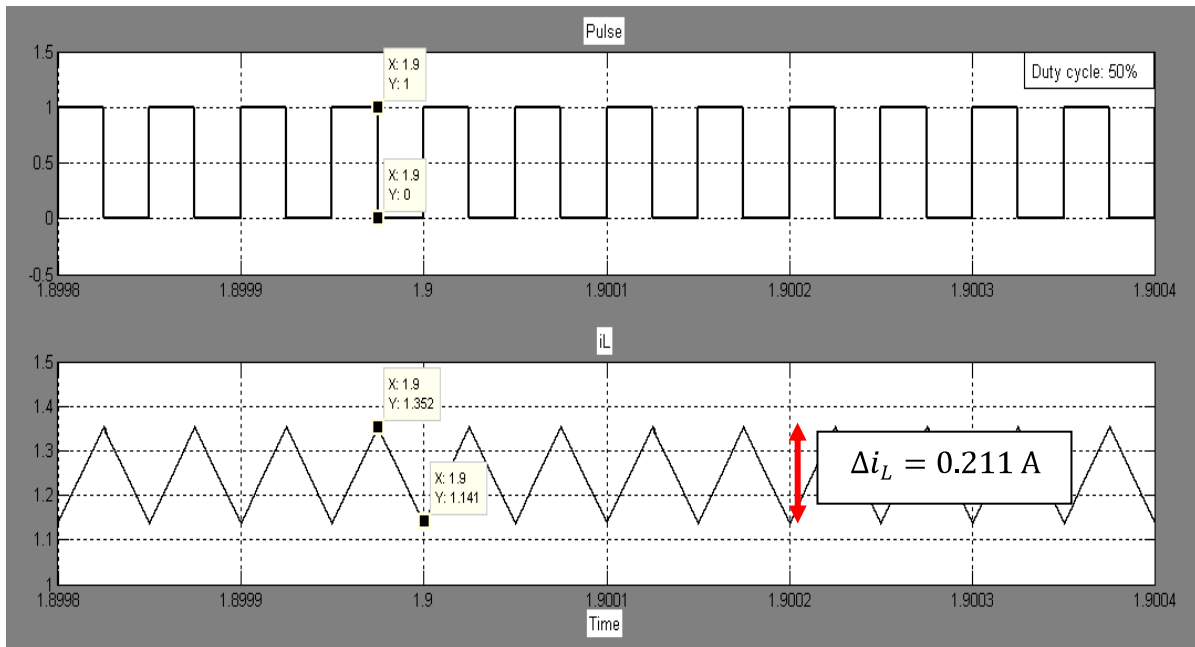


Figure 4.14: Graph of pulse with a duty cycle, D of 50% and the current ripple, Δi_L at the inductor

As shown in figure 4.14 above, since the duty cycle is 50%, the time on and the time off of the pulse (switching) is the same. The Δi_L calculated is $\Delta i_L = I_{max} - I_{min} = (1.352\text{A} - 1.141\text{A}) = 0.211\text{A}$. Figure 4.15 below shows the characteristic of the current ripple of 60% duty cycle. The time on is longer than the time off which means the time for the inductance to charge is longer than for it to dissipate its energy. the current ripple obtained is $\Delta i_L = I_{max} - I_{min} = (2.085 - 1.828\text{A}) = 0.257\text{A}$

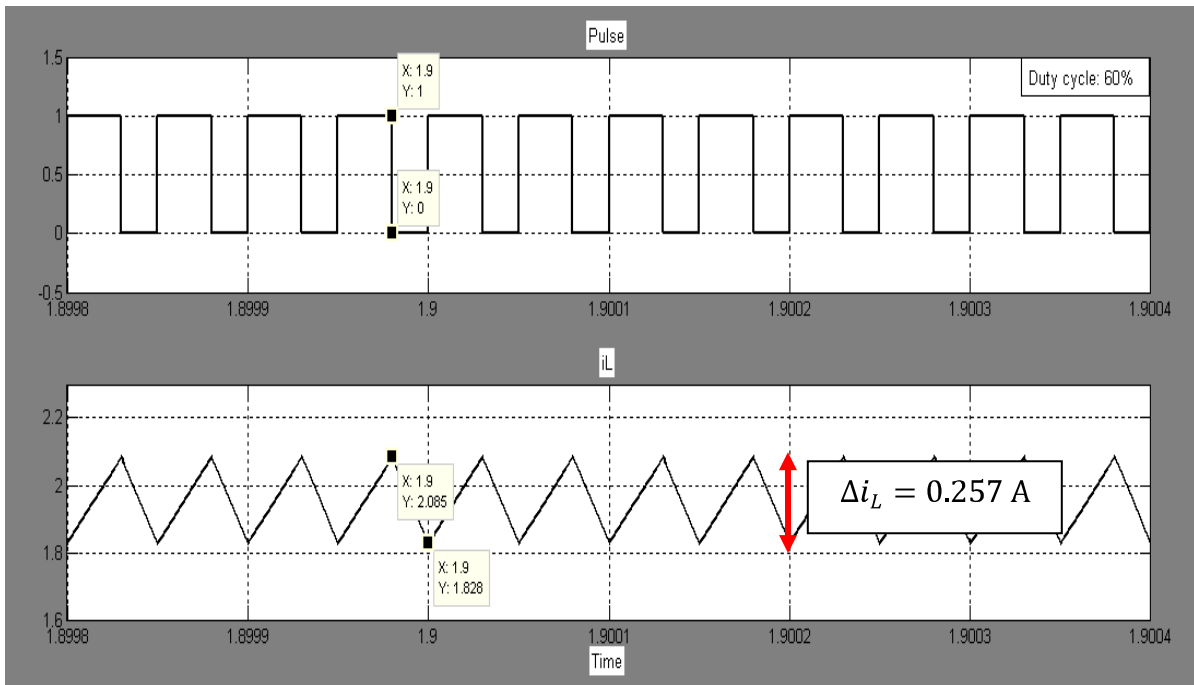


Figure 4.15: Graph of pulse with a duty cycle, D of 60% and the current ripple, Δi_L at the inductor

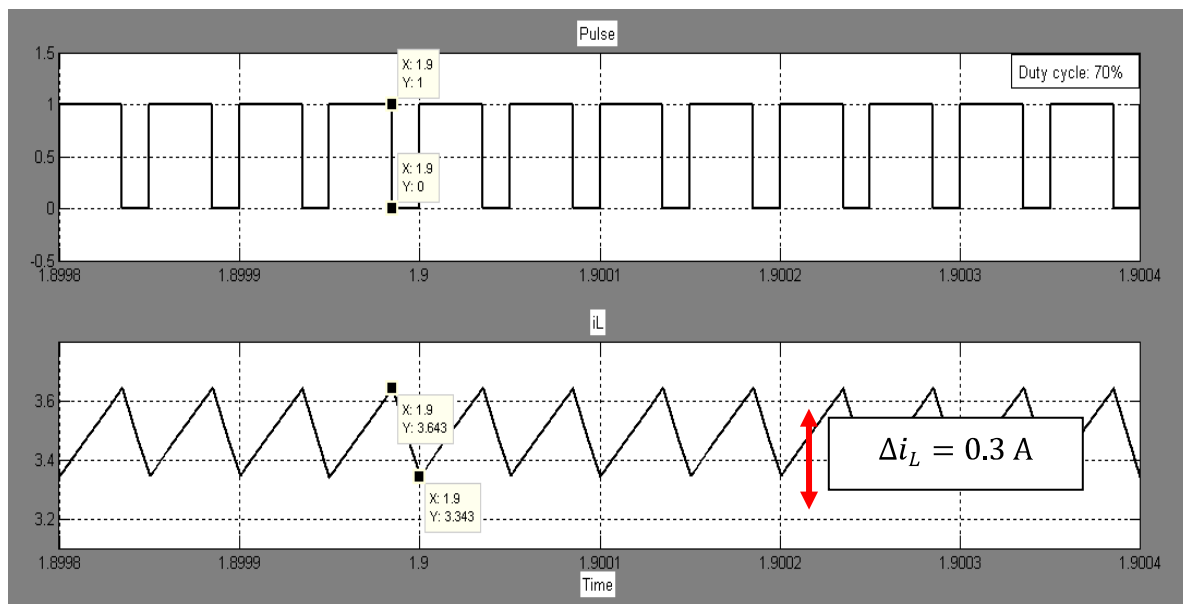


Figure 4.16: Graph of pulse with a duty cycle, D of 70% and the current ripple, Δi_L at the inductor

Up to 70%, it is noticed that as the higher the duty cycle, the larger the current ripple. The current ripple for 70% is $\Delta i_L = I_{max} - I_{min} = (3.643 - 3.343) = 0.3\text{A}$ as shown in figure 4.16 above. As for a duty cycle of 80% in figure 4.17, the Δi_L is $(8.051 - 7.708) = 0.343\text{A}$.

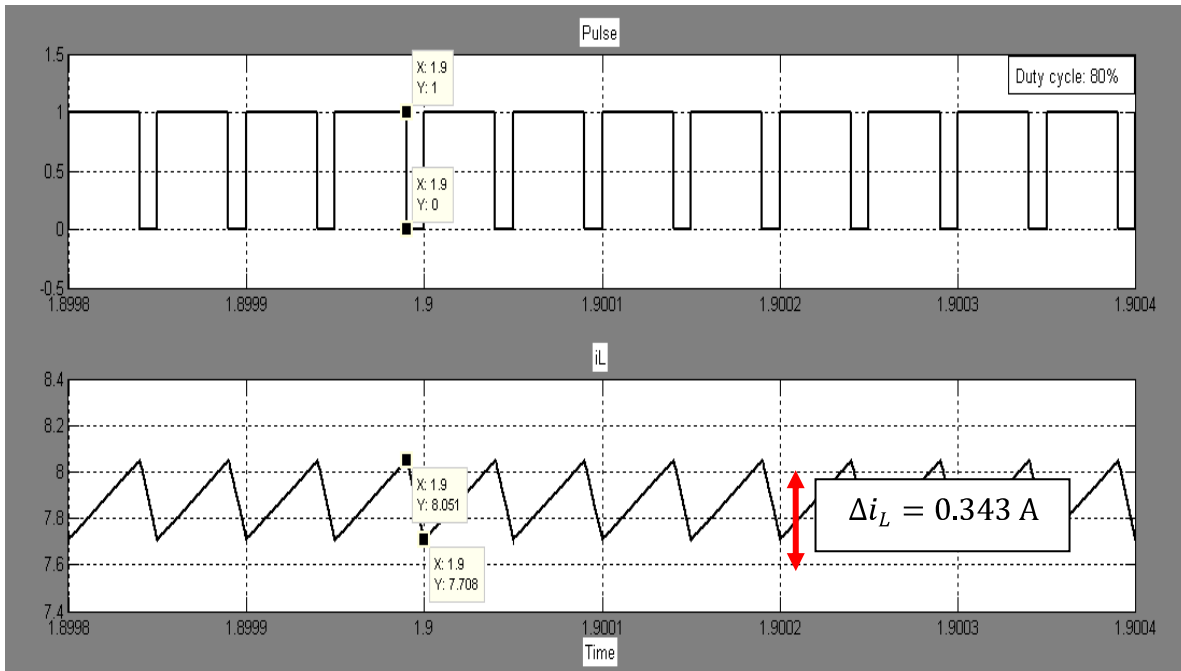


Figure 4.17: Graph of pulse with a duty cycle, D of 80% and the current ripple, Δi_L at the inductor

For the last parameter for the response of the current ripple towards the change of duty cycle is shown in figure 4.18 below. The figure 4.18 below shows that the time off for the switching is too brief. The same parameter will be tested in the experimental part to discover either does the experimental and simulation part differs. The Δi_L can be calculated as $\Delta i_L = I_{max} - I_{min} = (31.69 - 31.31) = 0.343\text{A}$

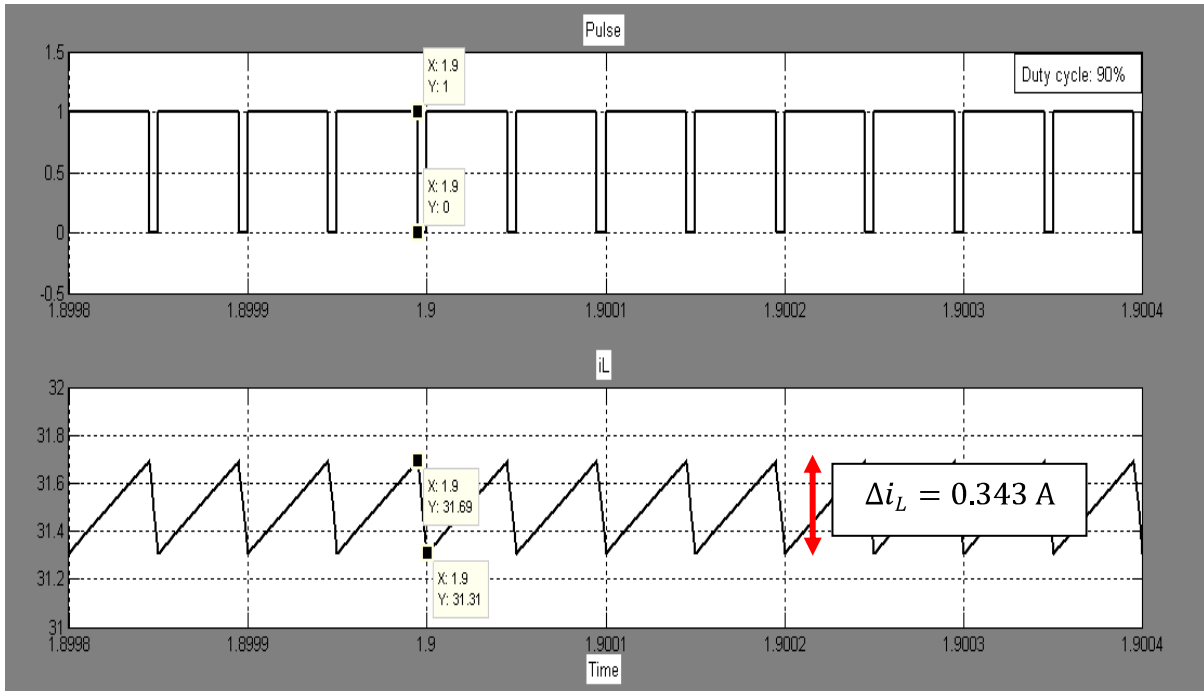


Figure 4.18: Graph of pulse with a duty cycle, D of 90% and the current ripple, Δi_L at the inductor

4.3 Experimental Results

The circuits are checked before connecting all the circuits as in figure 4.19 (boost circuit, gate drive, DSP), load and inductor together.

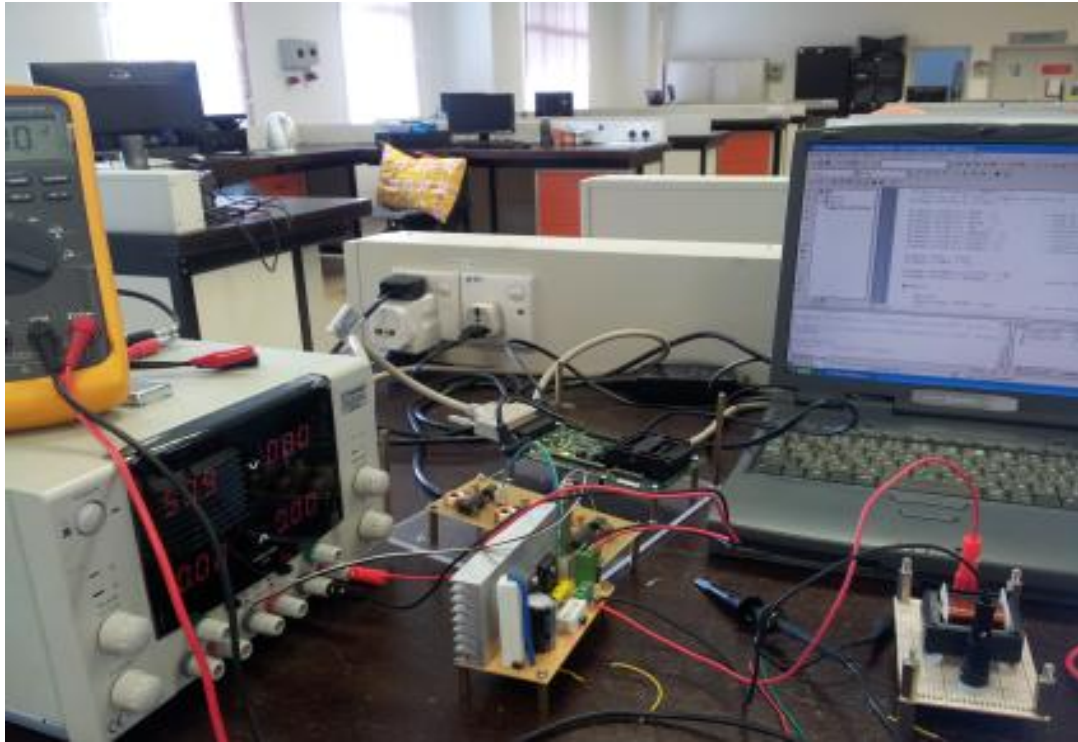


Figure 4.19: Setup of the boost circuit

The pulse width modulation (PWM) done in the code composer studio is uploaded into the DSP and the output of the DSP (connector P8 pin 15 as attached in Appendix D) is connected to the oscilloscope's probe. This is to recheck that pulse that is created in the coding. The PWM coding is attached in appendix E. By adjusting and changing the T1PR (for frequency and T1CMPR for duty cycle, the change of the pulse at the oscilloscope is monitored. The pulse obtained at the output is based on the setting of the T1PR and T1CMPR. Both commands are placed at the output window as shown in figure 4.20: Output window in the Code composer studio (CCS) and the system is set to continuous refresh so that both commands T1PR and T1CMPR can be edited at will. Figure 4.21 below is the illustration on the relationship of the T1PR and T1CMPR in the process of varying the frequency or duty cycle of the pulse.

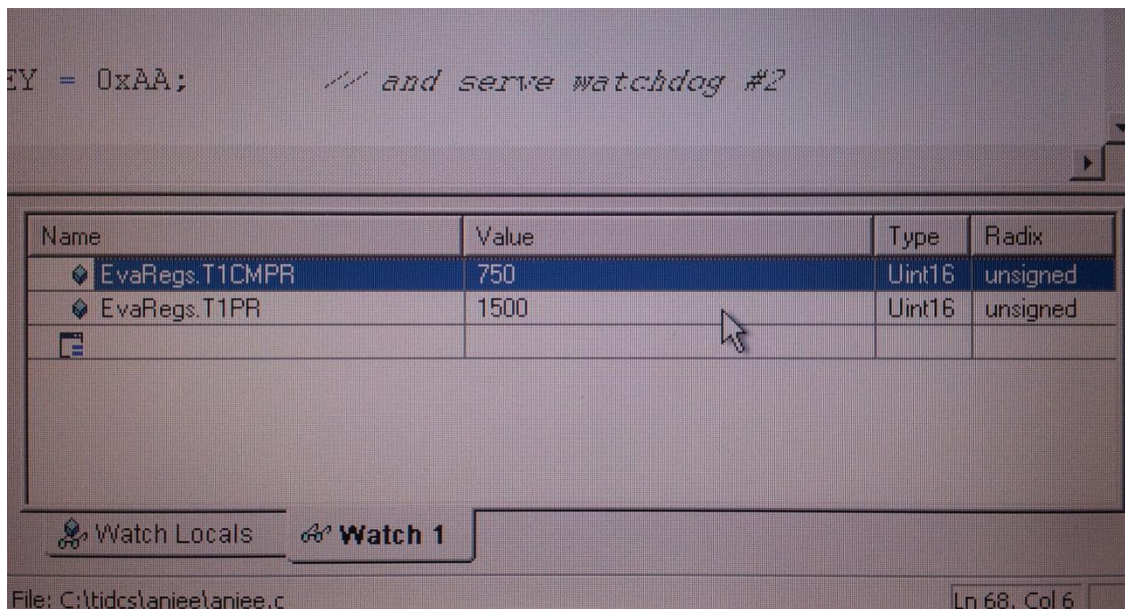


Figure 4.20: Output window

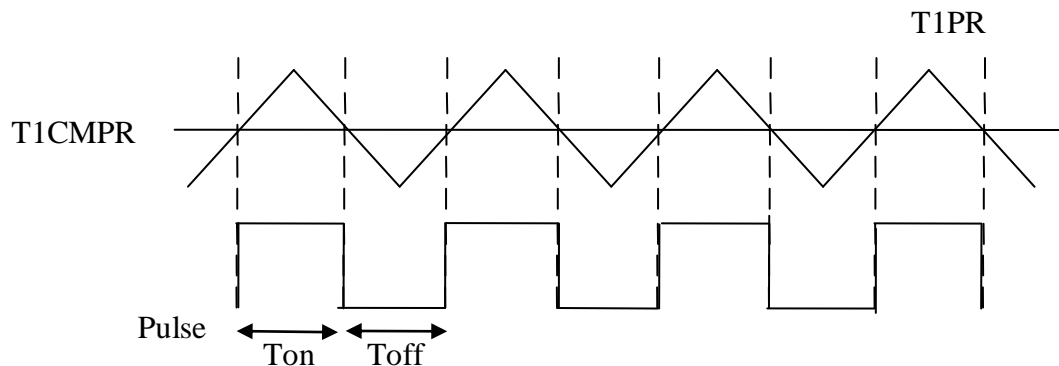


Figure 4.21: Relationship of T1PR command and T1CMPR command

As the output of the PWM is satisfied, the DSP is connected to the gate drive circuit with an input source of 5V. The output of the gate drive optocoupler (pin 5 and 8) is checked to have an output of 15V. This is necessary to ensure that the pulse from the gate drive is able to drive the IGBT according to the pulse. The pulse from the IGBT is connected to the oscilloscope to see its output. The boost circuit is then connected to the amplified pulse from the gate drive circuit. The input source of the boost circuit is set to 12V and a multimeter is

used to check the output of the boost circuit. With a duty cycle of 50%, the output of the boost circuit must be twice the value of the input which is 24V.

The probe from the oscilloscope is then connected in series with the inductance to see the current ripple. Unfortunately, the current ripple is too small it is not visible at the oscilloscope as stated in figure 4.22: Current ripple below.

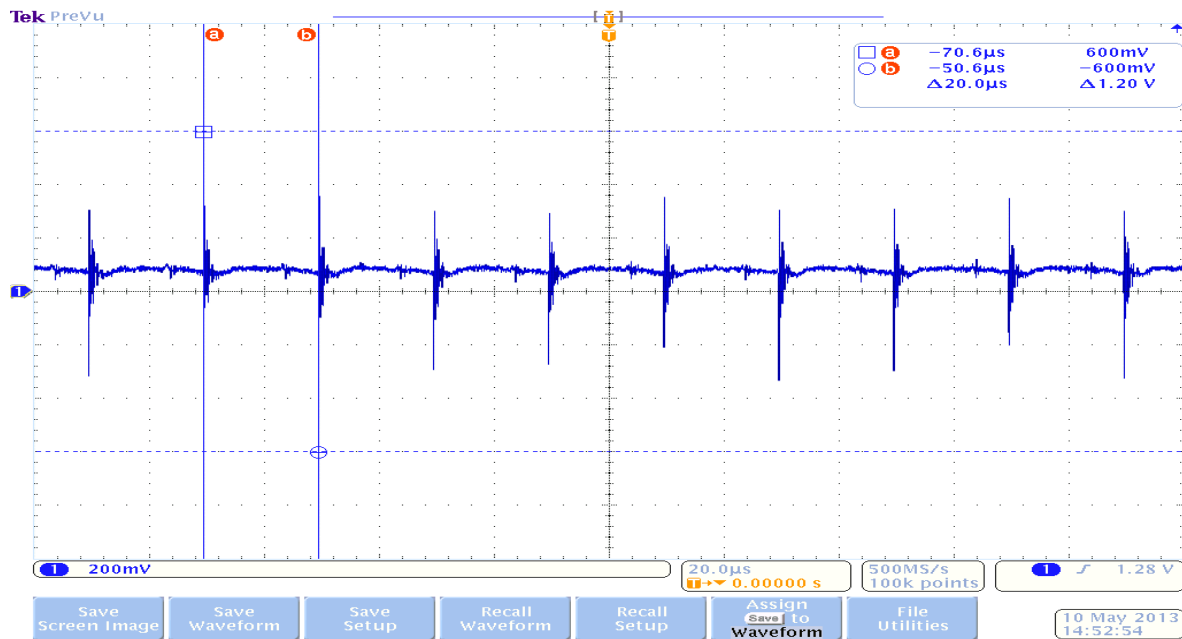


Figure 4.22: Current ripple

Based on the output in figure 4.22: Current ripple above, modification is done to the circuit where a current transducer is added into the circuit. The current transducer is used to be able to sense signals or measurements that falls outside ranges. With the addition of the current sensor, the ranges that are unavailable to obtain with common requirements, can be detected and diagnose. The calibration is done between the current sensor and the oscilloscope as the whereby, 100mV per division in the oscilloscope is equal to 500mA or in other words, it is with a ratio of 1:5. The datasheet of the current transducer is attached in Appendix F. Once the modified circuit is reconnected, the output at the oscilloscope is obtained as will be explained in this chapter. The full experimental setup is attached in appendix G.

4.3.1 Case 1: The effect towards current ripple when the value of frequency is varied

As shown in figure 4.10 the experimental result of varying the value of frequency (10 kHz) for the boost circuit is captured and saved using the oscilloscope. The result as stated at the upper right corner of the result is in mV. Since the configuration scale set between the current transducer and the oscilloscope is 100mV/div for every 500mA (1:5m), the amount of mV needs to be converted into the actual value (in current, A). The current transducer is used to magnify the result obtained (to enlarge the scale) so that the output can be monitored and seen at the oscilloscope as well for galvanic isolation between the primary and the secondary circuit. Based on the result in figure 4.23 below, the current ripple, Δi_L from Eq. (2-3) when the frequency is 10 kHz is with a maximum current, I_{max} of 1.29A and a minimum current, I_{min} of 0.87A thus the Δi_L is $\Delta i_L = I_{max} - I_{min} = (1.29 - 0.87) = 0.42 A$

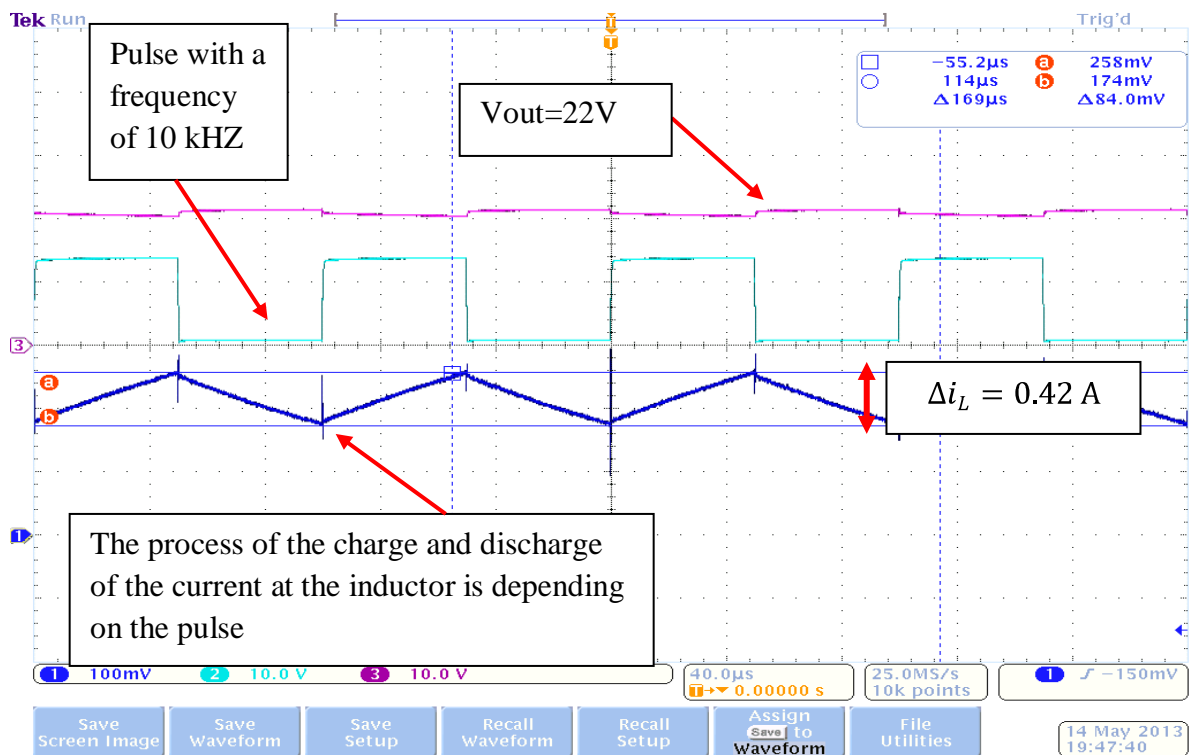


Figure 4.23: Pulse with a frequency, f of 10 kHz and the current ripple, i_L at the inductor

The result shown in figure 4.24 is the result when the frequency of the boost converter is set to 20 kHz. The current ripple obtained is $\Delta i_L = I_{max} - I_{min} = (1.21 - 0.97) = 0.24 \text{ A}$

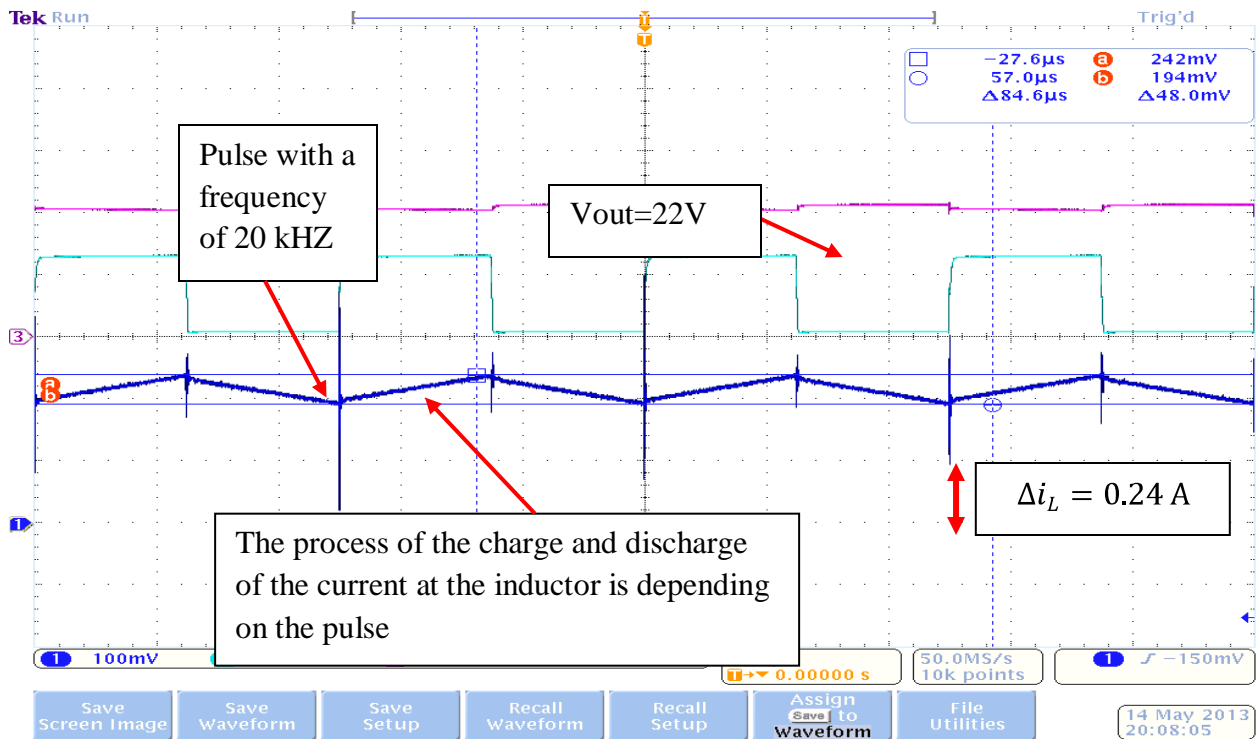


Figure 4.24: Pulse with a frequency, f of 20 kHz and the current ripple, i_L at the inductor

As can be seen in figure 4.25 below, the I_{max} is $235\text{mV/div} \times 5\text{mA} = 1.175\text{A}$ and the I_{min} is $202\text{mV/div} \times 5\text{mA} = 1.01$. Therefore, the Δi_L is 0.165A

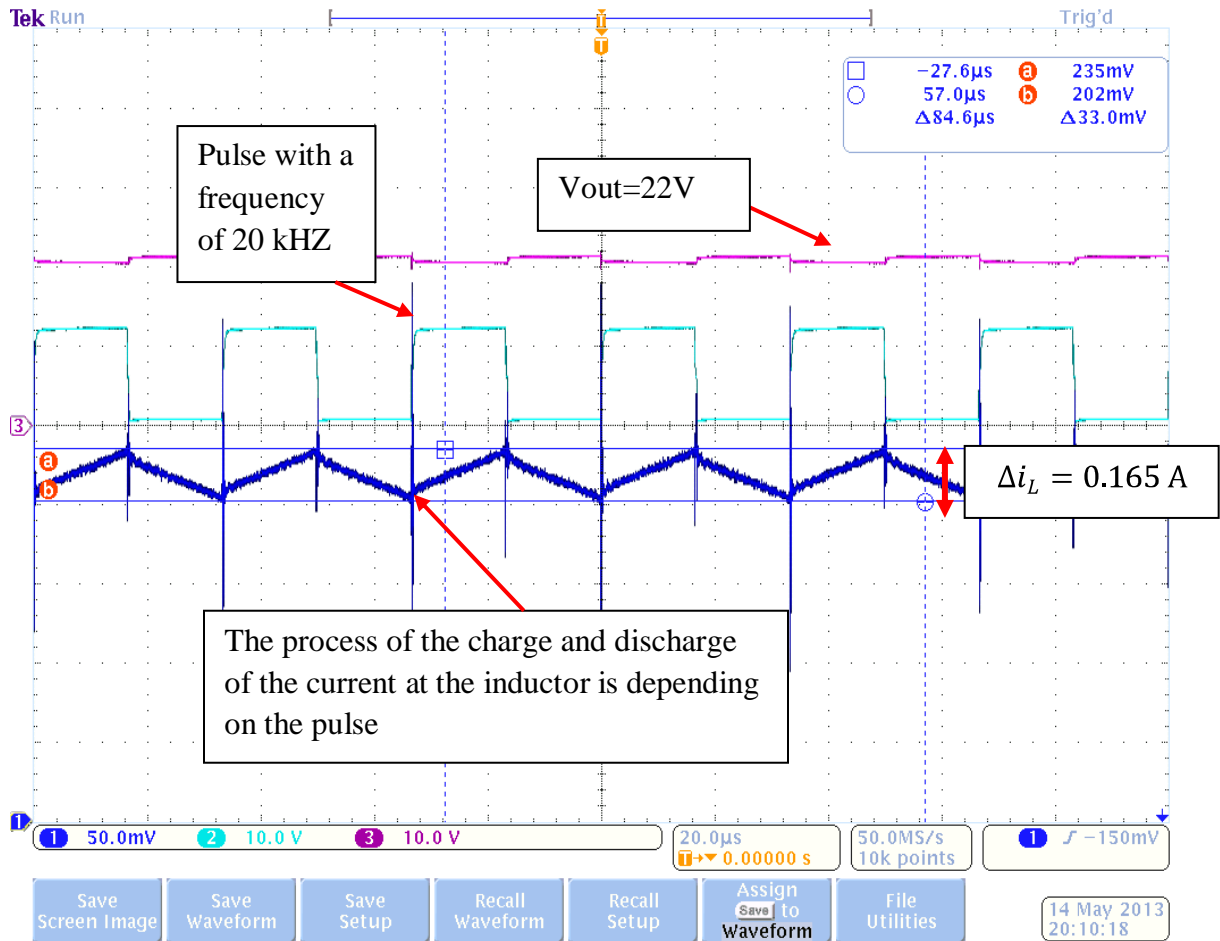


Figure 4.25: Pulse with a frequency, f of 30 kHz and the current ripple, i_L at the inductor

As for figure 4.26 below, when the frequency is increased to 40 kHz, the switching process would be faster in a second. In figure 4.26, the minimum current is 1 A and the maximum current is 1.15 A resulting of a current ripple, Δi_L of 0.15A.

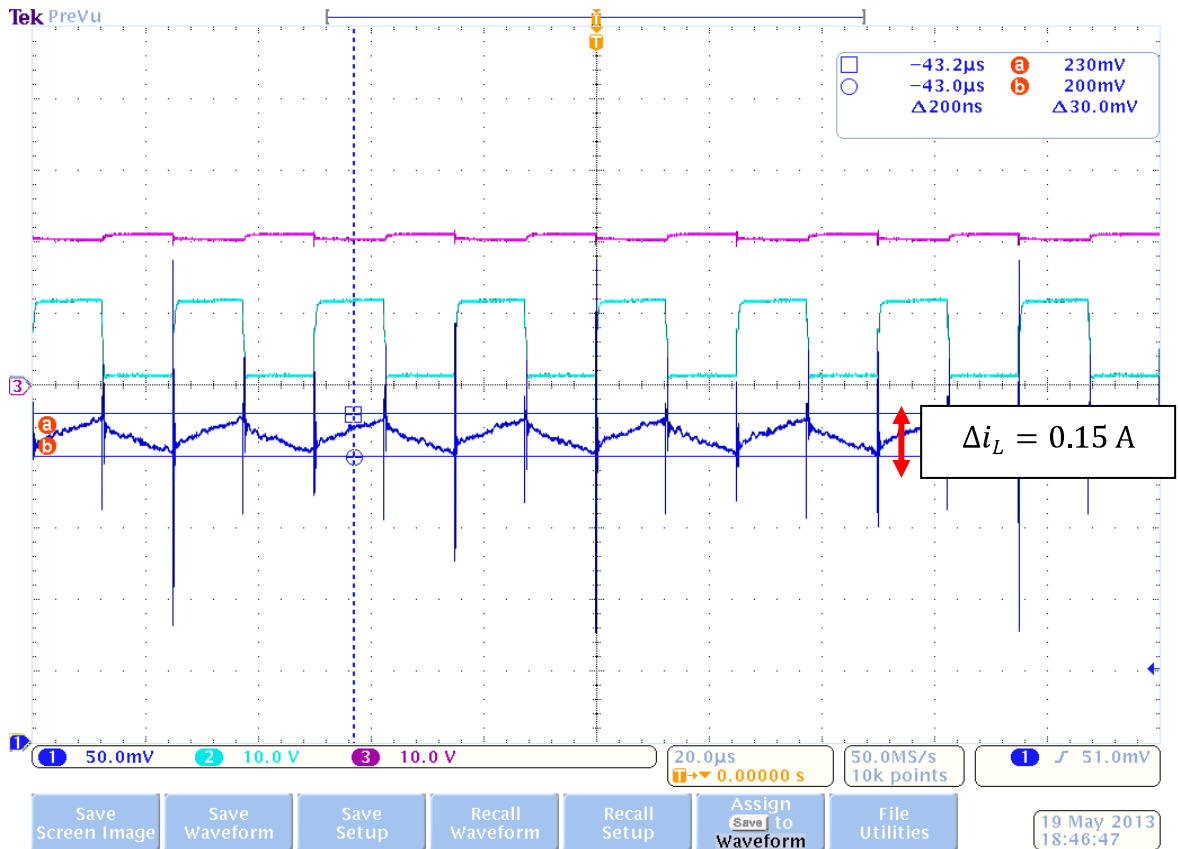


Figure 4.26: Pulse with a frequency, f of 40 kHz and the current ripple, i_L at the inductor

The frequency of the boost converter is added again to 50 kHz as illustrated in figure 4.27 below causing the switching process of the boost converter even faster. The current ripple would also reduce. The Δi_L is 0.125A.

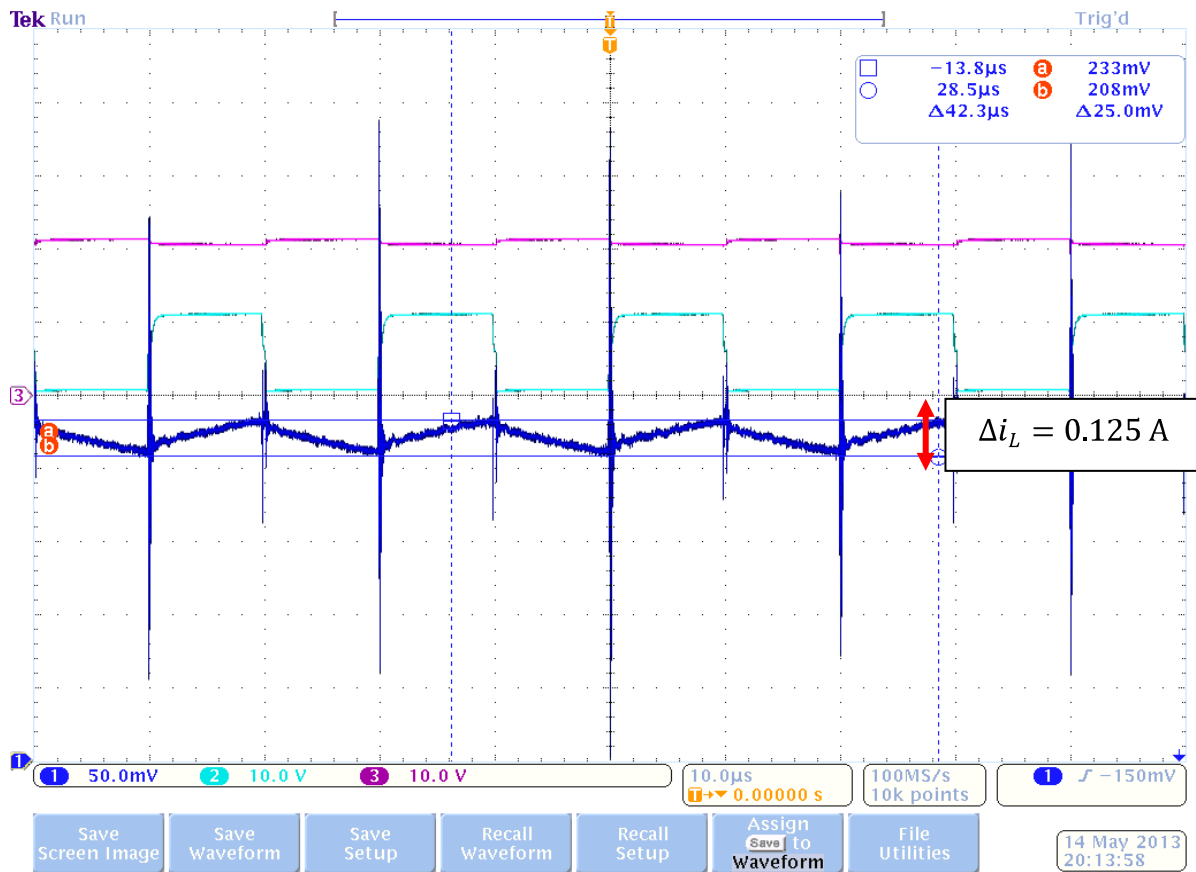


Figure 4.27: Pulse with a frequency, f of 50 kHz and the current ripple, i_L at the inductor

As can be seen in figure 4.28 below, the Δi_L calculated is 0.105 A with a frequency of 60 kHz.

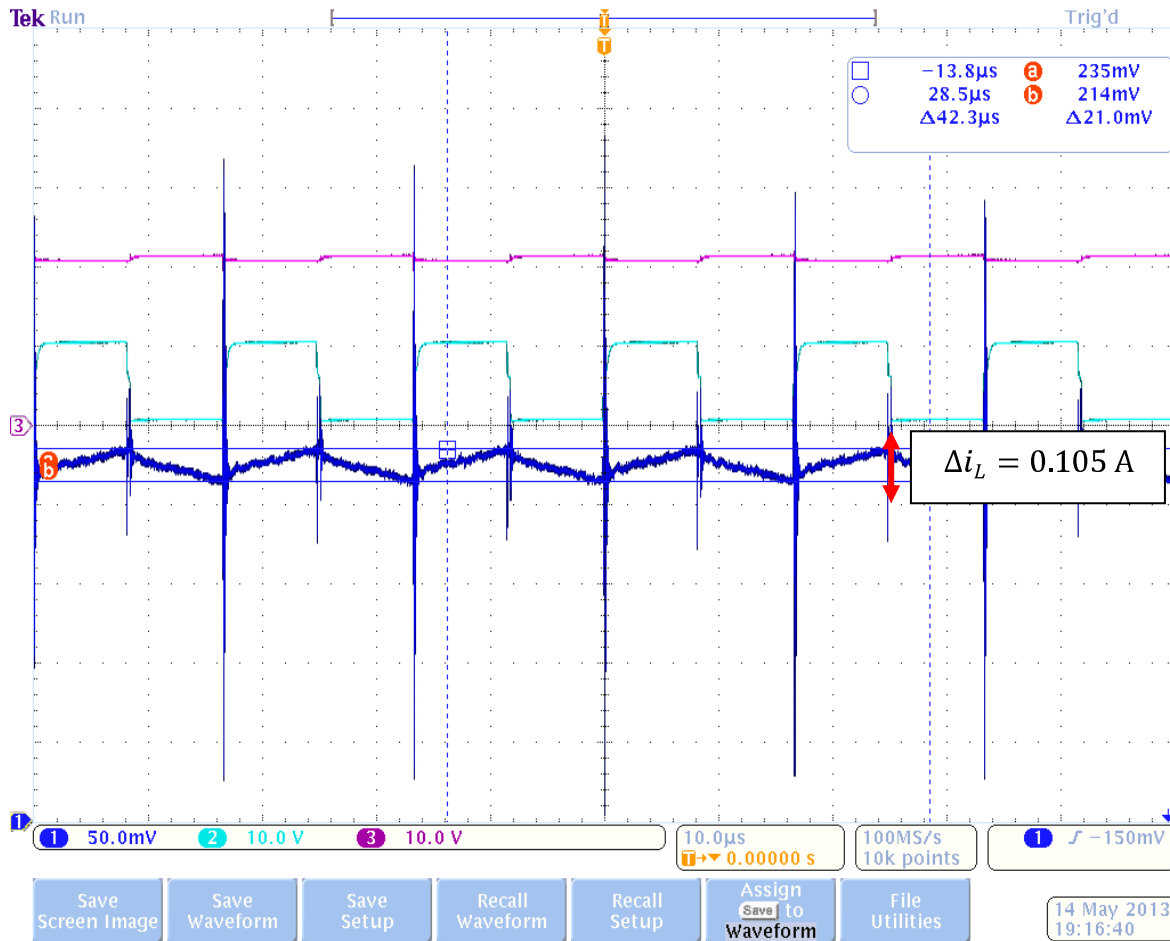


Figure 4.28: Pulse with a frequency, f of 60 kHz and the current ripple, i_L at the inductor

As can be seen in figure 4.29, the circuit is tested with a frequency of 70 kHz. The minimum current, I_{min} is 1.115A and the maximum current, I_{max} is 1.08A resulting of a current ripple of $\Delta i_L = 0.035A$. The circuit is then tested with a frequency of 80 kHz. When the frequency is increased, a buzzing sound starts to erupt. Since an unfamiliar sound is heard, the experiment is stopped abruptly.

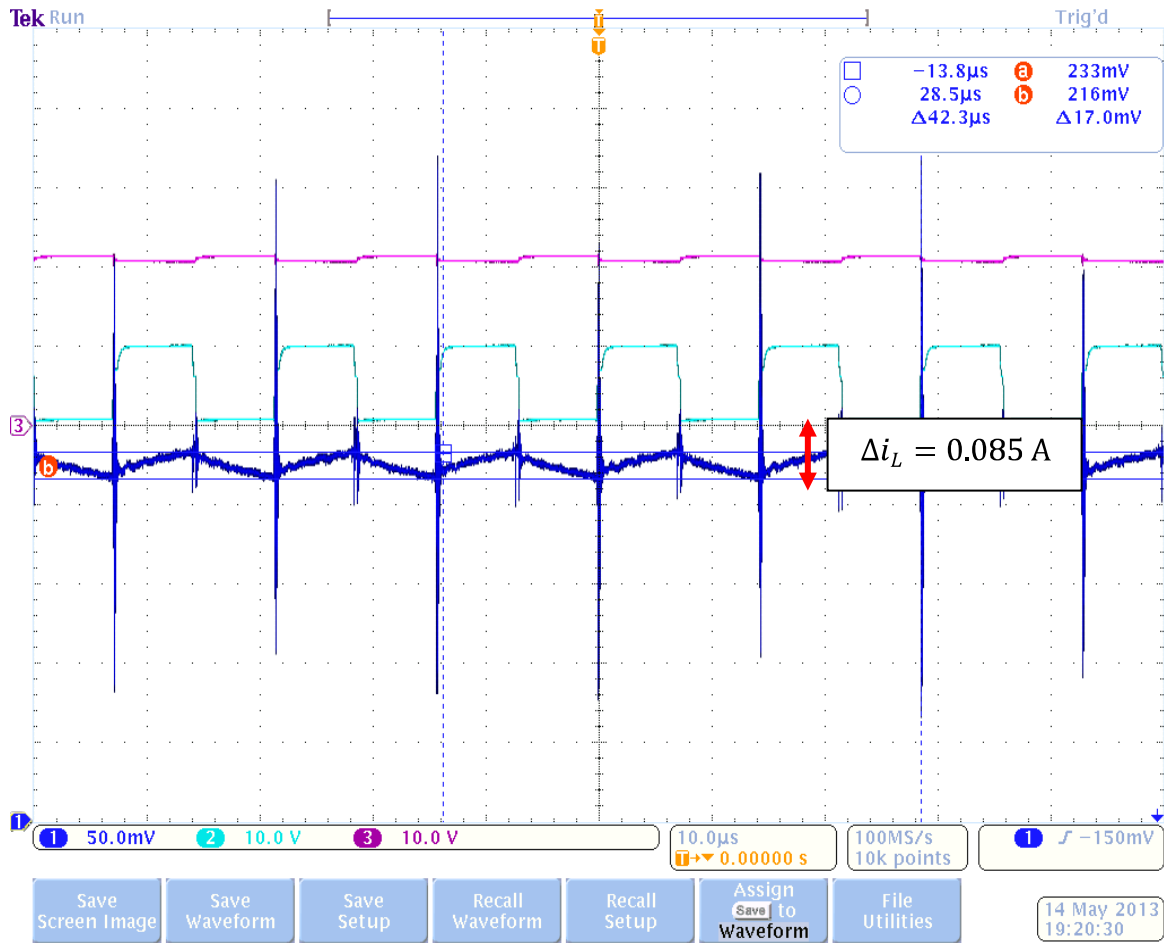


Figure 4.29: Pulse with a frequency, f of 70 kHz and the current ripple, i_L at the inductor

4.4.2 Case 2: The effect towards current ripple when the value of duty cycle is varied

As can be seen in figure 4.3, with a duty cycle of 10%, the turn on state is only for a brief second while the turn off state is longer. The current ripple is with a Δi_L of 0.048 A. Figure 4.31 below shows a Pulse with a duty cycle, D of 20% and the current ripple, i_L at the inductor is $\Delta i_L=0.095$ A.

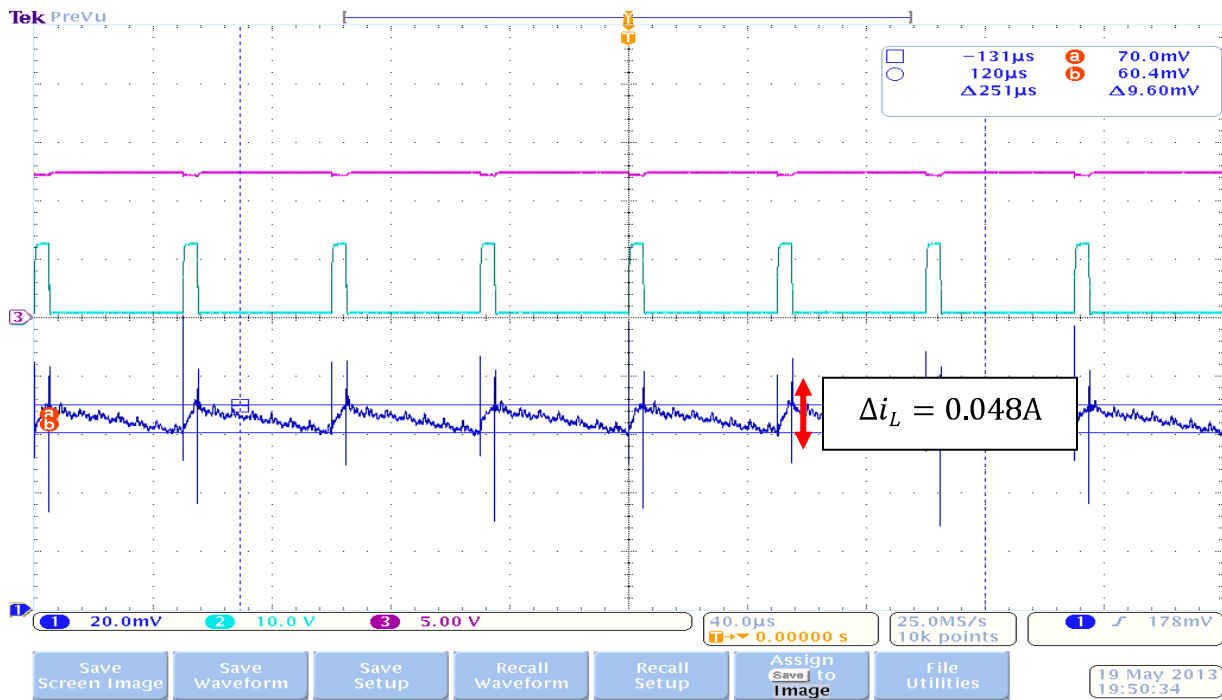


Figure 4.30: Pulse with a duty cycle, D of 10% and the current ripple, i_L at the inductor

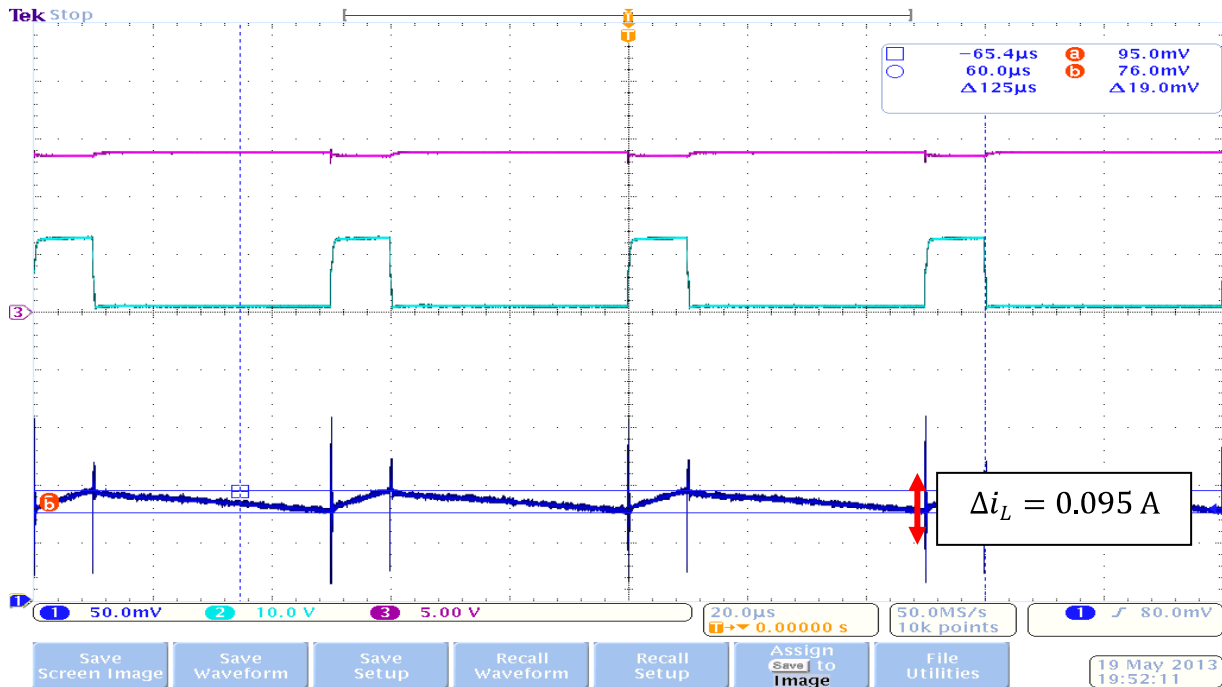


Figure 4.31: Pulse with a duty cycle, D of 20% and the current ripple, i_L at the inductor

Figure 4.32 below shows the effect of current ripple when the duty cycle is 30%. The current ripple is $\Delta i_L = 0.14 \text{ A}$.

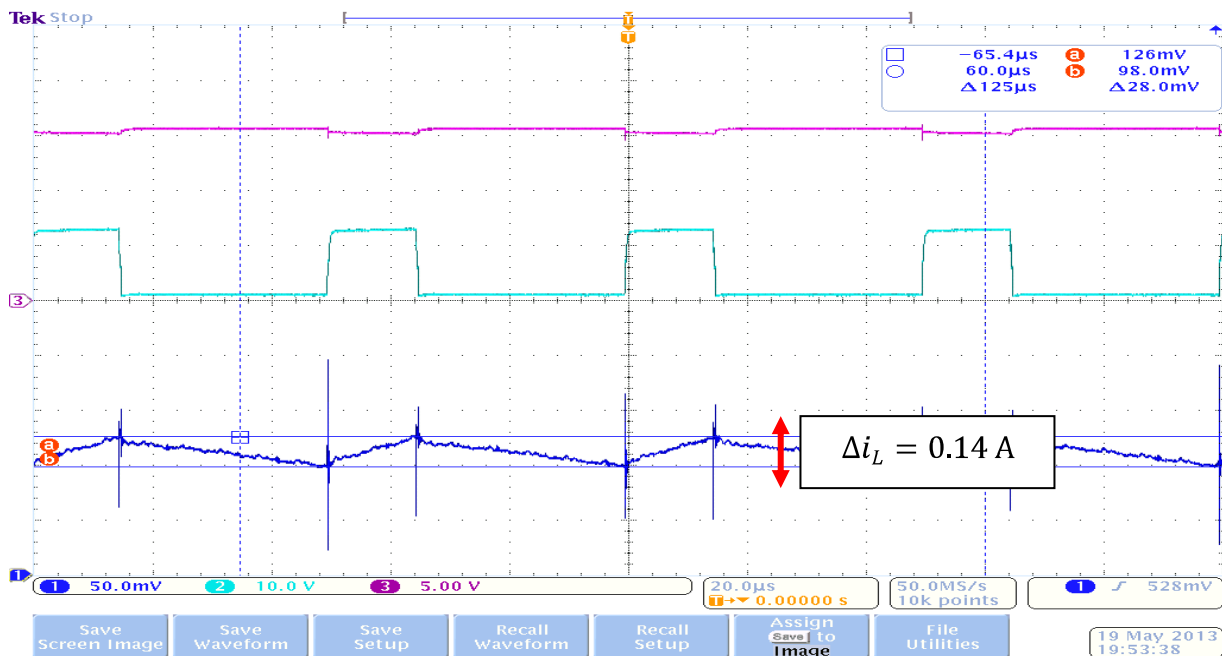


Figure 4.32: Pulse with a duty cycle, D of 30% and the current ripple, i_L at the inductor

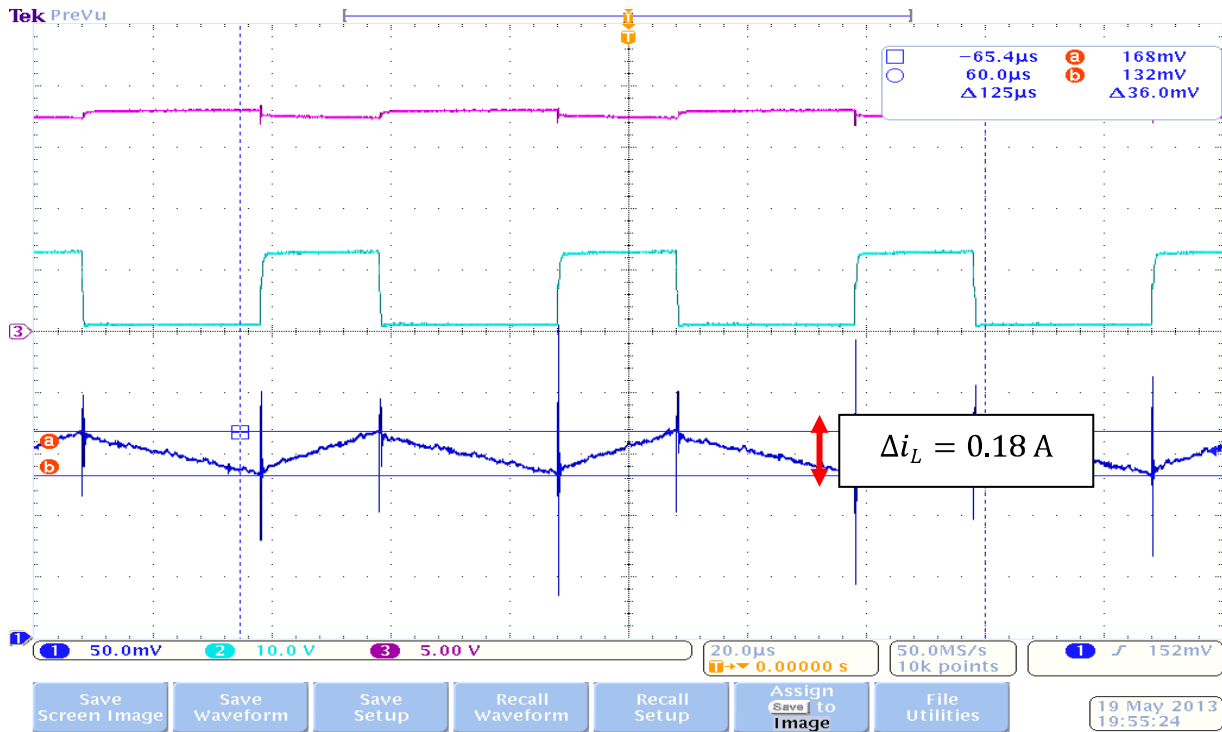


Figure 4.33: Pulse with a duty cycle, D of 40% and the current ripple, i_L at the inductor

As the duty cycle increases, the on state also increases. The charging of the current during the on state increases linearly. The current ripple $\Delta i_L = 0.18 \text{ A}$. As for a duty cycle for 50% as illustrated in figure 4.34 below, the current ripple also increase. The current ripple Δi_L for a duty cycle of 50% is 0.23 A .

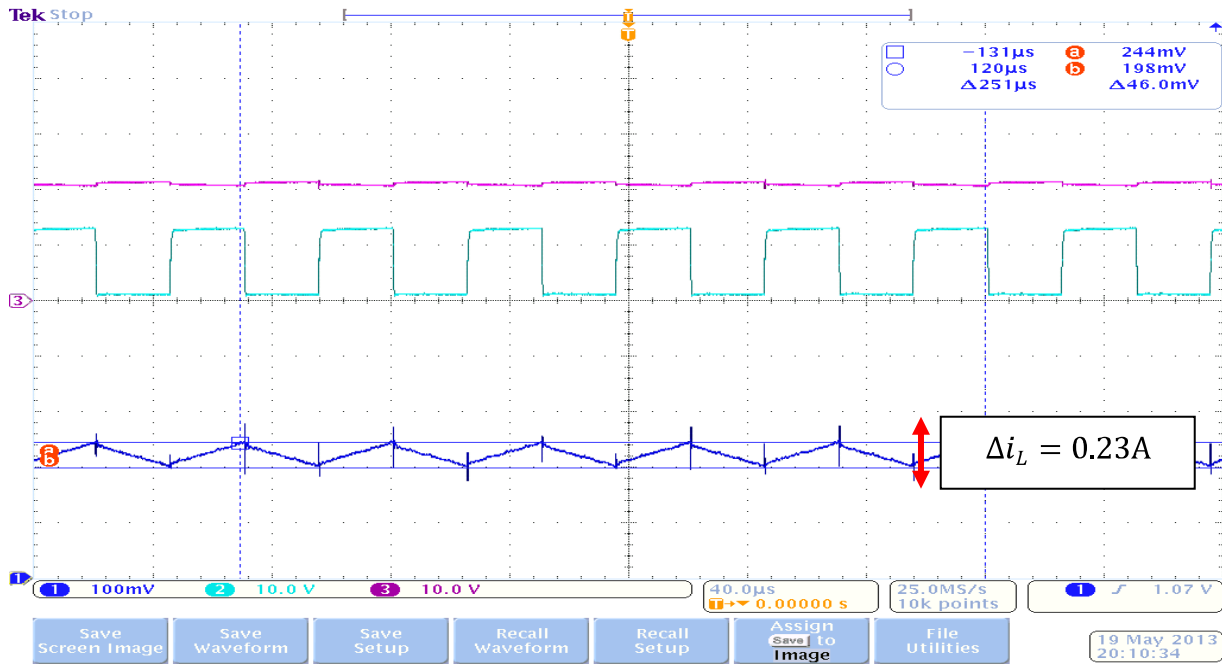


Figure 4.34: Pulse with a duty cycle, D of 50% and the current ripple, i_L at the inductor

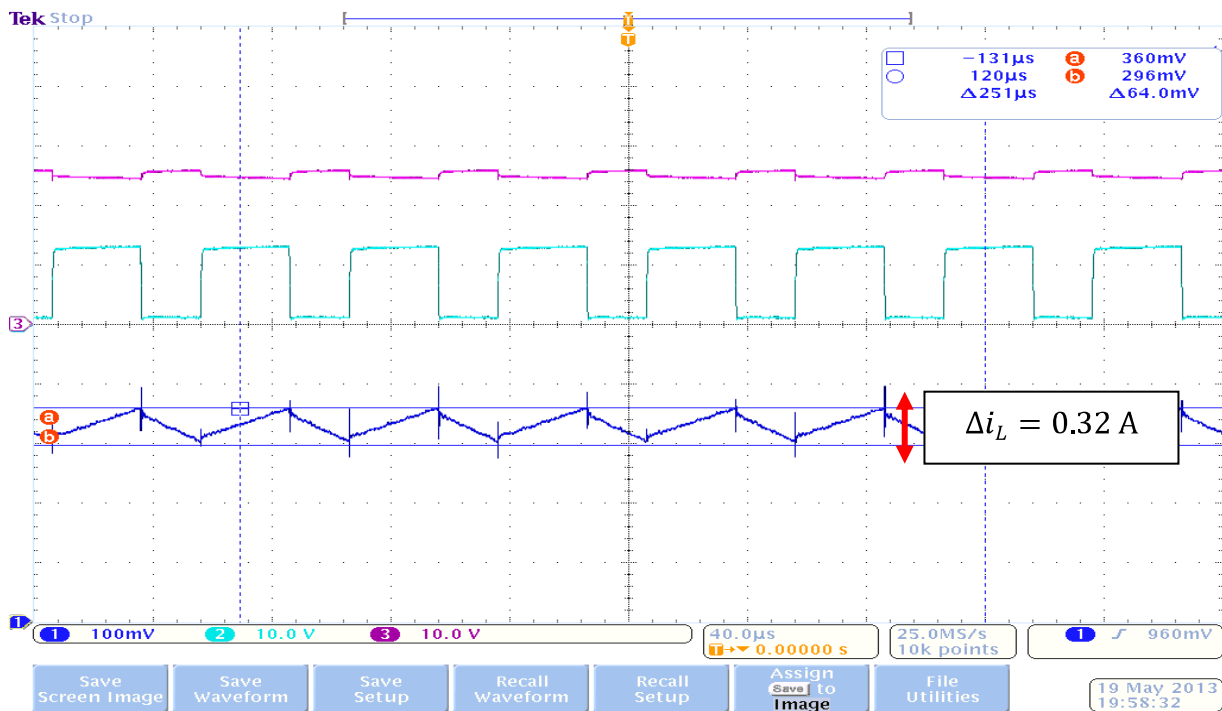


Figure 4.35: Pulse with a duty cycle, D of 60% and the current ripple, i_L at the inductor

Another 10% of duty cycle is increased as in figure 4.36 causing the duty cycle to be 60% of the input voltage. The current ripple Δi_L for 60% duty cycle is 0.5A. Figure 4.36 and figure

4.37 with a duty cycle of 70% and 80% the Δi_L with a duty cycle of 70% is 0.5A and the Δi_L for a duty cycle of 80% is 0.39A. as the duty cycle increases, so does the current ripple.



Figure 4.36: Pulse with a duty cycle, D of 70% and the current ripple, i_L at the inductor

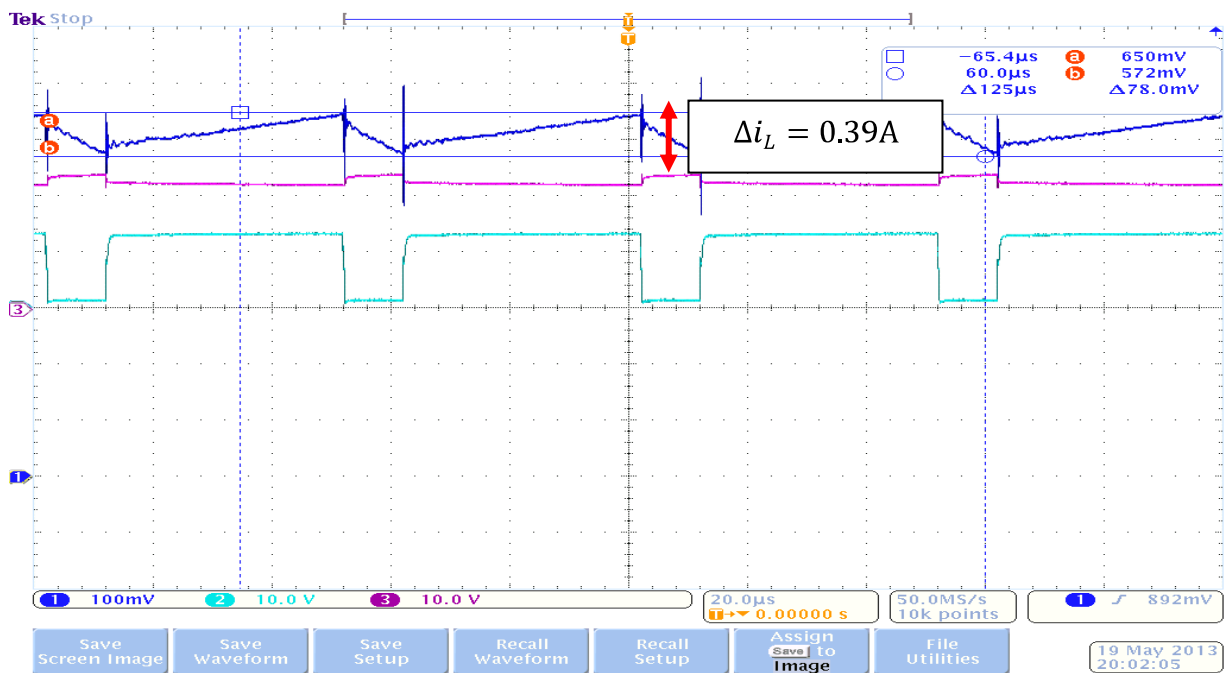


Figure 4.37: Pulse with a duty cycle, D of 80% and the current ripple, i_L at the inductor

4.4 Chapter summary

Chapter 4 is the results obtained from three methods on determining the effect of varying the duty cycle and the frequency towards the current ripple of the boost converter. Based on the result obtained, the higher the frequency, the lower the current ripple in the inductor but as for the duty cycle, the higher the duty cycle, the higher the current ripple in the boost converter. The analysis of the results obtained is discussed in the next chapter which is chapter 5: Analysis and discussion part of the report.

CHAPTER 5

ANALYSIS AND DISCUSSION

5.1 Introduction

Chapter 5 is where the analysis and discussion takes part. In this chapter, all the data for calculation, simulation and hardware is compared by placing all the values into a table thus it is being discussed and analyzed. It can be categorized into two cases which is case 1: Monitoring and analyzing the effect of the current ripple by varying the value of frequency and case 2: Monitoring and analyzing the effect of the current ripple if the value of duty cycle is varied. The result of calculation, simulation and experimental of both cases are discussed.

5.2 Analysis

5.2.1 Analysis on the effect towards the current ripple when varying the value of frequency

Table 5.2 shows the result of current ripple at the inductor, Δi_L (A) for calculation, simulation and experimental for frequency ranging from 10 kHz to 80 kHz. The frequency is varied by changing the T1PR command at the watch tab to 10 kHz, 20 kHz, 30 kHz, 40 kHz, 50 kHz, 60 kHz, 70 kHz and 80 kHz while maintaining the duty cycle to be 50%. All the data's are recorded. Based on the results obtained in table 5.2 it can be seen that as the frequency increases, the current ripple decreases. The calculation, simulation and experimental result values differ but are acceptable as all three results differ in an acceptable range. For simulation, the values are different than calculation is because of the type of solver used for the configuration parameter in the MATLAB simulink.

Different type of solver would result differently. The relative tolerance set to the simulink would also be the cause of the differences of value. As for the experimental part, the result differ from the calculation as the components is not ideal since each components has its own tolerance as well as other factors that affect the circuit such as voltage drop and losses during the switching process. Even so, all three methods, calculation, simulation and experimental shows the same pattern whereas, the higher the frequency, the lower the current ripple.

Table 5.1: Δi_L (A) for calculation, simulation and experimental when varying the value of frequency

Frequency (kHz)	Δi_L (A): Calculation	Δi_L (A): Simulation	Δi_L (A): Experimental
10	0.428	0.421	0.42
20	0.214	0.211	0.24
30	0.143	0.143	0.165
40	0.107	0.108	0.145
50	0.0857	0.062	0.125
60	0.0714	0.061	0.105
70	0.0612	0.057	0.085
80	0.0535	0.053	-

In the experimental part of the project, the graphs obtained are captured and saved from the oscilloscope. The result as stated at the upper right corner of the result graph is in mV. Since the configuration scale set between the current transducer and the oscilloscope is 100mV/div for every 500mA (1:5m), the amount of mV needs to be converted into the actual value (in current, A). The current transducer is used to magnify the result obtained (to enlarge the scale) so that the output can be monitored and seen at the oscilloscope as well for galvanic isolation between the primary and the secondary circuit.

Based on the result in figure 5.1 below, the current ripple, Δi_L from Eq. (5-3) when the frequency is 10 kHz is with a maximum current, I_{max} of 1.29A obtained from $(258 \times 5m = 1.29A)$ and a minimum current, I_{min} of 0.87A obtained from $(174 \times 5m = 0.87A)$ thus the Δi_L is

$$\Delta i_L = I_{max} - I_{min} \quad (5-3)$$

$$\begin{aligned} \Delta i_L &= 1.29 - 0.87 \\ &= 0.42 \text{ A} \end{aligned}$$

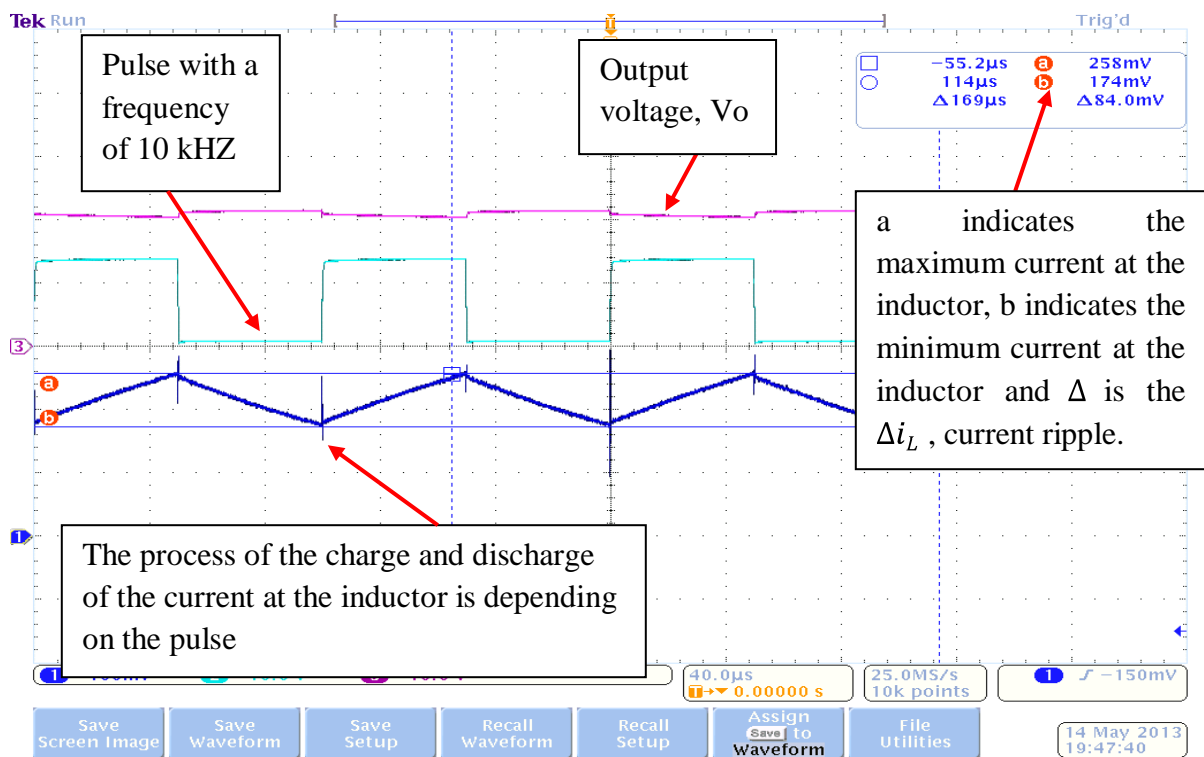


Figure 5.1: Obtaining the result from graph

Compared to the 10 kHz output in chapter 4 figure 4.2 simulation part, the cycle of per pulse in a boost converter of 80 kHz is faster which includes 8 pulses for each 0.1ms. Therefore it can be stated that, the higher the frequency, the faster the switching for each 0.1ms. When talking about high frequency, the design of the circuit requires more attention on parasitic impedances which includes the effect from the PCB layout, and spikes due to

switching. The current ripple, Δi_L when the frequency is 80 kHz is with a maximum current, I_{max} of 1.272A and a minimum current, I_{min} of 1.219A thus the Δi_L from Eq. (4-3) is $\Delta i_L = 1.271 - 1.219 = 0.053 A$. As for the experimental result, no result is obtained for the frequency of the boost converter of 80 kHz. This is because, during the experimental base, once the frequency at the DSP program T1PR is changed to have a frequency of 80 kHz, a buzzing sound erupts throughout the experiment. The experiment was stopped abruptly. When analysis and research is done, it is concluded that the buzzing sound is the effect from the inductor. Since the switching is too fast, the operation between the switch turn on and switch turn off becomes fast causing the buzzing sound due to the alternating magnetic field in the coils of the inductor reacting against the wires and the core of the inductor. To eliminate this buzzing sound, better mechanical construction of the inductor is needed. Based on the figure 5.2: Graph of current ripple reduction by varying the value of frequency below, the result obtained from the experimental hardware matches the result obtained from the simulation and calculation and satisfies the results obtained from previous researches that the higher the frequency is set to the boost converter, the smaller the current ripple of the boost converter. These results are based on the values obtained from Table 5.1: Current ripple, Δi_L (A) for calculation, simulation and experimental

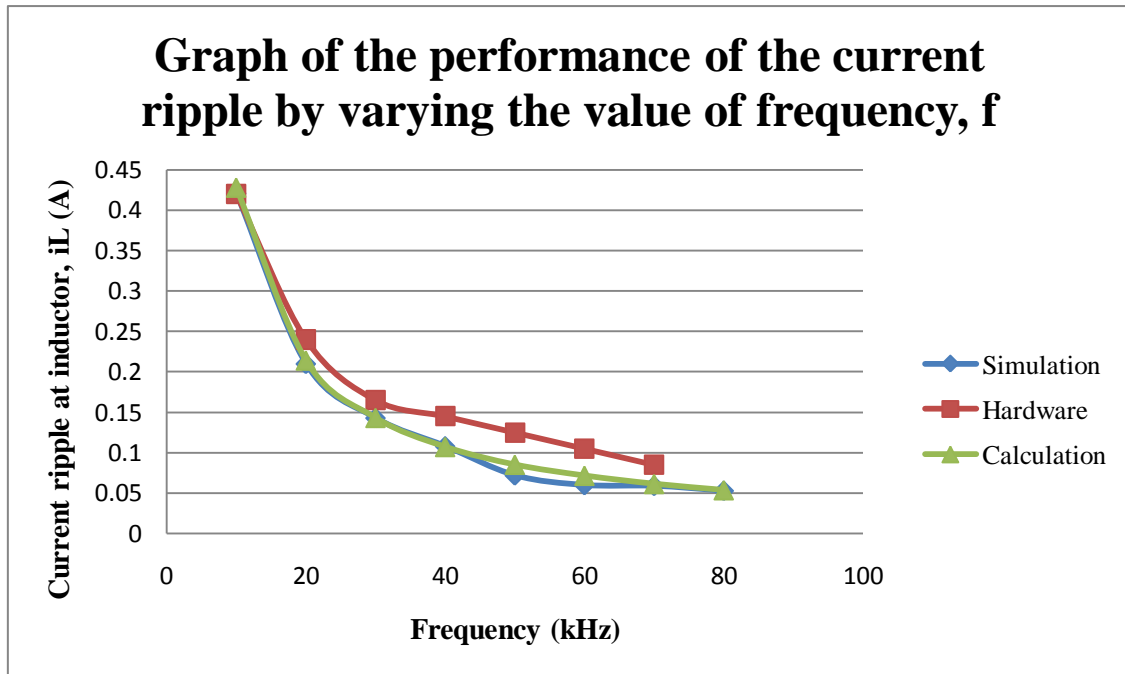


Figure 5.2: Graph of current ripple reduction by varying the value of frequency

5.2.2 Analysis on the effect towards the current ripple when varying the value of duty cycle

The next case is to see the effect of varying the duty cycle towards the current ripple. The parameters are remained constant as the previous case (varying the value of frequency) but only the duty cycle varies.

Table 5.2 below shows the result of current ripple at the inductor, Δi_L (A) for calculation, simulation and experimental for duty cycle ranging from 10 % to 90%. The duty cycle is varied by changing the T1CPR command at the watch tab to 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% while maintaining the frequency to be 20 kHz. All the data's are recorded as presented in table 5.2.

Table 5.2: Varying the value of duty cycle

Duty cycle, D	Calculation		Simulation		Experimental	
	Δi_L (A)	Vout (V)	Δi_L (A)	Vout (V)	Δi_L (A)	Vout (V)
0.1	0.0428	13.33	0.0418	13.33	0.048	12.37
0.2	0.085714	15	0.0846	15	0.095	13.79
0.3	0.1284	17.14	0.1284	17.14	0.14	15.56
0.4	0.1714	20	0.1675	20	0.18	17.83
0.5	0.214	24	0.2110	24	0.23	20.83
0.6	0.25714	30	0.2570	30	0.32	24.91
0.7	0.3	40	0.3000	40	0.5	30.54
0.8	0.348	60	0.3430	60	0.39	22.65
0.9	0.3857	120	0.3800	120	0.18	11.09

In the simulation part, all data's are obtained from 10% of duty cycle up to 90%. For a duty cycle of 10%, the time on of the pulse generated is only 10% of the total time or period of the pulse causing the current to charge at a short period and discharge at a longer period.

In the hardware part is also with a scale of $100\text{mV}/\text{div}=500\text{mA}$ which is equivalent to 1: 5m as explained in case 1: Current ripple reduction by varying the value of frequency (In the hardware part), it can be seen that when the duty cycle is 10% of the input voltage, the output voltage increases up to 12.37V from a 12V input. This is related to the equation (2-3). The output voltage is directly proportional the amount of duty cycle that is set; therefore the larger the duty cycle, the bigger the output voltage and the larger the duty cycle, the current ripple would enhance as well. In the experimental part, when the duty cycle is increased up to 70% the output voltage increases up to 30.50V from an input of 12V. The current ripple also increases up to 0.5A. Another 10% is increased to the duty cycle which results to a duty cycle of 80%. The output voltage and the current ripple starts to drop to 22.65V and 0.39A. This event is possible due to the switching itself. The time off of the pulse is too short that no switching is likely to happen as 2 pulses occur for every 0.001s.

This condition continues as the duty cycle is set to 90% of the input voltage causing the output voltage to drop to 11.09V and a current ripple of 0.18A. When the duty cycle is 90%, the inductor would reach a saturation point whereby would act almost to have the characteristic of a DC. The inductor would act like a short circuit to the DC causing the voltage and current to drop. This case only apply to the experimental part this is because, in calculation and simulation, both are based on ideal cases unlike the experimental part where real time application is applied whereby the losses and voltage drop as well as the components used may affect the performance of the circuit itself.

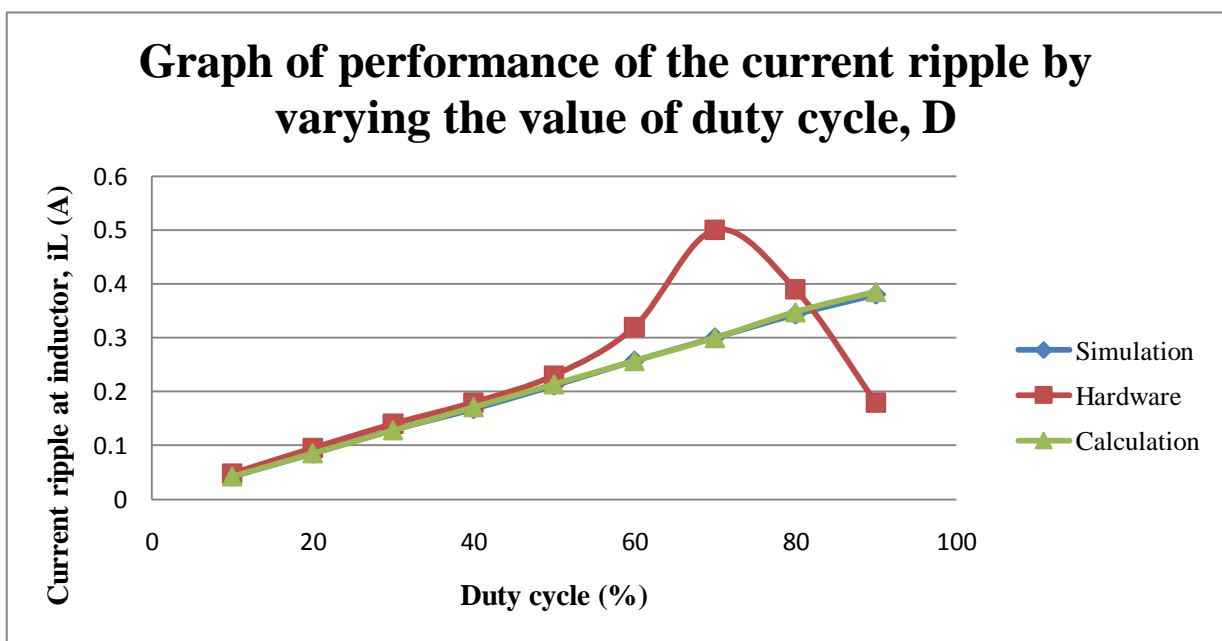


Figure 5.3: Graph of performance of the current ripple by varying the value of duty cycle, D

As illustrated in the graph of performance of the current ripple by varying the value of duty cycle, D in figure 5.3 above, the calculation and simulation matches as the higher the duty cycle which results in a longer time on and a shorter period of time off, the current ripple increases. As shown in the figure 5.3 above, the hardware result differs a when the duty cycle reaches 80%. When the duty cycle reaches 80% the current ripple starts to decrease. This is because, the output voltage also decreases since the switching has reached a peak where the time off of the pulse is too brief. When the time off per cycle is too brief, the switching is most likely unable to switch (making switch close all the time) this would cause the voltage to drop

as illustrated in figure 5.4 below. Therefore, it can be stated that the minimum duty cycle is 10% and the maximum duty cycle available for the parameters used is only up 70%.

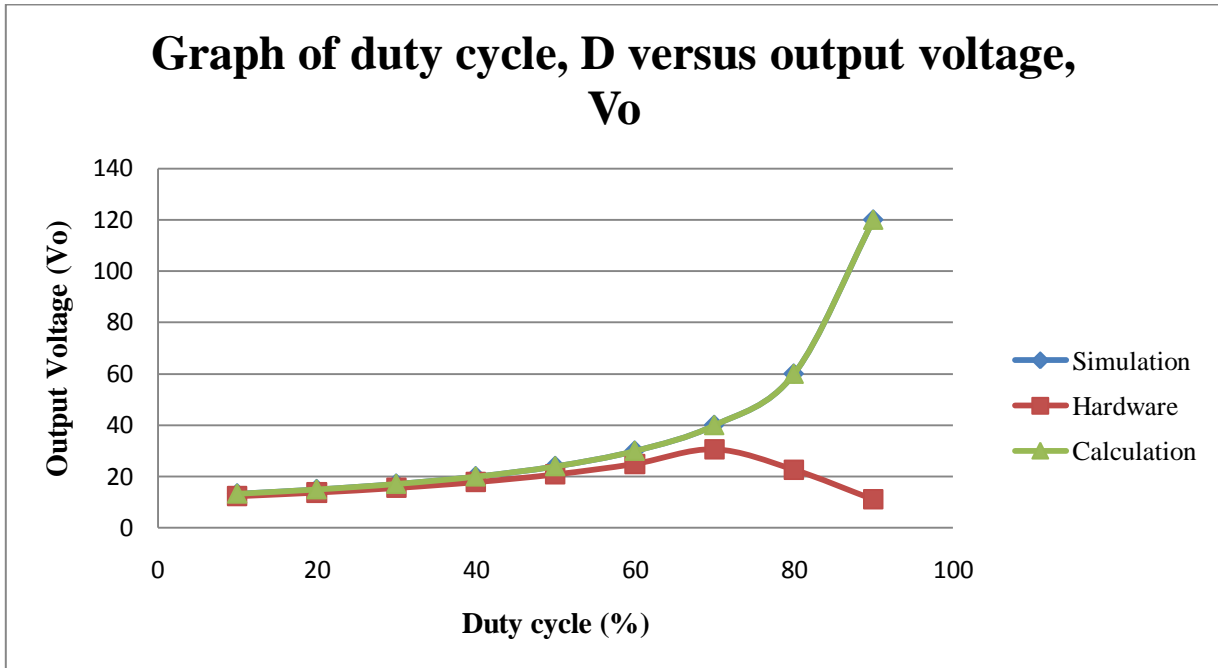


Figure 5.4: Graph of duty cycle, D versus output voltage, V_o

5.3 Chapter Summary

Chapter 5 analyzes and discusses on the process of obtaining the result by varying the value of frequency and by varying the value of duty cycle of the boost converter. Based on these parameters, the affect that both parameters bring is seen. The higher the frequency, the lower the current ripple in the boost converter but as for the duty cycle, the higher the duty cycle, the higher the current ripple in the boost converter.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Introduction

Chapter 6 includes the conclusion obtained from the implementation of the project entitled simulation and design of the DC-DC switching boost converter for current ripple reduction. This chapter also includes the recommendation part for future improvements to be made.

6.2 Conclusion

As a conclusion, all the objectives are achieved. Four objectives has been set from the beginning of the project whereby the first objective is to design a DC-DC switching boost converter and to obtain the correct parameters of a DC-DC switching boost converter for current ripple reduction. For a boost converter or also known as the step up converter, the output voltage is larger than the input voltage. When the pulse created through the DSP TMS320F2812 gives an on state to the boost converter, the current through the inductor increases therefore the inductor starts to charge energy. When the pulse is at the off state, the energy stored in the inductor starts to dissipate causing the inductor to discharge. The current is forced to flow through the diode and load during the off state. Due to this phenomenon, the voltage across the load exceeds the source voltage. Based on the results obtained, the higher the duty cycle, the higher the current ripple will be. But to select the duty cycle, it is important to determine the application that needs to be used. This is because, the duty cycle relates directly to the output voltage. When the duty cycle increases, the so does the output voltage. As for the varying the value of the frequency, the higher the frequency, the lower the current ripple. A high switching frequency is desired to reduce the current ripple. The second objective is to understand the effect of switching to current ripple. This objective is directly

related to parameters that are varied (frequency and duty cycle). This is because, the frequency determines how many pulse it is in a second. The higher the frequency, the faster the switching process within a second it is. As for the duty cycle, it controls the switching of the boost converter for the on and off state. It is either the turn on state is longer than the turn off state causing the time for the inductor to charge slower and to discharge faster or the opposite. As for the third and fourth objective, it has been accomplished throughout the implementation of the project. The DC-DC switching boost converter for current ripple is modeled, simulated and analyzed using the MATLAB software and the hardware prototype of the DC-DC boost converter is developed with a switching control from a program developed in the DSP TMS320F2812.

6.3 Recommendation

The switching topology using the DSP TMS320F2812 is definite reliable way to control the switching of the pulse as the switching can be edited at will by directly re-uploading the program into the DSP. As the switching process continues, the high current switching would generate noise as well as voltage spike during the turn off and turn on state of the switching process. In this project implemented, only a basic boost circuit is developed. In order to overcome the downsides of the switching phenomenon, special measures like filtering, shielding of components is recommended. In this project, a lot of power supply is used at a time which includes, the input voltage for the boost converter, the 5V input voltage for the gate drive circuit, the 5V input voltage for the digital signal processing and a +/- of 15V for the current transducer. It is recommended for further studies on how to reduce these input powers as required. The boost converter developed is bulky in size. For future development, it is recommended to build a boost converter that is small in size but with high performance.

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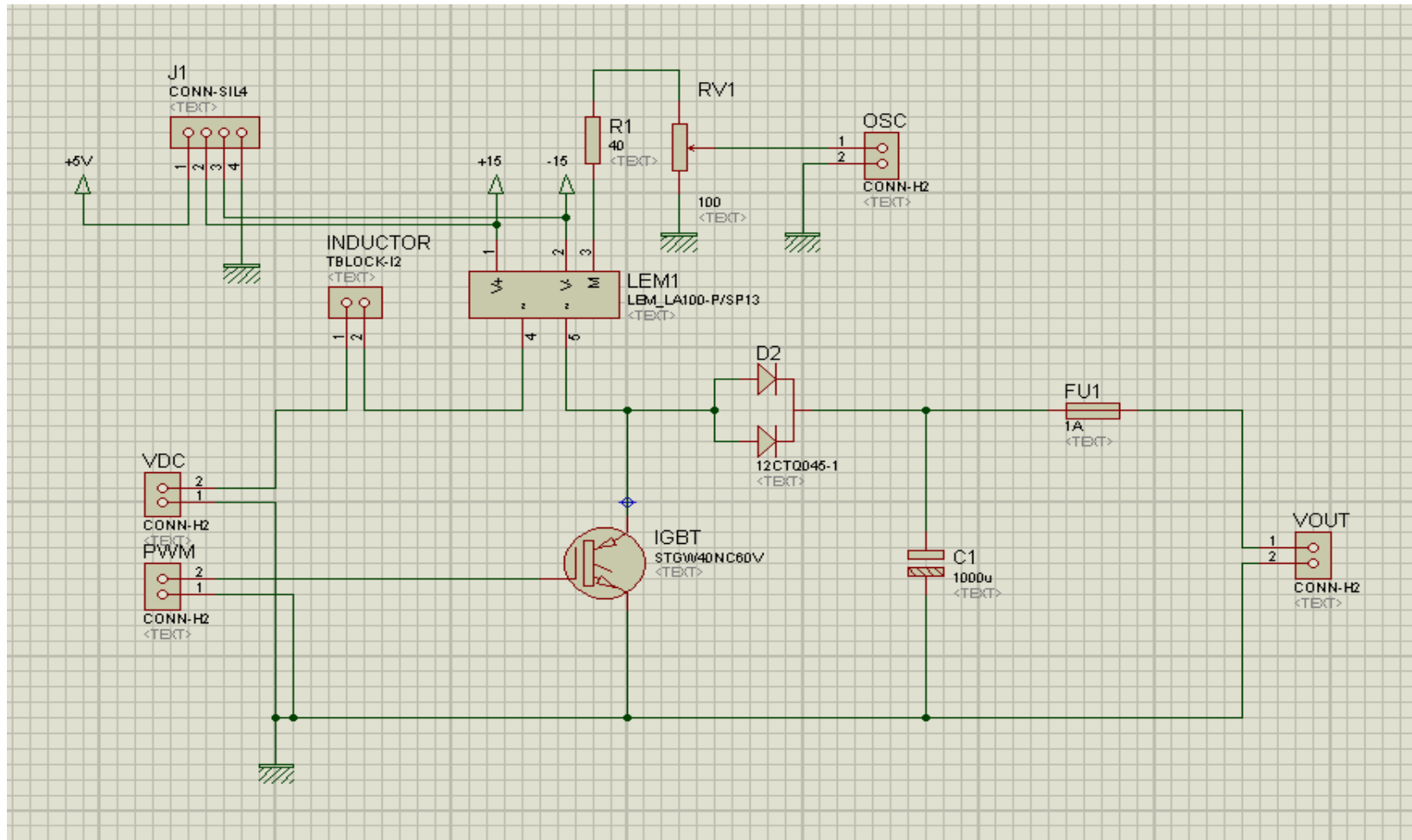
APPENDIX A

Project Schedule of Project Activities (Gantt chart)

No.	Task	Month																		
		Sept 2012		Oct 2012		Nov 2012		Dec 2012		Jan 2013		Feb 2013		March 2013		April 2013		May 2013		June 2013
	Week	W1	W3	W5	W7	W9	W11	W13	W15	W17	W19	W1	W3	W5	W7	W9	W11	W13	W15	W17
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		W2	W4	W6	W8	W1	W12	W14	W16	W18	W20	W2	W4	W6	W8	W10	W12	W14	W16	W18
1	FYP title selection -Research and analysis																			
2	Research on related materials																			
3	Preparation of FYP project proposal -Project background, problem statement, objective, gantt chart, flow chart																			
4	Submission of FYP project proposal																			
5	Theoretical based analysis																			
6	Calculation based analysis																			
7	Software based analysis																			
8	Simulation based analysis																			
9	Preparation of progress report -abstract, problem statement, objective, project scope, literature review, methodology, result and discussion, conclusion																			
10	Switching controller (DSP TMS320F2812)																			
11	Components instalment via electrical part																			
12	Testing and problem troubleshoot																			
13	Submit first FYP draft report																			
14	Preparation for oral presentation																			
15	Oral presentation																			
16	Submission of FYP final draft report and logbook																			
17	Submission of technical report																			

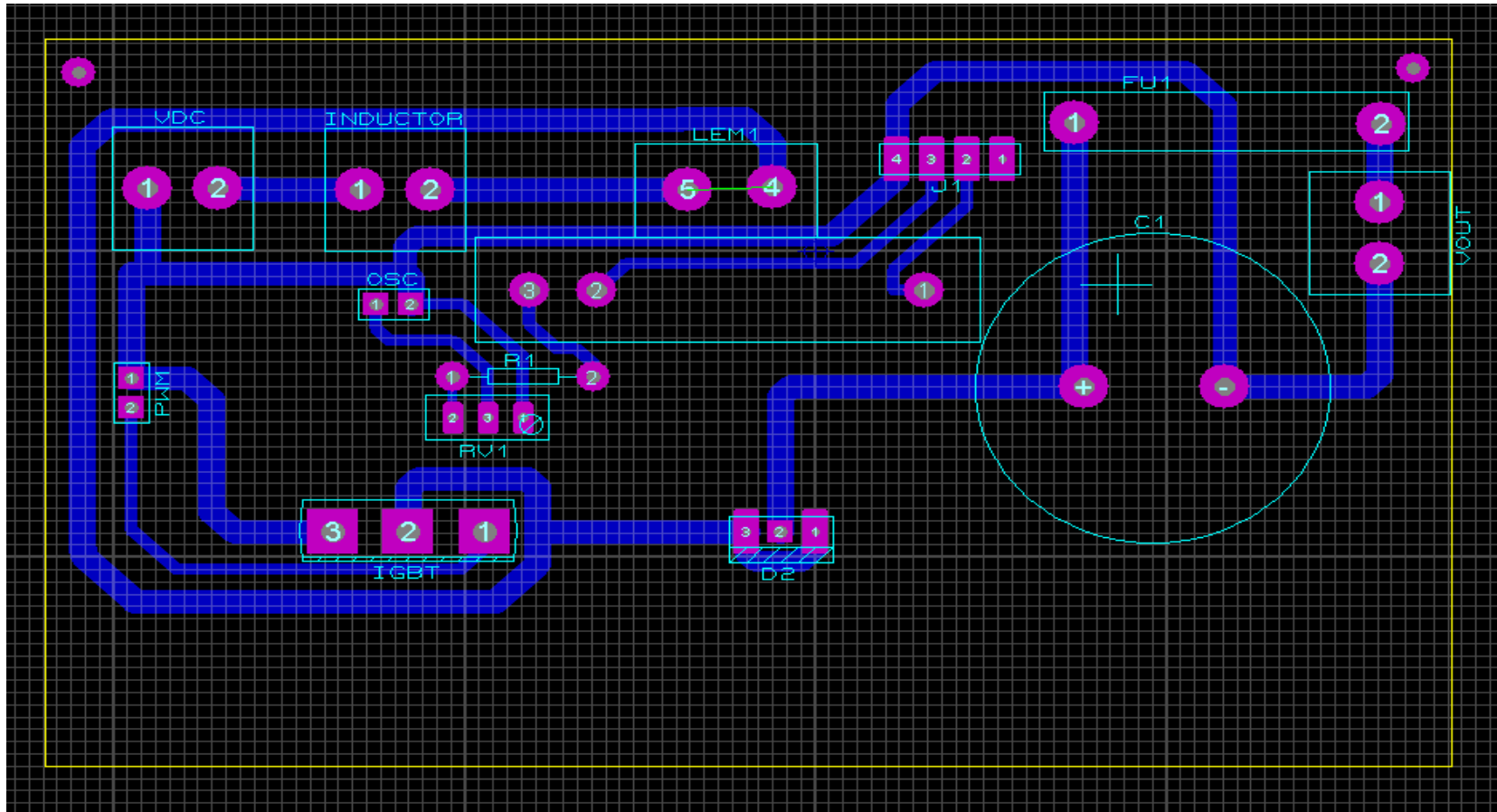
APPENDIX B

BOOST CIRCUIT LAYOUT DIAGRAM



APPENDIX C

BOOST CIRCUIT SCHEMATIC DIAGRAM



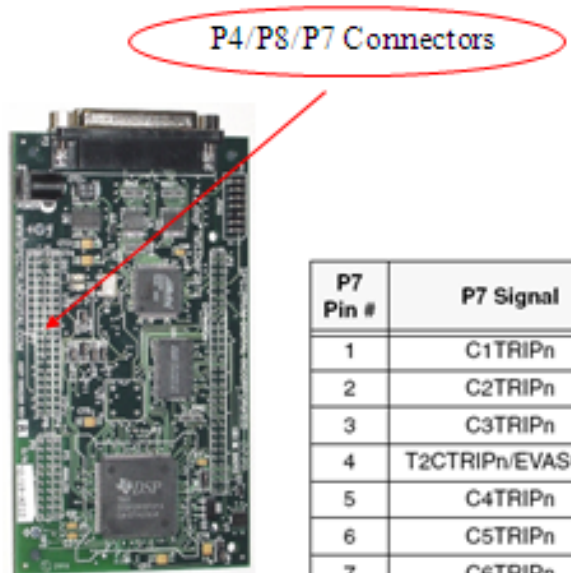
APPENDIX D

INPUT/ OUTPUT CONNECTOR AND SIGNAL DESCRIPTION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	P4	
2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	P8	
1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39		
1	2	3	4	5	6	7	8	9	10	P7											

Signal Description

P4 Pin #	P4 Signal	P8 Pin #	P8 Signal	P8 Pin #	P8 Signal
1	+3.3V/+5V/NC *	1	+3.3V/+5V/NC *	2	+3.3V/+5V/NC *
2	XINT2/ADCSOC	3	SCITXDA	4	SCIRXDA
3	MCLKXA	5	XINT1n/XBIO _n	6	CAP1/QEP1
4	MCLKRA	7	CAP2/QEP2	8	CAP3/QEP11
5	MFSXA	9	PWM1	10	PWM2
6	MFSRA	11	PWM3	12	PWM4
7	MDXA	13	PWM5	14	PWM6
8	MDRA	15	T1PWM/T1CMP	16	T2PWM/T2CMP
9	No connect	17	TDIRA	18	TCLKINA
10	GND	19	GND	20	GND
11	CAP5/QEP4	21	No connect	22	XINT1N/XBIO _n
12	CAP6/QEPI2	23	SPISIMOA	24	SPISOMIA
13	T3PWM/T3CMP	25	SPICLKA	26	SPISTEA
14	T4PWM/T4CMP	27	CANTXA	28	CANRXA
15	TDIRB	29	XCLKOUT	30	PWM7
16	TCLKINB	31	PWM8	32	PWM9
17	XF/XPLLDIS _n	33	PWM10	34	PWM11
18	SCITXDB	35	PWM12	36	CAP4/QEP3
19	SCIRXDB	37	T1CTRIP/PDPINT _n	38	T3CTRIP/PDPINT _{Bn}
20	GND	39	GND	40	GND



P7 Pin #	P7 Signal
1	C1TRIP _n
2	C2TRIP _n
3	C3TRIP _n
4	T2CTRIP _n /EVASOC _n
5	C4TRIP _n
6	C5TRIP _n
7	C6TRIP _n
8	T4CTRIP _n /EVBSOC _n
9	No connect
10	GND

APPENDIX E**PROGRAM FOR PWM**

```
#include "DSP281x_Device.h"
#include "IQmathLib.h"

// function call declaration
void Gpio_select(void);
void InitSystem(void);
interrupt void T1_Compare_isr(void);

void main(void)
{
    InitSystem();          // Initialize DSP's core registers

// function call declaration
    Gpio_select();
    InitPieCtrl();
    InitPieVectTable();

//enable interrupt & synchronous with timer
    EALLOW;
    PieVectTable.T1CINT = &T1_Compare_isr;
    EDIS;

    PieCtrlRegs.PIEIER2.bit.INTx5=1;

    IER = 2; //interrupt enable register

    EINT;
```

```

ERTM;

EvaRegs.GPTCONA.bit.TCMPOE = 1;
EvaRegs.GPTCONA.bit.T1PIN = 1;

//General purpose timer 1 control register
EvaRegs.T1CON.bit.FREE = 0;
EvaRegs.T1CON.bit.SOFT = 0;
EvaRegs.T1CON.bit.TMODE = 2;
EvaRegs.T1CON.bit.TPS = 0;
EvaRegs.T1CON.bit.TENABLE = 0;
EvaRegs.T1CON.bit.TCLKS10 = 0;
EvaRegs.T1CON.bit.TCLD10 = 0;
EvaRegs.T1CON.bit.TECMPR = 1;

//To vary frequency and duty cycle
EvaRegs.T1PR = 1500;
EvaRegs.T1CMPR = 750;

EvaRegs.EVAIMRA.bit.T1CINT = 1;
EvaRegs.T1CON.bit.TENABLE = 1;

while(1)
{
    EALLOW;
    SysCtrlRegs.WDKEY = 0xAA;
    EDIS;
}
}
void Gpio_select(void)
{

```

```

    EALLOW;
    GpioMuxRegs.GPAMUX.bit.T1PWM_GPIOA6 = 1;

GpioMuxRegs.GPADIR.all = 0x00FF;
GpioMuxRegs.GPAQUAL.all = 0x0;

    EDIS;
}
void InitSystem(void)
{
    EALLOW;
    SysCtrlRegs.WDCR= 0x00AF;

    SysCtrlRegs.SCSR = 0;
    SysCtrlRegs.PLLCR.bit.DIV = 10;

    SysCtrlRegs.HISPCP.all = 0x1;
    SysCtrlRegs.LOSPCP.all = 0x2;

    SysCtrlRegs.PCLKCR.bit.EVAENCLK=1;
    SysCtrlRegs.PCLKCR.bit.EVBENCLK=0;
    SysCtrlRegs.PCLKCR.bit.SCIAENCLK=0;
    SysCtrlRegs.PCLKCR.bit.SCIBENCLK=0;
    SysCtrlRegs.PCLKCR.bit.MCBSPENCLK=0;
    SysCtrlRegs.PCLKCR.bit.SPIENCLK=0;
    SysCtrlRegs.PCLKCR.bit.ECANENCLK=0;
    SysCtrlRegs.PCLKCR.bit.ADCENCLK=0;
    EDIS;
}

interrupt void T1_Compare_isr(void)

```

```
{  
  
    EALLOW;  
    SysCtrlRegs.WDKEY = 0x55;  
    EDIS;  
    EvaRegs.EVAIFRA.bit.T1CINT = 1;  
  
    PieCtrlRegs.PIEACK.all = PIEACK_GROUP2;  
}
```

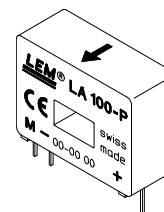
APPENDIX F

CURRENT TRANSDUCER LA 100-P

Current Transducer LA 100-P

$$I_{PN} = 100 \text{ A}$$

For the electronic measurement of currents : DC, AC, pulsed..., with a galvanic isolation between the primary circuit (high power) and the secondary circuit (electronic circuit).



Electrical data

I_{PN}	Primary nominal r.m.s. current	100	A					
I_P	Primary current, measuring range	0 .. ± 150	A					
R_M	Measuring resistance @	$T_A = 70^\circ\text{C}$		$T_A = 85^\circ\text{C}$				
		$R_{M \min}$	$R_{M \max}$	$R_{M \min}$	$R_{M \max}$			
		with $\pm 12 \text{ V}$	@ $\pm 100 \text{ A}_{\max}$	0	50	0	42	Ω
			@ $\pm 120 \text{ A}_{\max}$	0	22	0	14	Ω
		with $\pm 15 \text{ V}$	@ $\pm 100 \text{ A}_{\max}$	0	110	20	102	Ω
	@ $\pm 150 \text{ A}_{\max}$	0	33	20	25	Ω		
I_{SN}	Secondary nominal r.m.s. current	50	mA					
K_N	Conversion ratio	1 : 2000						
V_C	Supply voltage ($\pm 5\%$)	$\pm 12 \dots 15$	V					
I_C	Current consumption	$10(@\pm 15 \text{ V}) + I_S$	mA					
V_d	R.m.s. voltage for AC isolation test, 50 Hz, 1 mn	2.5	kV					

Accuracy - Dynamic performance data

X	Accuracy @ $I_{PN}, T_A = 25^\circ\text{C}$	@ $\pm 15 \text{ V} (\pm 5\%)$	± 0.45	%
		@ $\pm 12 \dots 15 \text{ V} (\pm 5\%)$	± 0.70	%
e_L	Linearity		< 0.15	%
I_O	Offset current @ $I_P = 0, T_A = 25^\circ\text{C}$	Typ	± 0.10	mA
		Max	± 0.15	mA
I_{OM}	Residual current ¹⁾ @ $I_P = 0$, after an overload of $3 \times I_{PN}$		± 0.05	mA
I_{OT}	Thermal drift of I_O	- $25^\circ\text{C} \dots + 85^\circ\text{C}$	± 0.05	mA
		- $40^\circ\text{C} \dots - 25^\circ\text{C}$	± 0.10	mA
t_{ra}	Reaction time @ 10 % of $I_{P \max}$		< 500	ns
t_r	Response time ²⁾ @ 90 % of $I_{P \max}$		< 1	μs
di/dt	di/dt accurately followed		> 200	A/ μs
f	Frequency bandwidth (-1 dB)		DC .. 200	kHz

General data

T_A	Ambient operating temperature	- 40 .. + 85	$^\circ\text{C}$	
T_S	Ambient storage temperature	- 50 .. + 95	$^\circ\text{C}$	
R_S	Secondary coil resistance @	$T_A = 70^\circ\text{C}$	120	Ω
		$T_A = 85^\circ\text{C}$	128	Ω
m	Mass Standards ³⁾		18	g
			EN 50178	

Notes : ¹⁾ The result of the coercive field of the magnetic circuit

²⁾ With a di/dt of 100 A/ μs

³⁾ A list of corresponding tests is available

Features

- Closed loop (compensated) current transducer using the Hall effect
- Printed circuit board mounting
- Insulated plastic case recognized according to UL 94-V0.

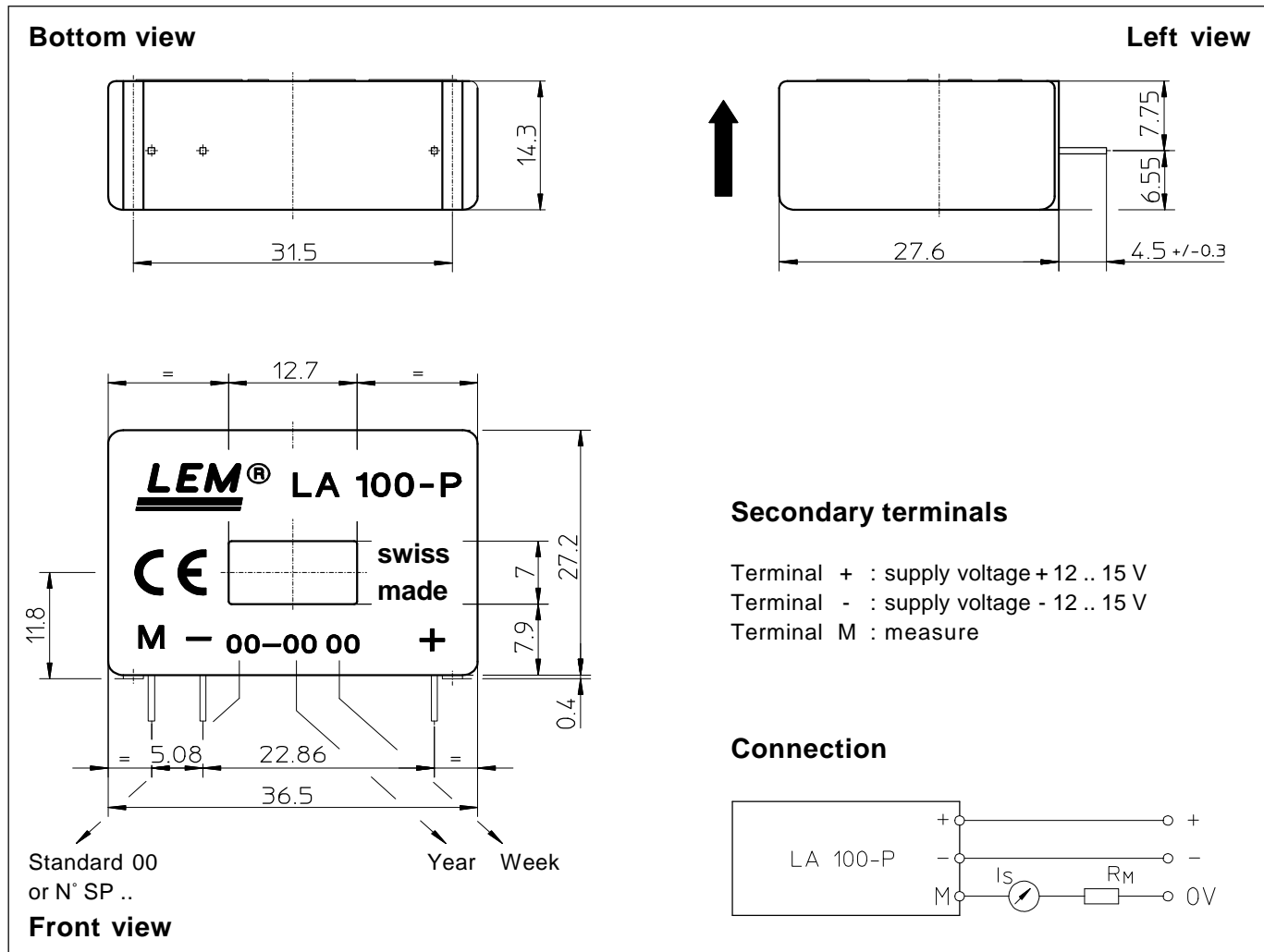
Advantages

- Excellent accuracy
- Very good linearity
- Low temperature drift
- Optimized response time
- Wide frequency bandwidth
- No insertion losses
- High immunity to external interference
- Current overload capability.

Applications

- AC variable speed drives and servo motor drives
- Static converters for DC motor drives
- Battery supplied applications
- Uninterruptible Power Supplies (UPS)
- Switched Mode Power Supplies (SMPS)
- Power supplies for welding applications.

Dimensions LA 100-P (in mm. 1 mm = 0.0394 inch)



Mechanical characteristics

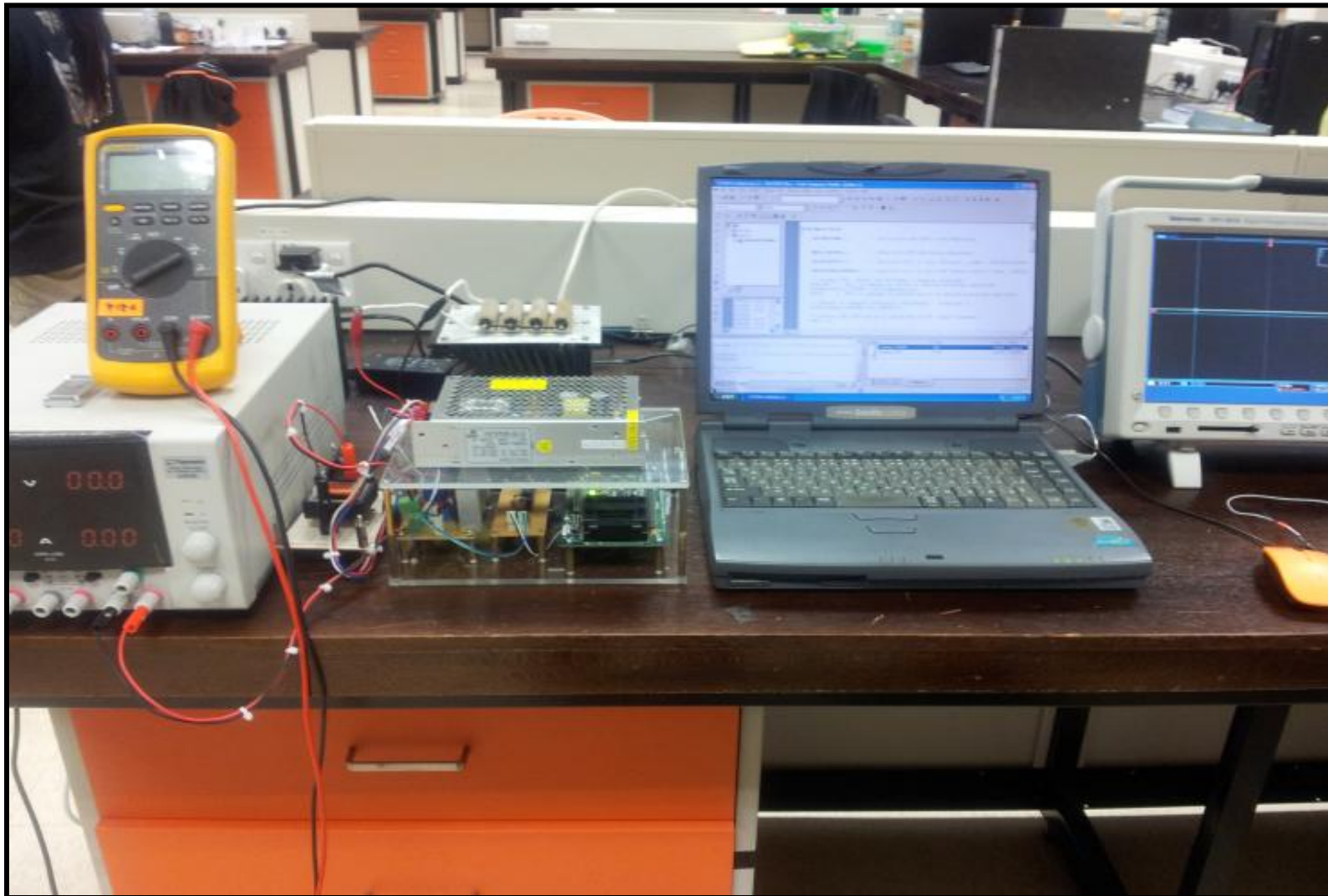
- General tolerance ± 0.2 mm
- Primary through-hole 12.7 x 7 mm
- Fastening & connection of secondary 3 pins
 0.63 x 0.56 mm
 Recommended PCB hole 0.9 mm

Remarks

- I_s is positive when I_p flows in the direction of the arrow.
- Temperature of the primary conductor should not exceed 100°C.
- Dynamic performances (di/dt and response time) are best with a single bar completely filling the primary hole.
- In order to achieve the best magnetic coupling, the primary windings have to be wound over the top edge of the device.
- This is a standard model. For different versions (supply voltages, turns ratios, unidirectional measurements...), please contact us.

APPENDIX G

EXPERIMENTAL SETUP



APPENDIX H

TURNITIN