IMPROVEMENT STUDY OF EMI ANALYSIS IN DC-DC BUCK CONVERTER USING RCD-RLD SNUBBER NETWORK

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2006

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Majidah Binti Muhamad

ABSTRACT

This project will cover the study in EMI analysis of integrated RCD and RLD type of snubber network in a 100W 50 kHz buck converter. The purpose of this study is to improve the efficiency and to reduce the EMI conducted emission in the circuit. A comparison of EMI conducted emission and efficiency in buck converter with various snubbers is included. In this paper, the integrated RCD and RLD snubber circuit is effectively reduce the EMI conducted emission. However, the efficiency of the circuit is still at low level. To improve the efficiency of this circuit, a combination of synchronous rectifier, parallel Schottky diode and integrated RCD and RLD type of snubber network is proposed. The desired results are not achieved because the proposed component is not available in PSPICE library. Another alternative is presented by increasing the load resistor. From this method, the efficiency of the circuit with integrated RCD and RLD snubber after improvement is 2.63% higher than the converter without snubber and 1.92% higher than the converter with RCD+RLD snubber before improvement. For EMI, the circuit after improvement could reduce 6.14 dBuV less than the circuit without snubber and 0.88 dBuV less than the circuit before improvement.

ACKNOWLEDGEMENTS

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Finally I would like to dedicate the thesis to my family for their love and support in these years. The great thank goes to my mother for her accompanying me and sacrifice during the time for preparing the thesis. With the full cooperation from the various people above, I have successfully achieved the objective of Final Year Project. That's all thank you.

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LIST OF ABBREVIATIONS

EMI	Electromagnetic Interference
LISN	Linear Impedance Stabilization Network
CCM	Continuous Conduction Mode
DCM	Discontinuous Conduction Mode
RCD	Resistor, Capacitor, Diode
RLD	Resistor, Inductor, Diode

CHAPTER 1
INTRODUCTION

1.1 Background Study

Electromagnetic Interference (EMI) can be defined as the interference of one piece of electronic equipment on the operation of another by means of electromagnetic energy transfer [1]. In EMI study, there are 3 main categories that need to be concerned. The 3 main categories in EMI are EMI disturbance or EMI source, EMI control and EMI measurement as shown in Figure 1.

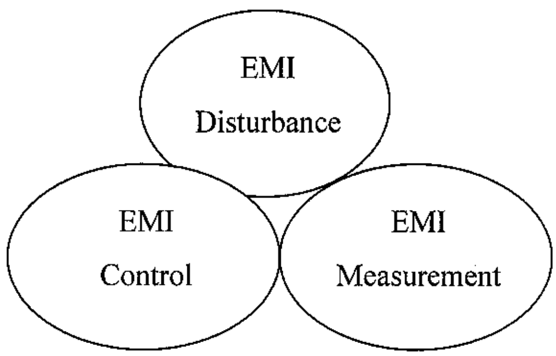

Figure 1 : Three main categories in EMI studies

In EMI disturbance, EMI is generated by EMI generator such as free wheeling diode. In EMI control, the controlled parameters are the rise time and fall time of the switching devices, the rate change of current (di/dt) and the rate change of voltage (dv/dt). The other category is EMI measurement where Linear Impedance Stabilization Network (LISN) is used to predict EMI conducted emission [2].

However, in this paper, EMI control in a switch mode power supply specifically in a DC-DC buck converter is focused. Buck converter is a step-down DC-DC converter. As the name implies, a step-down converter produces a lower average output voltage than its dc input voltage. Its main application is in regulated DC power supplies and DC motor speed control. Configuration of a Buck converter is shown in the methodology part. Operation of the buck converter can be either in Continuous Conduction Mode (CCM) or in Discontinuous Conduction Mode (DCM). In this paper, CCM operation is discussed.

Switching converter, particularly in buck converter is one among the worst EMI generators due to the pulsating input current waveform and switching action of its semiconductor switches [3].During turn on and turn off, the switching losses and EMI noise is generated. In order to control this EMI noise in the converter, a solution must be taken. This paper presents the integrated RCD and RLD snubber network to solve for this problem.

However, applying the integrated RCD and RLD snubber network can only solve for the EMI problem. The efficiency of the buck converter is then slightly reduced when the EMI is reduced. To solve this problem, this paper presents Synchronous rectifier and parallel Schottky diode. Through this method, the efficiency of the buck converter is expected to be improved.

1.2 Problem Statement

EMI noises are mainly generated during turn on and turn off switching transient in switching power supply. This is due to the high frequency operation. Unfortunately, higher switching frequency causes higher switching loss and greater EMI. Serious EMI noise will affect the circuit performance and efficiency. An EMI control simulation is the best approach to solve this problem at early or design stage to reduce cost and for better performance.

1.3 Objectives

- To study the effect of the various snubbers to the EMI conducted emission and the efficiency of the buck converter.
- To improve the efficiency of the buck converter with integrated RCD-RLD snubber.
- To study the concept of synchronous rectifier with parallel Schottky diode
- To familiarize with the calculation and PSPICE program.

1.4 Scope of Study

This project will cover all the calculation to design buck converter and snubber circuit, the effect of the integrated RCD and RLD snubber to the EMI and to the circuit efficiency, the concept of synchronous rectifier with parallel Schottky diode in order to increase the efficiency of the buck converter. All the simulation works are done by using PSPICE software.

CHAPTER 2
LITERATURE REVIEW

Snubber networks are normally added to the power switching devices to relieve switches overstress during switching. The purposes of snubber circuits are:

- To reduce the switching power losses in the main power device in the power electronic circuit.
- To avoid second breakdown.
- To control the device rate change of voltage (dv/dt) and rate change of current (di/dt).

In EMI control, the third purpose of snubber network is implemented. There are many types of turn on and turn off snubber circuits available today. RCD snubber or also known as turn off snubber are implemented in the buck converter to limit the rate change of voltage (dv/dt) during device turn off by the appearance of capacitor. Theoretically, turn off snubber shall provide a zero voltage across the switching device while the current turns off. For RLD snubber or turn on snubber, an inductor is used to limit the rate change of current (di/dt) [4].

According to the study done by Elasser and D. A. Tony [5], to control EMI effect in the switch mode power supply, the soft switching techniques has been introduced. The most proposed lossless snubber circuit is active snubber [5], [6]. This is because its capability to reduce loss using auxiliary switches. However, because of using an additional switch, it tends to increase the complexity of the power and control circuits as well as its cost.

In order to solve these problems, the energy-recovery scheme without additional auxiliary switch is proposed. This type of snubber is also known as passive snubber [7], [8], [9], [10], [11].The RCD snubber circuit is proposed because of the simplest structures and its advantage in minimizing the cost. However, this type of snubber has some disadvantages like worst performance since the switching losses are dissipated through resistors and can reduce efficiency [12], [13],[14],[15],[16].

In the late of 1980s, a resonant converter is then introduced. The advantage of this topology is reduced power losses, achieving high frequency and high density while maintaining high efficiency. Unfortunately, this topology also has several limitations which are higher conduction losses, high current stress and hard to design EMI filter and control circuit [17], [18].Comparing to the techniques discussed above, the passive lossless snubber can effectively reduce the switching losses and EMI noises. No active component and dissipative components are used anymore. No circulating energy generated and it works as simple as RCD snubber and high efficiency as an active snubber. Moreover, it can minimize cost as well as high performance and reliability [19].

As an extension, a comparative study of the conducted EMI suppression on power MOSFET (switching devices) in 100 watts 50 kHz buck converter has been developed using without and with RCD, RLD and integrated RCD and RLD passive lossless snubber circuits. The turn on snubber or RLD snubber is connected in series while the turn off or RCD snubber is placed across the main switching devices (MOSFET) and the integrated RCD and RLD snubber is connected mixed series and parallel for both simulation and experiment. The effectiveness of the integrated RCD and RLD snubber circuits is verified in reducing EMI conducted emission rather than without and with RCD and RLD snubber circuit respectively [20],[21].

Table 1 : Condition for simulation with the different types of snubber circuit

	CONDITION
1	Without snubber circuit
2	With RLD snubber circuit
3	With RCD snubber circuit
4	With RLD+RCD snubber circuit

Figure 2 shows the configuration of the DC-DC buck converter without snubber. DC-DC buck converter contains of DC input voltage (*V1*), gate voltage (*V2*), main inductor (L_{main}), main capacitor (C_{main}), diode (*D1*), switching device MOSFET (*M1*) and load resistor (R_{load}).

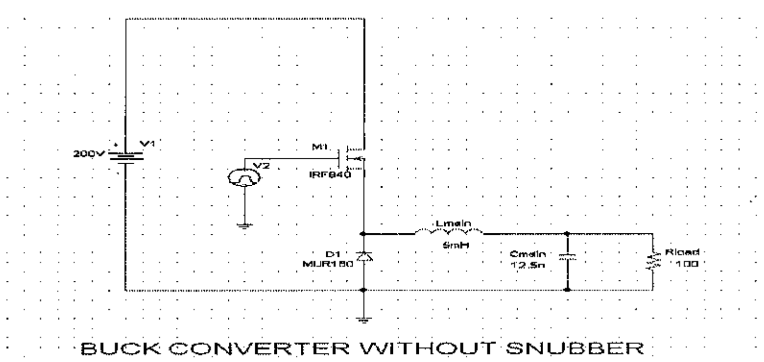

Figure 2 : Without snubber circuit

Figure 3 shows the configuration of the DC-DC buck converter with RCD snubber. RCD snubber or also known as turn off snubber are implemented in the buck converter to limit the rate change of voltage (dv/dt) during device turn off by the appearance of capacitor.

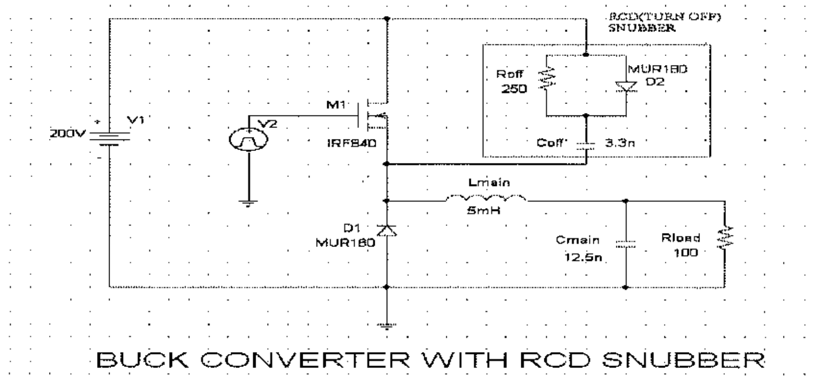

Figure 3 : With RCD snubber circuit

Figure 4 shows the configuration of the DC-DC buck converter with RLD snubber. For RLD snubber or turn on snubber, an inductor is used to limit the rate change of current (di/dt)

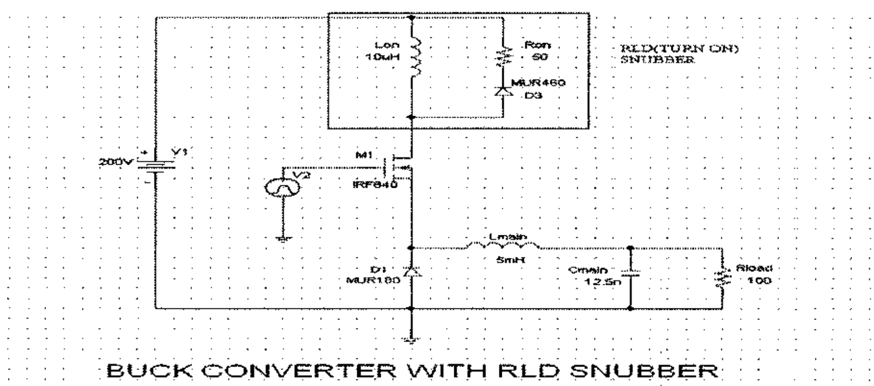

Figure 4 : With RLD snubber circuit

The integrated RCD and RLD snubber network is a dded to the buck converter as shown in Figure 5.This c ombination t ook benefit of b oth R CD a nd RLD s nubber. Both dv/dt and di/dt can be reduced.

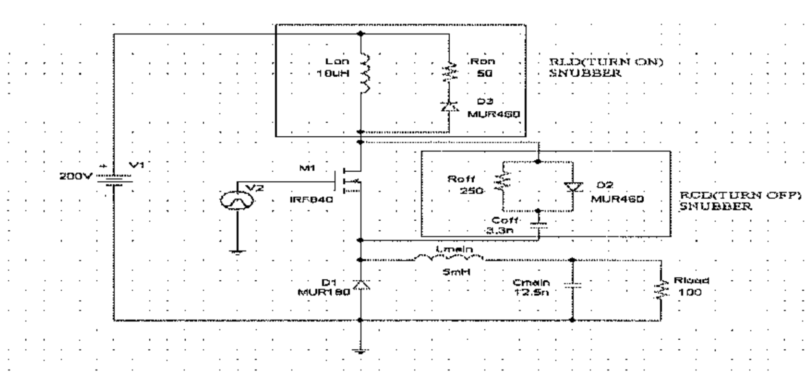

Figure 5 : With integrated RLD and RCD snubber circuit

The integrated RCD and RLD snubber network can only solve for the EMI problem. The efficiency of the buck converter is then slightly reduced when the EMI reduced. Trade off between EMI reduction and efficiency reduction should be concerned. For a solution, this paper presents Synchronous rectifier and parallel Schottky diode to the buck converter. Through this method, the efficiency of the buck converter can be improved [22].

CHAPTER 3
METHODOLOGY

3.1 DC-DC Buck Converter Design

The first step in this project is designing the buck converter circuit. At early stage of the design process, the design requirements are considered first. In this paper, a buck converter is designed with the design requirements of output power, Po =100 Watts, switching frequency, f_s = 50Hz, input voltage, V_{in} = 200V and duty cycle, D = 0.5.

During this design stage, some assumptions have been made such as maximum input current, $I_{in\ max}$ is equal to the maximum inductor current, $I_{L\ max}$ and minimum input current, $I_{in\ min}$ is equal to the minimum inductor current, $I_{L\ min}$. As mentioned earlier in the introduction part, buck converter can be in CCM mode or DCM mode. Regarding to this, another assumption have been made, for this project the buck converter will operate in CCM mode. For CCM mode, the value of inductor, L should be greater than critical inductor.

❖ Assumption made

- $I_{in\ max} = I_{L\ max}$
- $I_{in\ min} = I_{L\ min}$

❖ Assumption made

- CCM
- $L > L_{crit}$
- $L = 10\,L_{crit}$

Since we have all the design requirements, we need to calculate the values for L, C and R. The basic dc equation of the buck converter is given by following equation [15]:

$$\frac{V_o}{V_{in}} = D \tag{1}$$

Where

V_o = Output voltage

V_{in} = Input voltage

D = Transistor switching duty cycle.

Therefore, output voltage is got by calculation

$V_o = DV_{in}$

Hence the output current, I_o is

$$I_o = \frac{P_o}{V_o} \tag{2}$$

The value for output resistance, R_o is

$$R_o = \frac{V_o}{I_o} \tag{3}$$

To make the converter operate in continuous conduction mode (CCM), we set the value of $I_{L\min} = 0$ and solve for the value of critical inductance. The critical inductance for CCM is given by

$$L_{crit} = \frac{1-D}{2} TR \tag{4}$$

Where

T = time $= 1/f_s$

In CCM, the value for L is greater than L_{crit}, so

$$L = 10 L_{crit} \tag{5}$$

To find the value of capacitor C, we need to calculate the value of voltage ripple ratio, $\frac{\Delta V_o}{V_o}$ first because

$$C = \frac{(1 - D)}{8L \frac{\Delta V_o}{V} f^2} \tag{6}$$

To find $\frac{\Delta V_o}{V}$,

$$\frac{V_{o\max}}{V_{in}} = \frac{I_{in\max}}{I_o} \tag{7}$$

$$\frac{V_{o\min}}{V_{in}} = \frac{I_{in\min}}{I_o} \tag{8}$$

Where I_{in} = Input current

$I_{L\max}$ = Maximum inductor current

$I_{L\min}$ = Minimum inductor current

$$I_{L\max} = D V_{in}(\frac{1}{R} + \frac{(1 - D)T}{2L}) \tag{9}$$

$$I_{L\min} = D V_{in}(\frac{1}{R} - \frac{(1 - D)T}{2L}) \tag{10}$$

$$\frac{\Delta V_o}{V_o} = \frac{V_{o\max} - V_{o\min}}{V_o} \tag{11}$$

3.2 Snubber design and its operation

When dealing with switching power converter, the EMI problem is the issues. This problem occurs due to the fast switching action of the switching device during turn on and turns off time. In this project, the switching device is MOSFET IRF840.To overcome this problem, a snubber circuit is introduced. Snubber circuit has a main role in relieving switches from overstress during switching. It is normally added to the power switching devices.

In this project, a dissipative passive snubber circuits is used in the buck converter. In dissipative passive snubber circuit, the capacitor is functioning to slow the switching device (MOSFET) voltage rise, dv/dt during turn off while the inductor is used to slow the device current rise, di/dt during turn on. Figure 6 and 7 shows the turn on and turn off snubber or also known as Resistor, Inductor, Diode (RLD) and Resistor, Capacitor, Diode (RCD) snubber respectively.

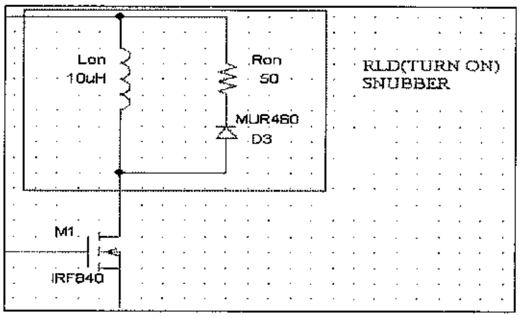

Figure 6 : Turn on snubber

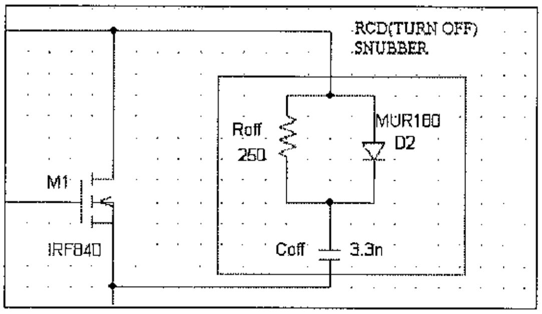

Figure 7 : Turn off snubber

In Figure 6, the inductor is used to slow down the rise of the inductor current di/dt (switch current) during turn on while in Figure 7, the capacitor is used to reduce the voltage rise dv/dt across the switch during turn off. Both dv/dt and di/dt can be reduced by transferring the switching energy from the switch (MOSFET) to the energy storage elements. Reducing both di/dt and dv/dt resulted in decreasing the power loss. By decreasing the power loss, the EMI conducted emission noise is also can be reduced.

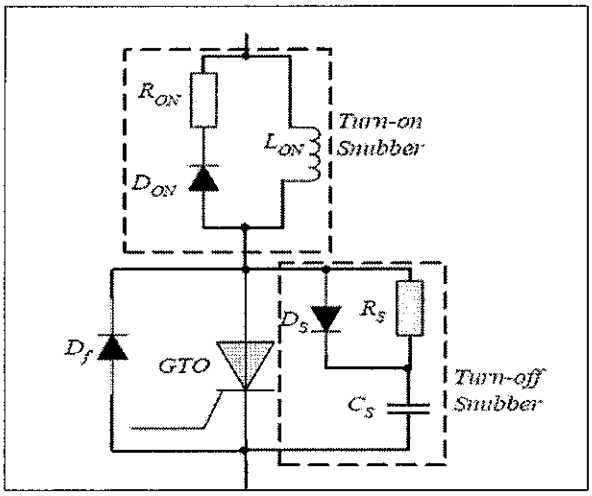

Figure 8 : Common turn off and turn on snubber [15]

In Figure 8 it shows the common turn off and turn on snubber circuit, the values for the snubber circuit could be calculated by using the following equations:

Turn on snubber:

$$R_{on} = \frac{\Delta V_{CE}}{Io} \tag{12}$$

$$L_s = \frac{(\Delta V_{CE} * t_{ri})}{I_o} \tag{13}$$

Turn off snubber:

$$R_s = \frac{(5 * V_d)}{I_o} \tag{14}$$

$$C_s = \frac{(I_o * t_{fi})}{(2 * V_d)} \tag{15}$$

Where,

R_{on} = Turn on resistor

ΔV_{CE} = Voltage drop across the switch during turn on

L_s = Turn on inductor

R_s = Turn off resistor

V_d = Diode voltage

t_{ri} = Current rise time

t_{fi} = Current fall time

C_s = Turn-off capacitor

All the design parameters are then summarized in the Table 2 as shown below.

Table 2 : Design parameters

Parameters	**Values**
V_{dc}	200V
f_s	50kHz
D	0.5
C_{main}	12.5nF
L_{main}	5mH
R_{load}	100 Ω
R_{off}	250 Ω
C_{off}	3.3nF
R_{on}	50Ω
L_{on}	10uF
MOSFET	IRF840 500V,0.75 Ω, 8A
D	MUR180

3.3 Efficiency Measurement

To measure efficiency of the buck converter, the output power, P_o and the input power, P_i are the most important parameters. The relationship between output power and input power to the circuit efficiency can be seen by the following equation:

$$Efficiency = \frac{P_o}{P_i} \times 100\% \qquad (16)$$

Generally, in PSPICE software, to measure the output power, the voltage and current probes are placed at the output side near the load resistance, R_{load} while for the input power, the voltage probe is placed at the input voltage, *V1* and the current probe is placed at the inductor, L_{main}. The output and input power are then calculated by multiply the output voltage with the output current and the input voltage with the input current respectively. Figure 9, 10, 11, 12 and 13 shows the efficiency measurement circuit for buck converter without snubber, with RCD snubber, with RLD snubber, with RCD-RLD snubber and with RCD-RLD snubber (improved) respectively.

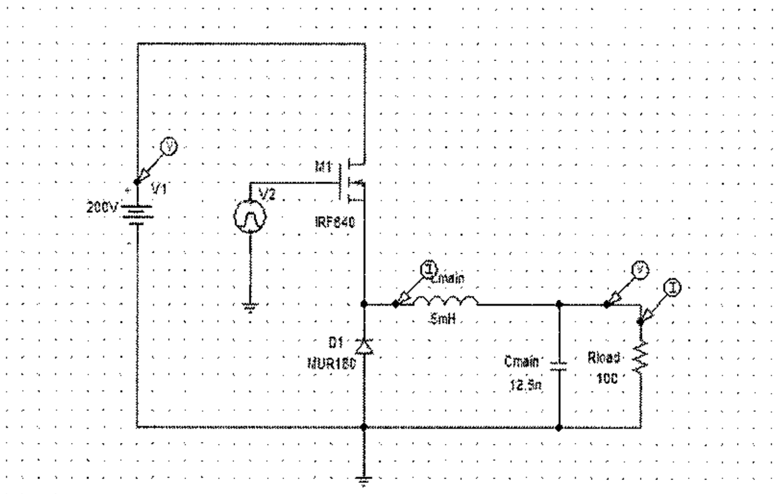

Figure 9 : Efficiency measurement circuit for buck converter without snubber

In Figure 10, RCD snubber was added parallel to the switching device MOSFET IRF840.Voltage probes was placed both at input side and output side as well as current probes. What is expected from simulation result is the efficiency of this circuit is lower than the circuit without snubber.

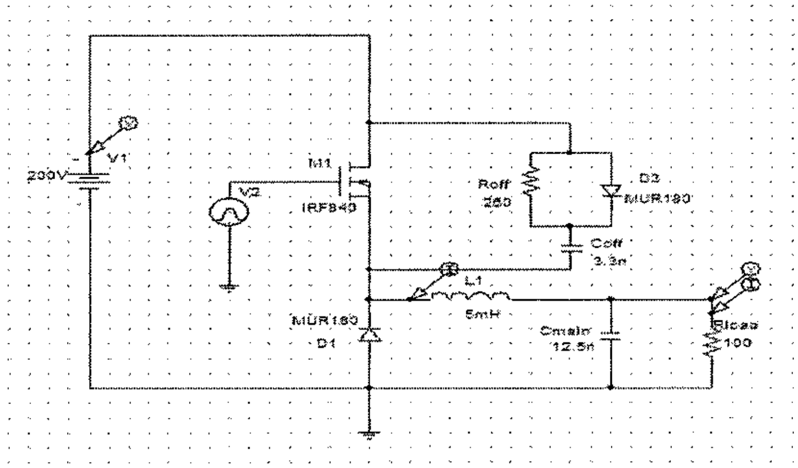

Figure 10 : Efficiency measurement circuit for buck converter with RCD snubber

RLD snubber was added series to the switching device MOSFET IRF840 in Figure 11. Similar to the previous circuit, voltage probes was placed both at input side and output side as well as current probes. The expected result from PSPICE simulation is the efficiency of this circuit is lower than the circuit without snubber.

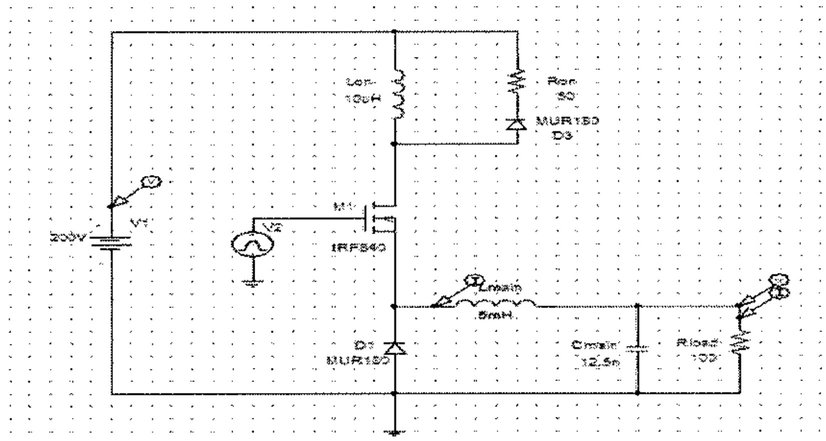

Figure 11 : Efficiency measurement circuit for buck converter with RLD snubber

It can be seen in Figure 12 the RCD and RLD snubber was added to the buck converter. As previous, to measure the output power, the voltage and current probes are placed at the output side near the load resistance, R_{load} while for the input power, the voltage probe is placed at the input voltage, *V1* and the current probe is placed at the inductor, L_{main}. The result is expected have lower efficiency.

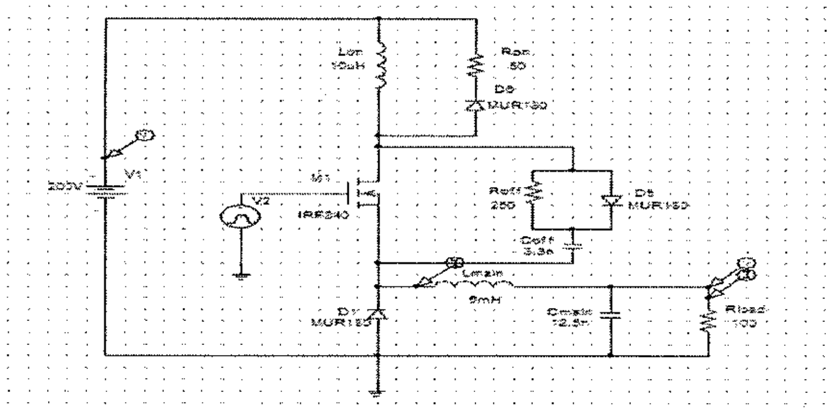

Figure 12 : Efficiency measurement circuit for buck converter with RCD-RLD snubber

For efficiency improvement, the circuit in Figure 13 was presented. This circuit contains integrated RCD and RLD snubber with different value of load resistor, R_{load}. In this project, the value for load resistor has been increased to 200Ω. The reason is the output power is directly proportional to the load resistor. By increasing the load resistor, the output power is increased too. The efficiency is expected to increase also.

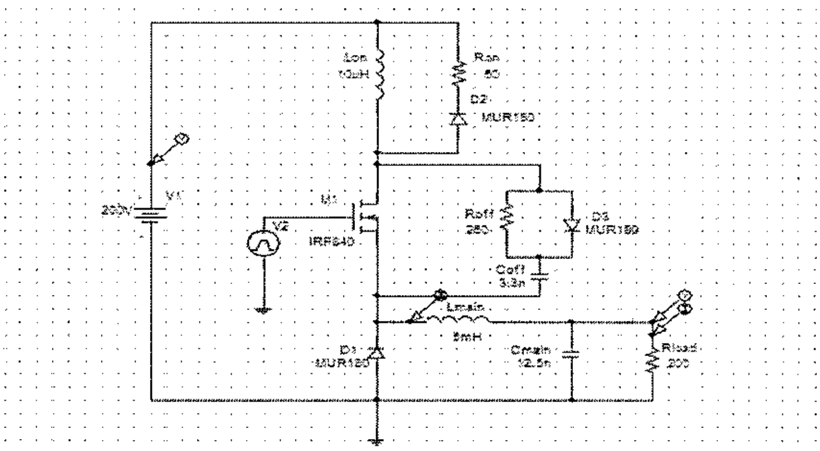

Figure 13 : Efficiency measurement circuit for buck converter with RCD-RLD snubber (improved)

3.4 EMI Simulation

EMI can be divided into two; EMI radiated emission and EMI conducted emission. This paper will focus on EMI conducted emission only. For EMI conducted emission measurement, a standard measurement circuit is needed. Figure 14 shows the standard circuit for EMI measurement using Linear Impedance Stabilization Network (LISN) with frequency range 150 kHz to 30MHz. This circuit contains of AC source, LISN, gate driving circuit and circuit under test. LISN is used to provide standard impedance for the measurement.

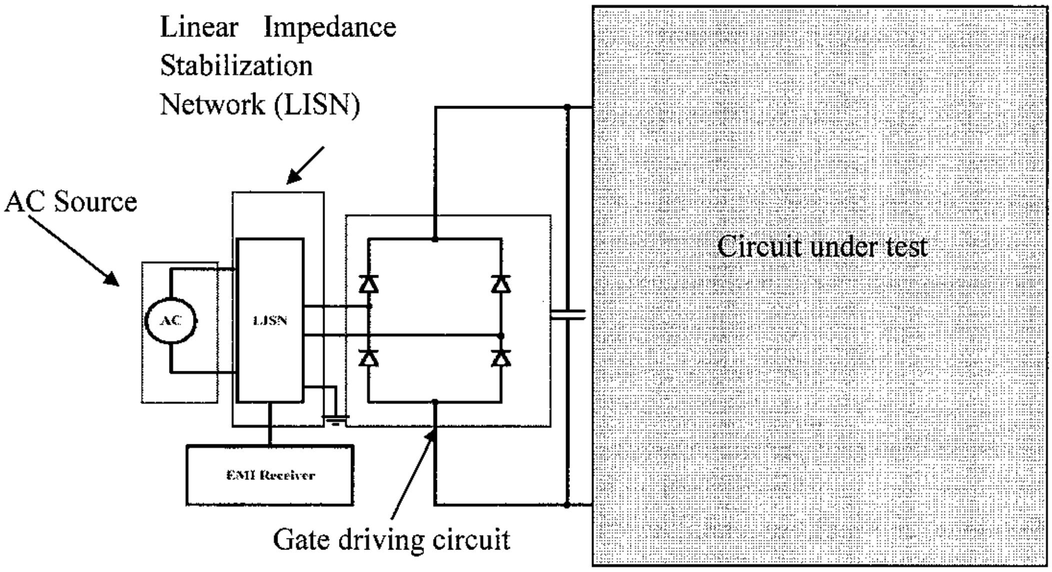

Figure 14 : Standard EMI measurement circuit [23]

The standard circuit is then constructed in the PSPICE program. The LISN is represented by its internal circuit as shown in the Figure 15 [23].This figure also shows how the circuit is constructed in PSPICE program. The circuit under test can be any circuit that we want to test. In this paper we are going to test some different circuits as shown in the Table 1 and also the buck converter with RCD-RLD snubber (improved) circuit. Before simulating, one probe is located at the ground and another one at the resistor, *R8* (see Figure 15).

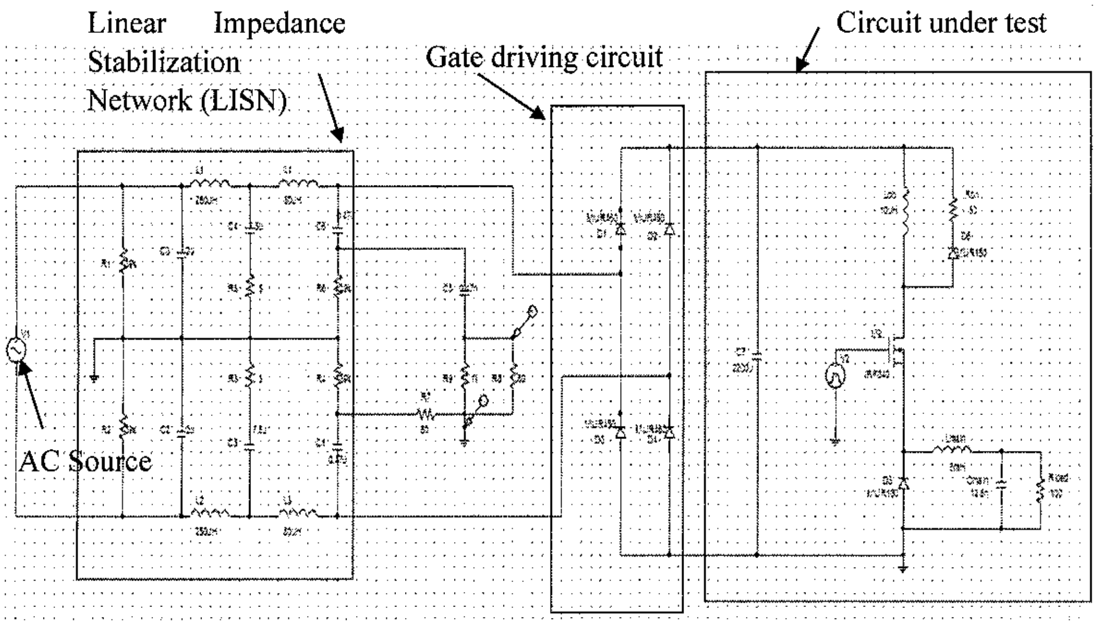

Figure 15 : EMI measurement circuit for buck converter with RLD snubber

During the simulation process, the simulation is done using the Fourier tool in PSPICE. There are some settings in PSPICE program need to be followed. Figure 16, 17 and 18 give more clear view about the setting. It can be seen in Figure 16 that analysis setup was set to AC Sweep and Transient.

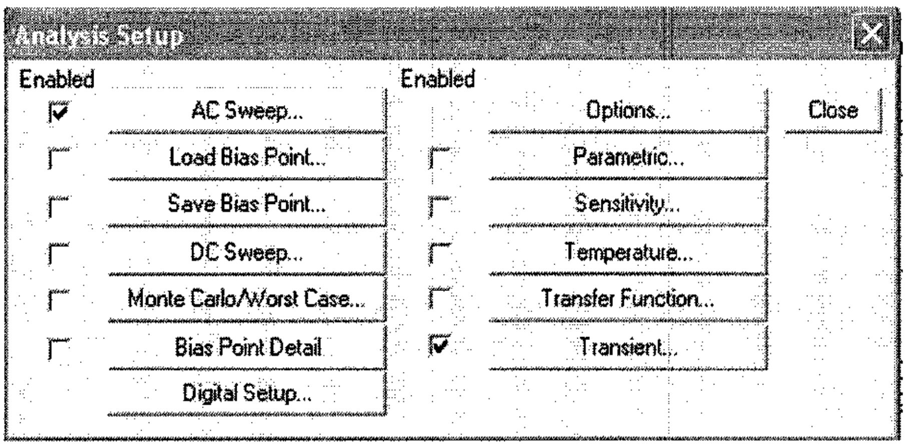

Figure 16 : Setting for analysis setup

For transient analysis, as shown clearly in Figure 17, the setting details are as follows:

Print step : 0ms

Final time : 1ms

Step ceiling : 0.01ms

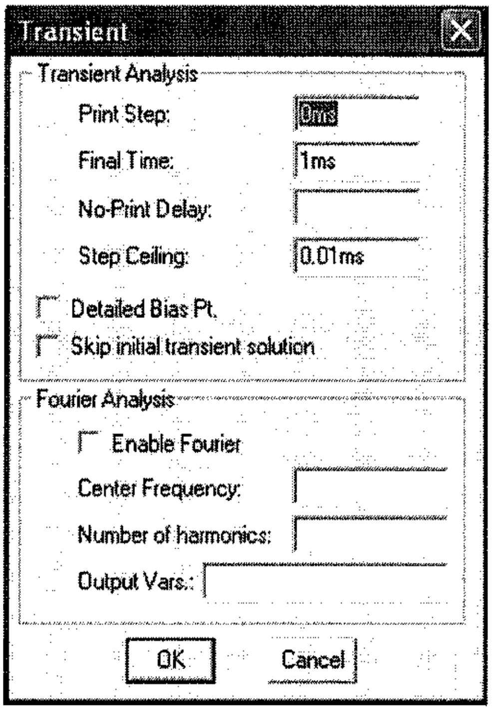

Figure 17 : Setting for transient analysis

For X-axis as shown in Figure 18, the setting details are as below:

Data range : 990 kHz to 1.01MHz

Scale : Log

Processing option : Fourier

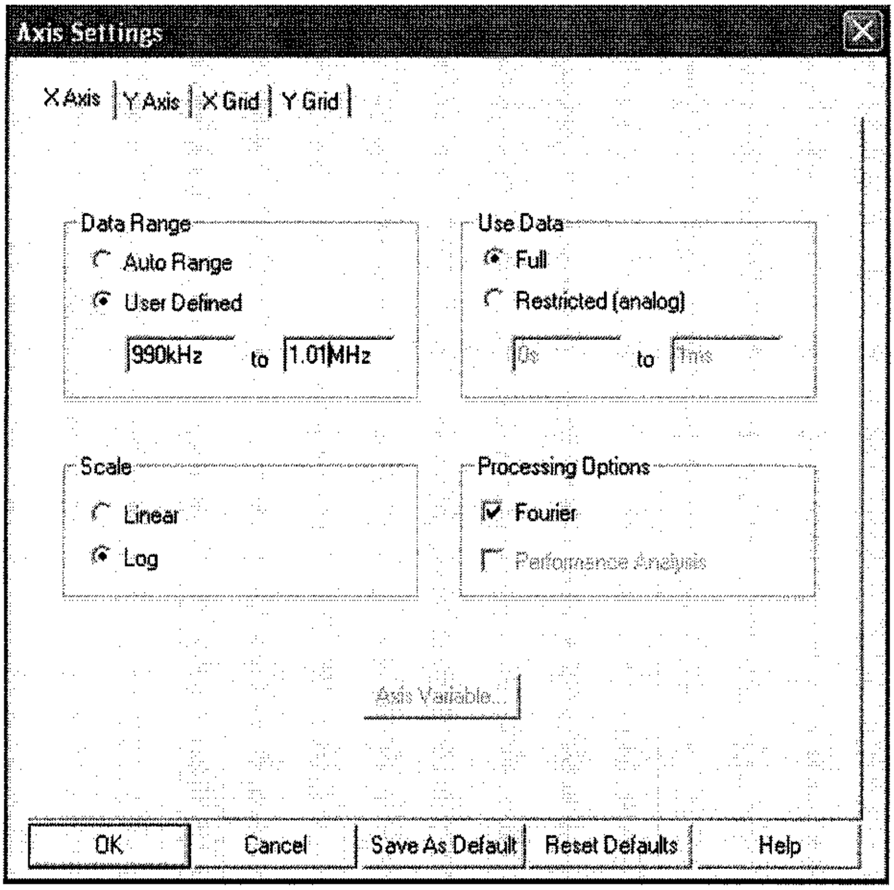

Figure 18 : Setting for X-axis

As shown in Figure 19, at first Y-axis was set as follows:

Data range : Auto Range

Scale : Linear

However, after simulation result is obtained, the setting for Y-axis was changed to a suitable value so that the waveform obtained more clear and easy to analyze. The EMI conducted emission is taken at one reference point which is 1MHz.The measurement circuit for the rest can be review in the Appendix part.

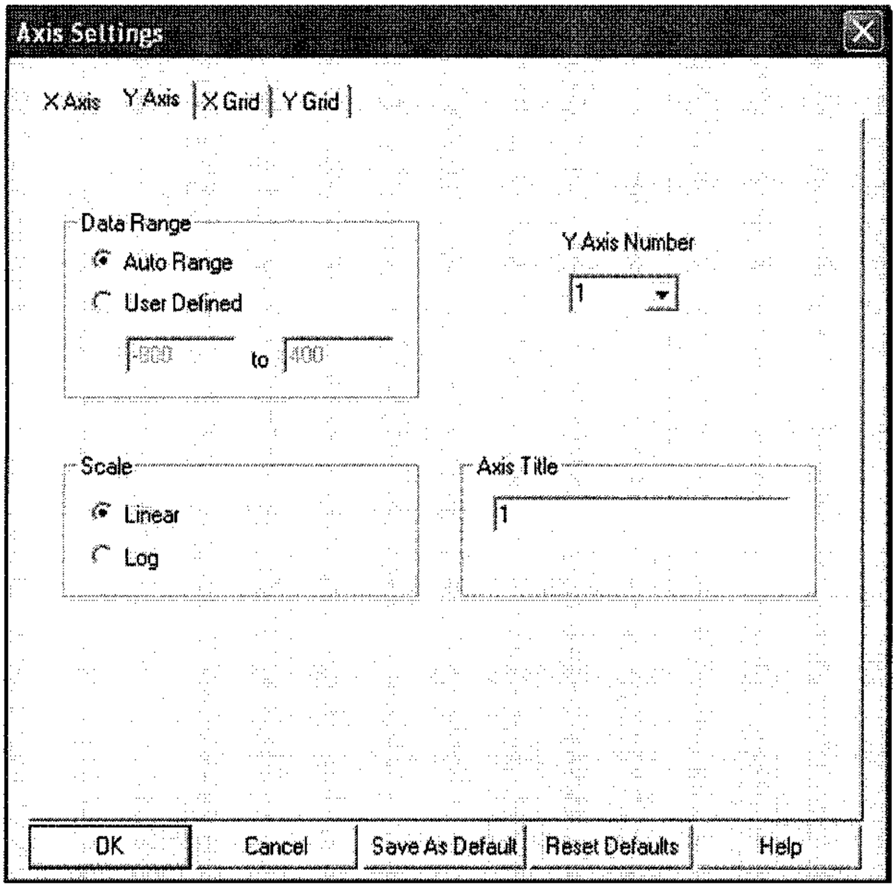

Figure 19 : Setting for Y-axis

3.5 Synchronous rectifier

Switching action may cause the switching loss. This switching loss will affect or reduce the efficiency of the converter. Related to this, one approach is used to improve the efficiency of the buck converter by applying the synchronous rectifier and parallel Schottky diode.

3.5.1 Operation of the synchronous rectifier

To increase the converter efficiency, the freewheeling diode in the converter will be replaced by an N-channel HDTMOS MOSFET. This is called Synchronous rectifier. This type of MOSFET is functioning as the main conducting device of the inductor current during the conventional MOSFET is turn off. When the synchronous rectifier MOSFET is turn on, the current is flow through the main switching device (MOSFET) instead of the conventional freewheeling diode. The low on-resistor of the synchronous rectifier reduces the losses that usually occur if we are using synchronous diode. To see the comparison of the two devices, the equation used for calculating the power dissipation of the diode and synchronous rectifier respectively given by:

$$P_{diode} = I_{out} \times (1-D) \times V_f \qquad (15)$$

Where,

V_f = Forward voltage drop of the diode

I_{out} = Power supply rated output current

D = Duty cycle

$$P_{MOSFET} = \left[I_D(1-D)\right]^2 \times R_{DS}(ON) \qquad (16)$$

I_D = Drain current of MOSFET

P_{MOSFET} = Power dissipation of the MOSFET

The value for $R_{DS\ (ON)}$ in HDTMOS is only a few milliohms, so the power loss in synchronous rectifier is much lower than the freewheeling diode in converter output circuit. For this case, $R_{DS\ (ON)}$ is 7 milliohms. The proposed HDTMOS in this project is N-Channel MOSFET Motorola MTD20N03HDL.

3.5.2 Parallel Schottky diode

Freewheeling diode in buck converter will be replaced by a Schottky diode in the output circuit which providing a continuous current path during the switch-over period of the two MOSFETs. This becomes parallel with the synchronous rectifier. Without the freewheeling diode, the current will flow through the parasitic diode of the low side MOSFET instead of the MOSFET itself. This will increase the power loss and parasitic diode of the MOSFET will perform like fast recovery diode. The proposed Schottky diode in this project is .Below is how the original circuit will be modified with the synchronous rectifier and parallel Schottky diode.

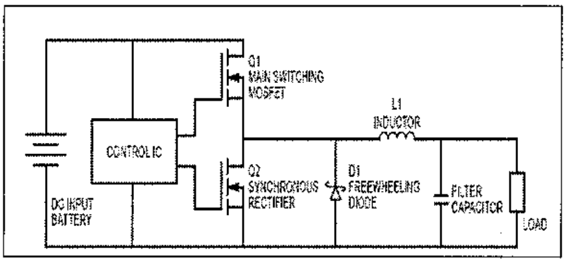

Figure 20 : Synchronous rectifier with parallel Schottky diode [21]

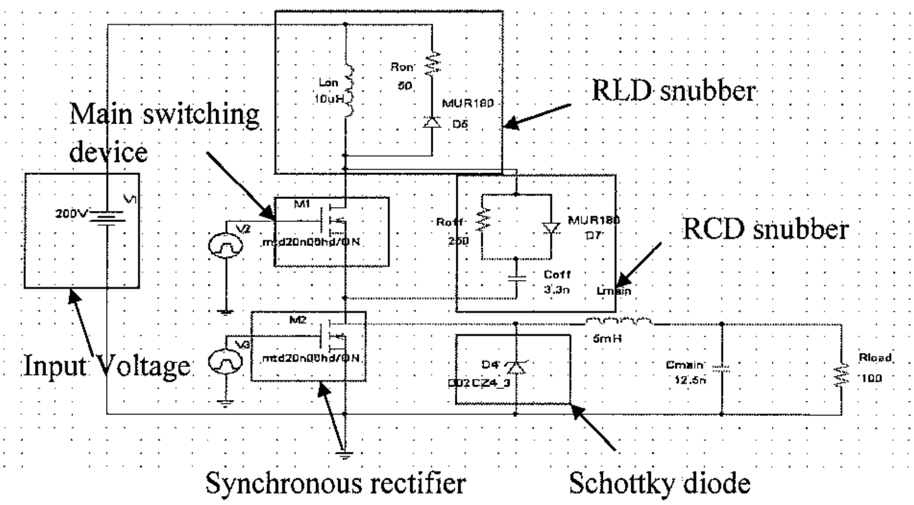

Figure 21 : Synchronous rectifier with parallel Schottky diode applied to the original circuit

CHAPTER 4
RESULTS AND DISCUSSION

4.1 The EMI conducted emission

The simulated waveform for EMI conducted emission in the buck converter without snubber can be seen in Figure 22.At the reference point which is 1MHz, the peak value for the noise level is 211.172nV. However, for EMI, normally the unit is in dBuV. The unit conversion can be done using equation (17) as below:

$$dBuV = 20 \times \log_{10}\left(\frac{V_{noise}(mV)}{10^{-6}}\right) \qquad (17)$$

After conversion, the EMI value for the buck converter without snubber circuit is 106.49 dBuV. The simulation circuit for this waveform can be referred in Appendix A.

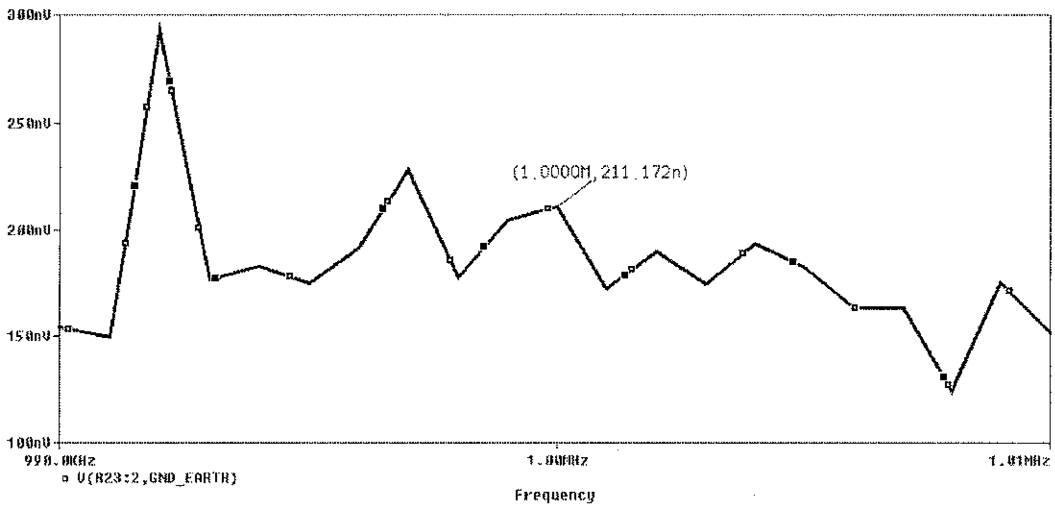

Figure 22 : EMI conducted emission in the buck converter without snubber

Figure 23 shows the simulated waveform for buck converter with RCD snubber circuit. At the reference point, the peak value for the noise level is 241.644nV.After conversion is done, the EMI value is 107.66 dBuV. The simulation circuit for this waveform can be referred in Appendix B.

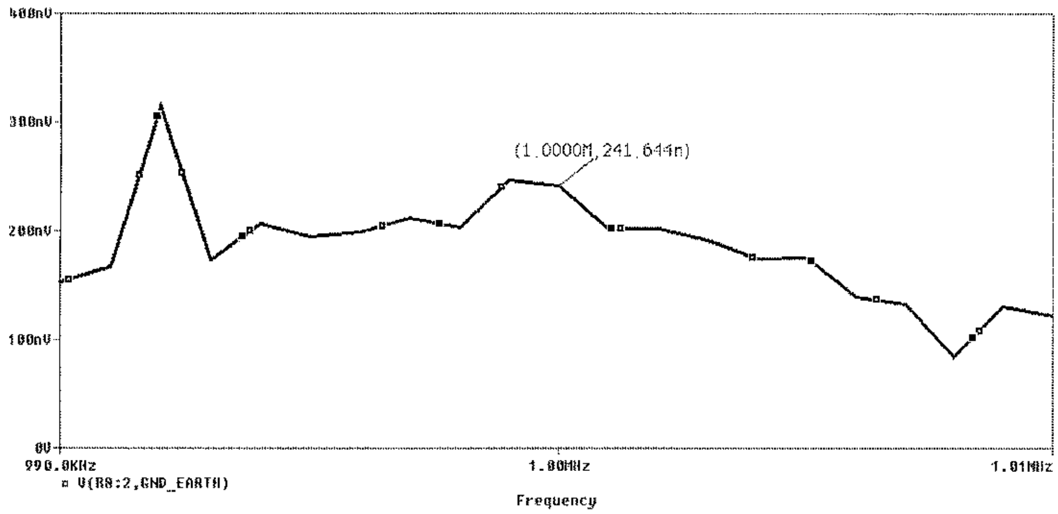

Figure 23 : EMI Simulation for Buck Converter with RCD Snubber

From Figure 24 we can see the simulated waveform for buck converter with RLD snubber circuit. At the reference point, the peak value for the noise level is 112.853nV.After conversion is done, the EMI value is 101.05 dBuV. The simulation circuit for this waveform can be referred in Appendix C.

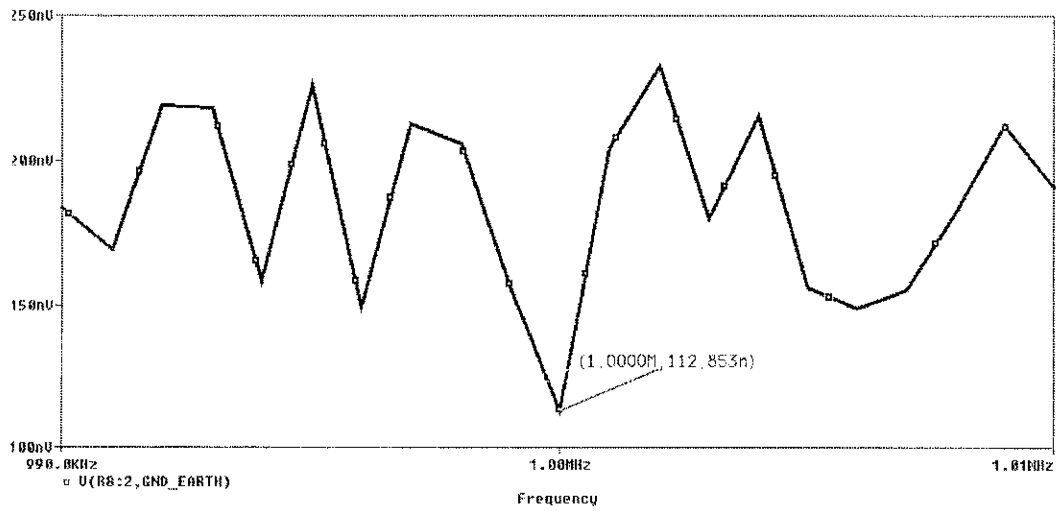

Figure 24 : EMI simulation for buck converter with RLD snubber circuit.

The simulated waveform for buck converter with RCD and RLD snubber circuit is shown in Figure 25. At the reference point, the peak value for the noise level is 114.807nV.After conversion is done, the EMI value is 101.2 dBuV. The simulation circuit for this waveform can be referred in Appendix D.

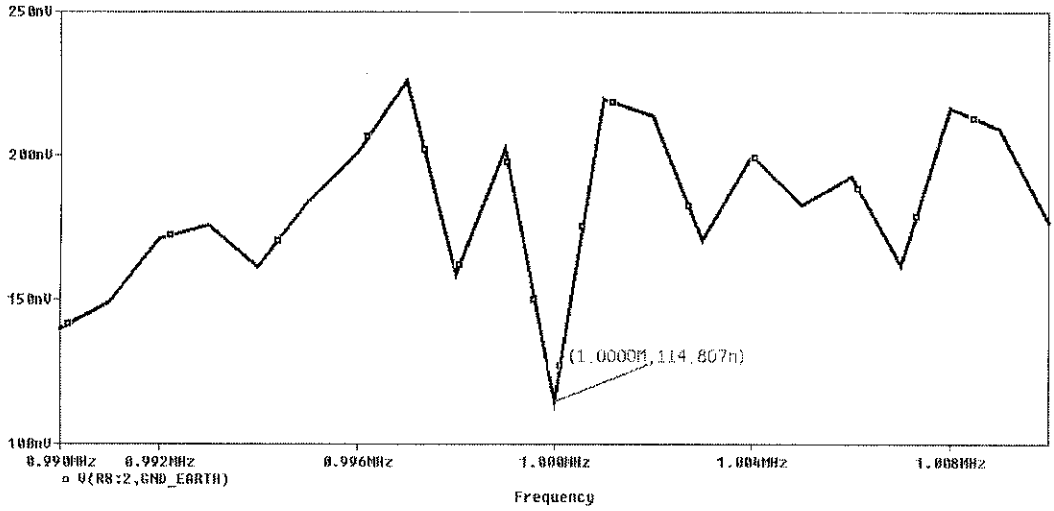

Figure 25 : EMI simulation for buck converter with RCD and RLD snubber circuit.

For simulated waveform for buck converter with RCD and RLD snubber circuit with increase load resistance in Figure 26, it can easily seen at the reference point, the peak value for the noise level is 103.791nV.After conversion is done, the EMI value is 100.32 dBuV. The simulation circuit for this waveform can be referred in Appendix E.

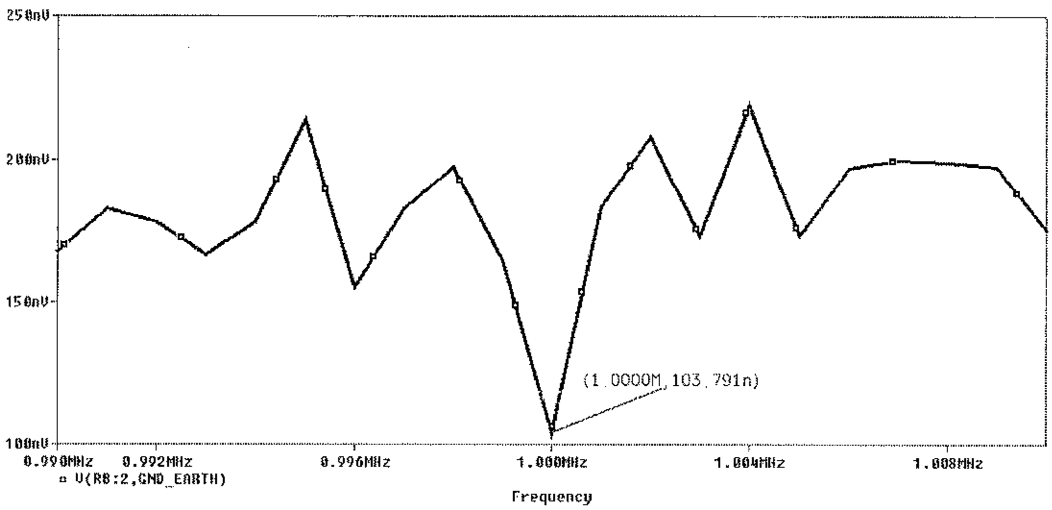

Figure 26 : EMI simulation for buck converter with RCD and RLD snubber (improved)

The simulated result and the calculated results are tabulated in the following table:

Table 3 : Peak noise level and EMI conducted emission

Condition	Peak Noise Level (V)	EMI (dBuV)
Without snubber circuit	211.172n	106.49
With RCD snubber	241.644n	107.66
With RLD snubber	112.853n	101.05
With RCD and RLD snubber	114.807n	101.2
With RCD and RLD snubber (improved)	103.791n	100.32

4.2 Efficiency comparison

From the circuit in Figure 27 below, the simulated result can be seen as shown in Figure 28 and 29.Figure 28 shows the maximum and minimum output and input power and Figure 29 shows the average output and input power for buck converter without snubber. In the Figure 28 and 29, we can notice that the maximum and the minimum output power is 115.942W and 82.415W respectively while its average is 91.936W and for the maximum and minimum input power, the value is 218.874W and 178.126W respectively while its average is 189.693W.By using equation (15) which already mentioned earlier in methodology part, the efficiency of the circuit is 48.47%.

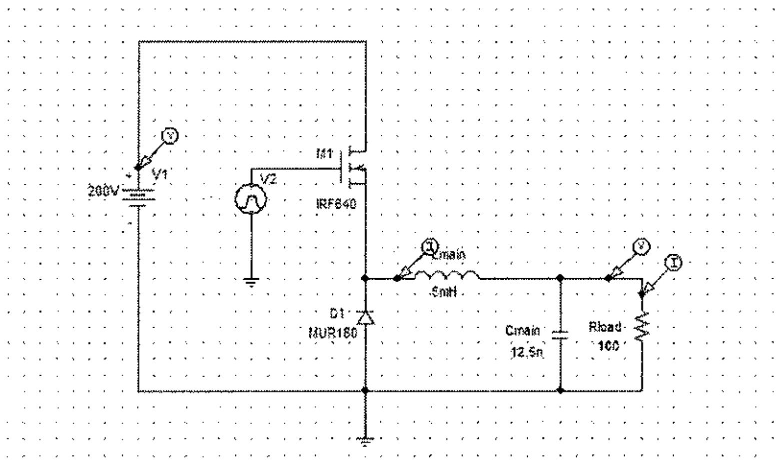

Figure 27 : Circuit Simulation for Buck Converter without Snubber

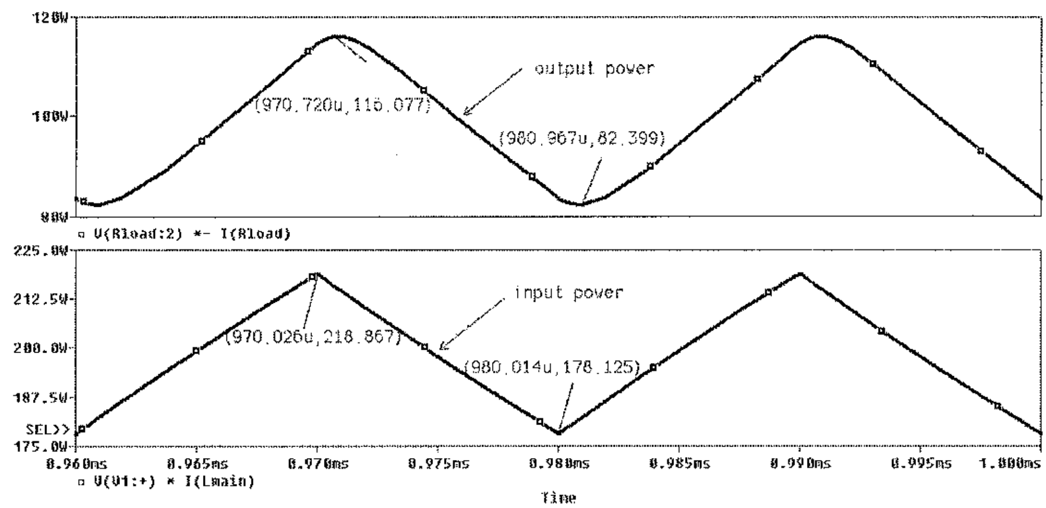

Figure 28 : Output power and input power for buck converter without snubber

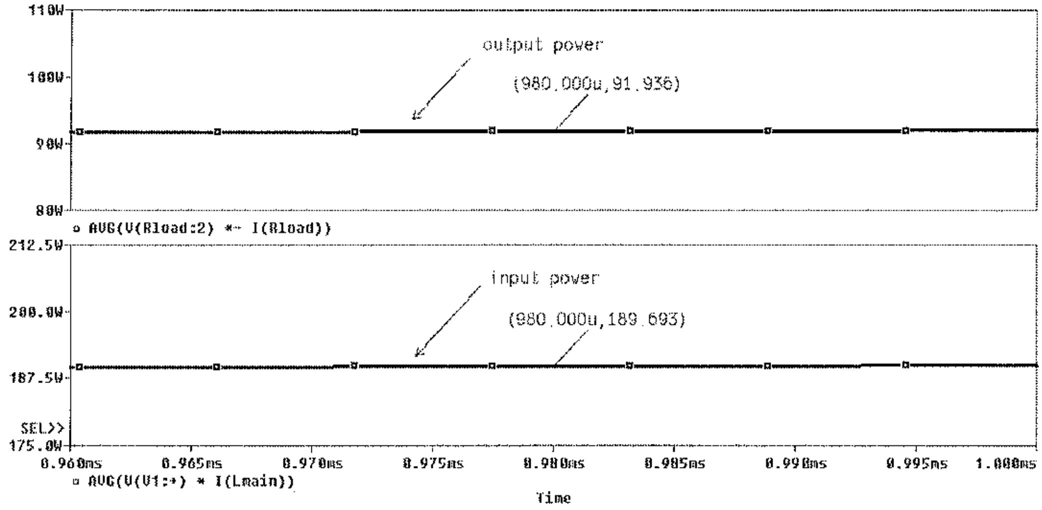

Figure 29 : Average output power and input power for buck converter without snubber

The simulated result for the circuit in Figure 30 is shown in Figure 31 and 32. Figure 31 shows the maximum and minimum output and input power and Figure 32 shows the average output and input power for buck converter with RCD snubber. It can be easily seen that the maximum and the minimum output power is 120.003V and 85.793V respectively while its average is 95.565V and for the maximum and minimum input power, the value is 221.82V and 181.824V respectively while its average is 193.495V. Therefore, the efficiency of the circuit is 49.39%.

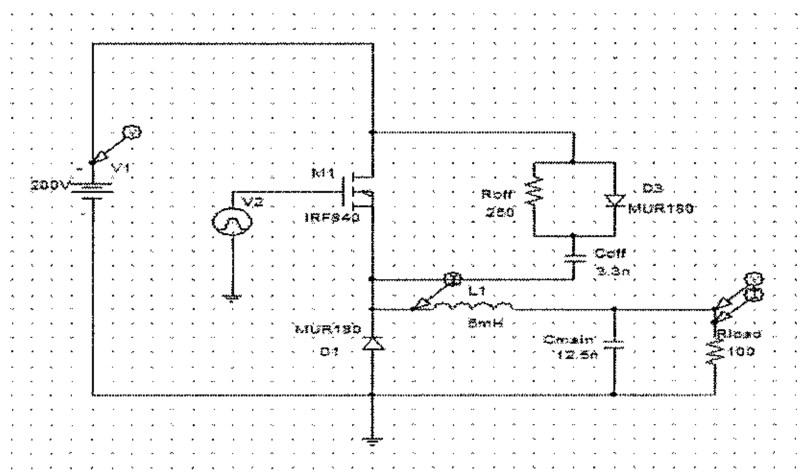

Figure 30 : Simulation circuit for buck converter with RCD snubber

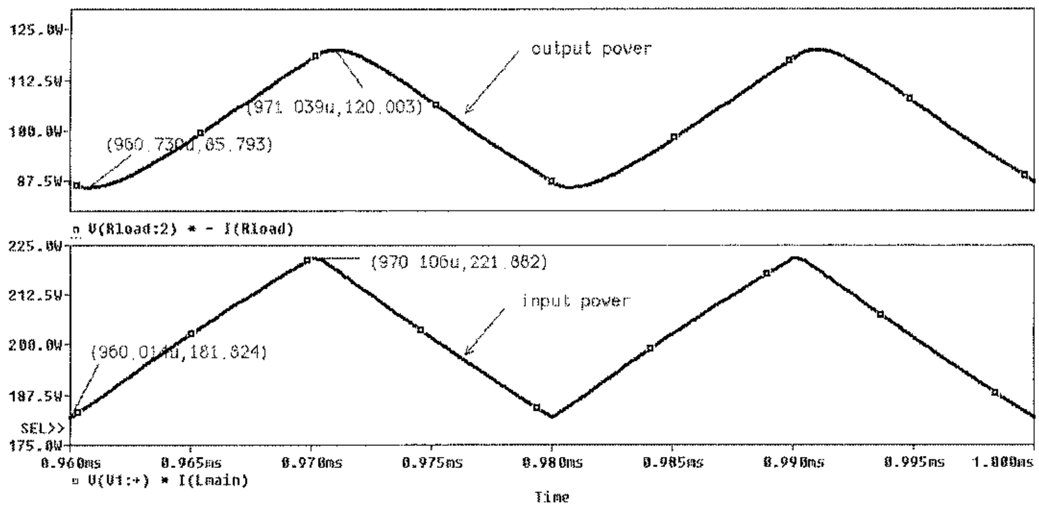

Figure 31 : Output power and input power for buck converter with RCD snubber

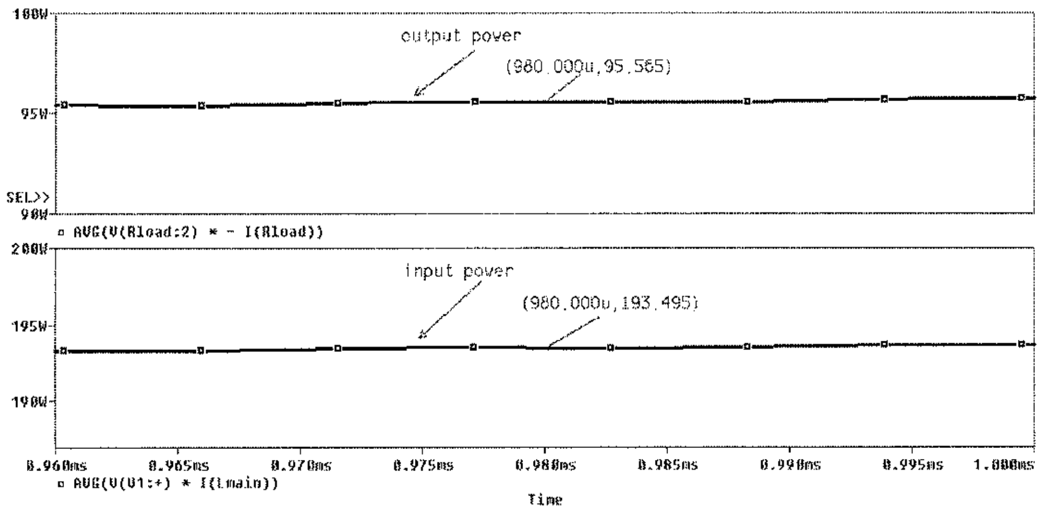

Figure 32 : Average output power and input power for buck converter with RCD snubber

Figure 33 shows the simulation circuit for buck converter with RLD snubber. After simulation, the results are as shown in Figure 34 and 35.Figure 33 represents the output power and input power for buck converter with RLD snubber while Figure 35 represents output power and input power for buck converter with RLD snubber. From the waveform we can see that the maximum and the minimum output power is 114.877W and 81.344W respectively while its average is 90.927W and for the maximum and minimum input power, the value is 177.204W and 217.752W respectively while its average is 188.672W.The calculated efficiency is 48.19%.

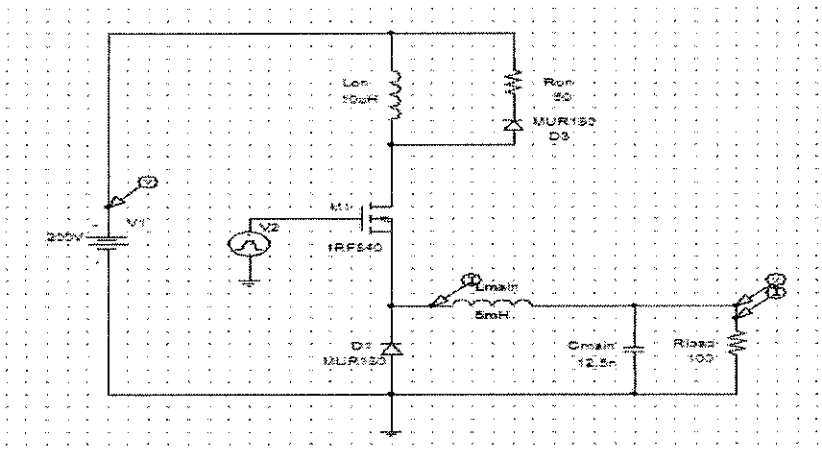

Figure 33 : Simulation circuit for buck converter with RLD snubber

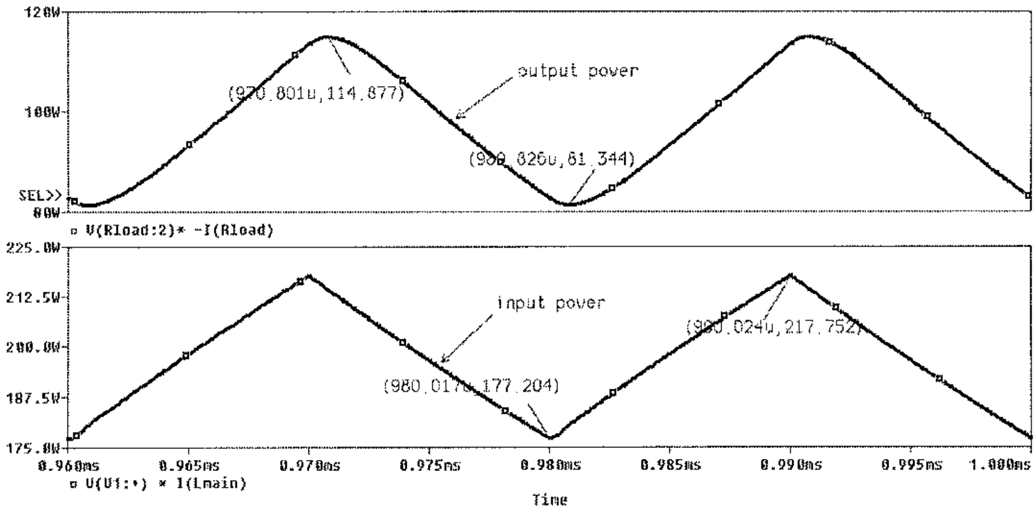

Figure 34 : Output power and input power for buck converter with RLD snubber

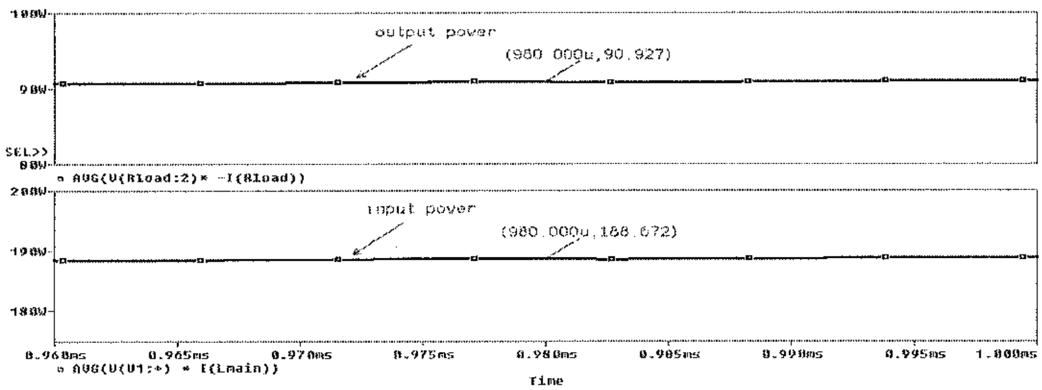

Figure 35 : Average output power and input power for buck converter with RLD snubber

For the circuit in Figure 36, the simulated results are shown in Figure 37 and 38.Figure 37 shows the maximum and minimum output and input power and Figure 38 shows the average output and input power for buck converter with RCD and RLD snubber. From the both figure, we can notice that the maximum and the minimum output power is 118.971W and 84.948W respectively while its average is 94.755W and for the maximum and minimum input power, the value is 220.932W and 181.128W respectively while its average is 192.670W. The efficiency of the circuit is 49.18%.

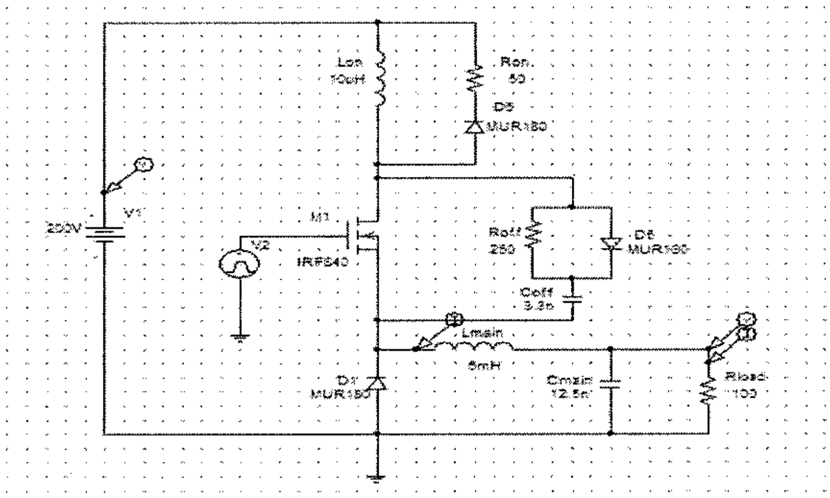

Figure 36 : Simulation circuit for buck converter with RCD and RLD snubber

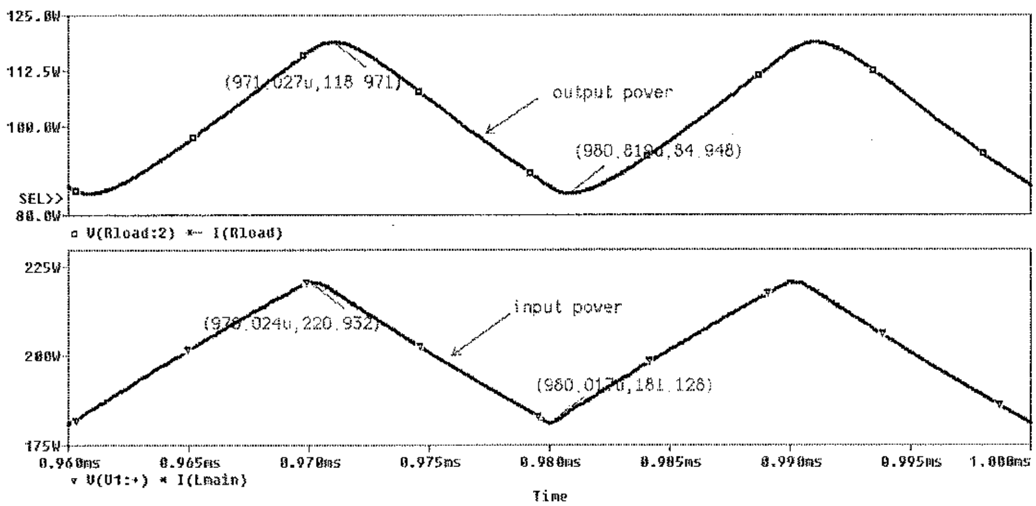

Figure 37 : Output power and input power for buck converter with RCD and RLD snubber

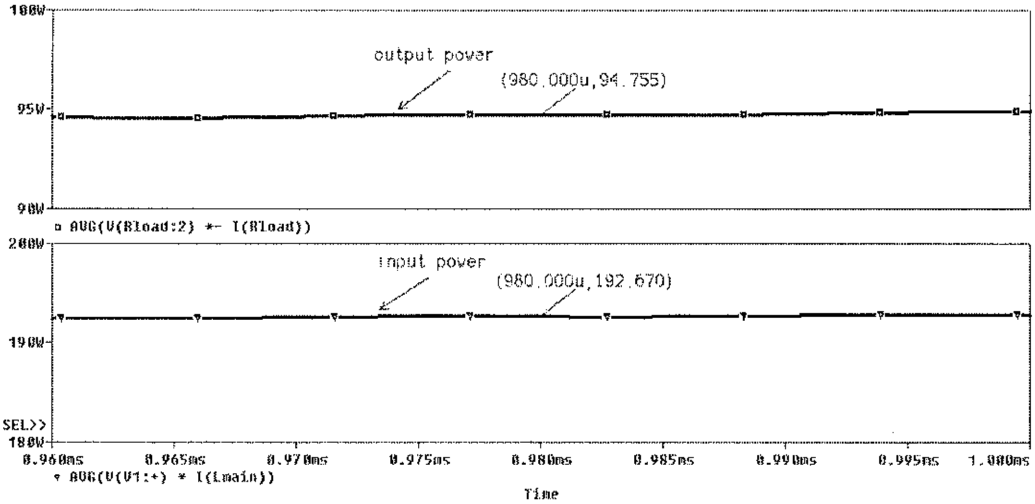

Figure 38 : Average output power and input power for buck converter with RCD and RLD snubber

Figure 39 shows the simulation circuit for buck converter with RCD and RLD snubber (improved). After simulation, the results are as shown in Figure 40 and 41.Figure 40 represents the output power and input power for buck converter with RCD and RLD snubber while Figure 41 represents output power and input power for buck converter with RCD and RLD snubber. From the waveform we can see that the maximum and the minimum output power is 68.109W and 39.146W respectively while its average is 51.514W and for the maximum and minimum input power, the value is 122.358W and 81.617W respectively while its average is 100.813W.The calculated efficiency is 51.1%.

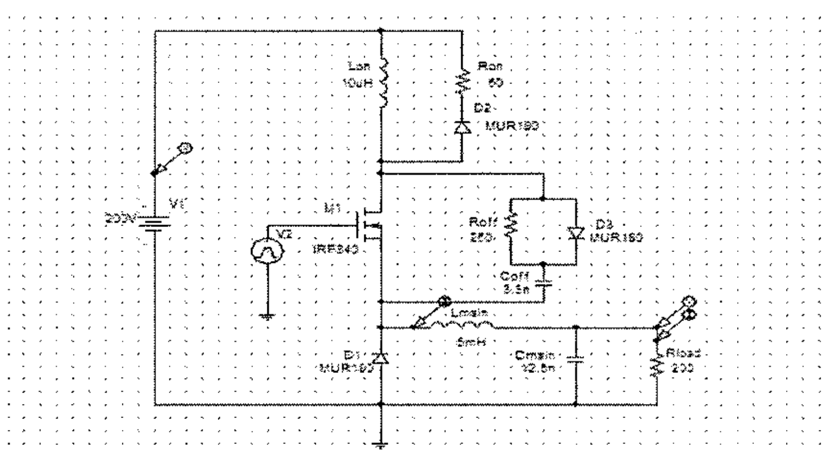

Figure 39 : Simulation circuit for buck converter with RCD and RLD snubber (improved)

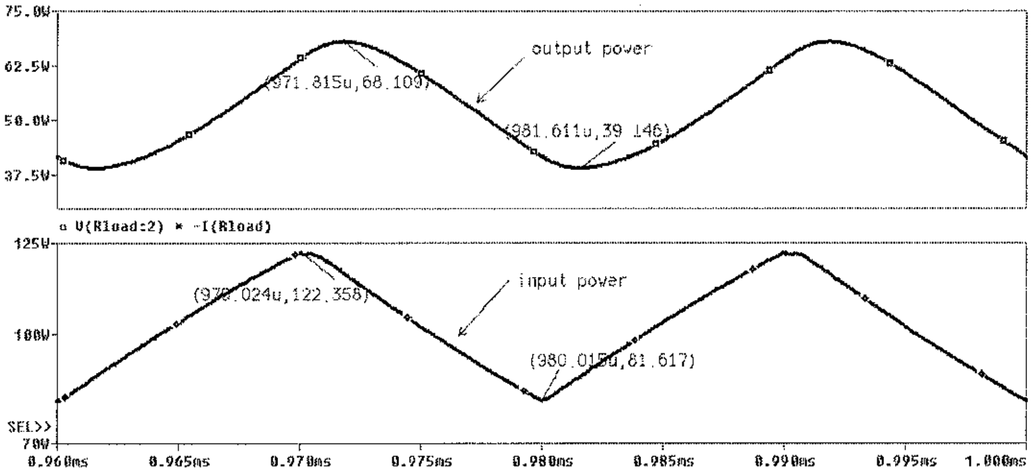

Figure 40 : Output power and input power for buck converter with RCD and RLD snubber (improved)

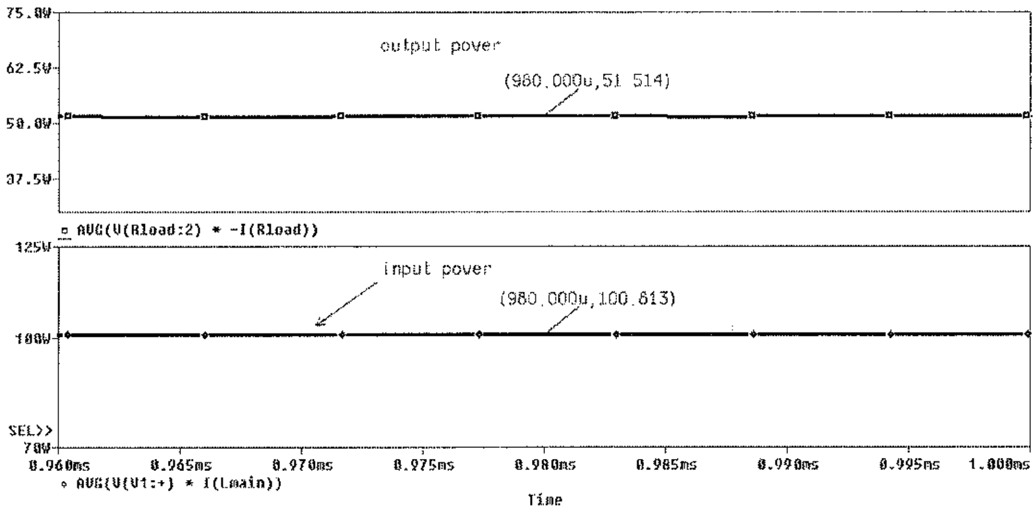

Figure 41 : Average output power and input power for buck converter with RCD and RLD snubber (improved)

Table 4 : Comparison table for efficiency and EMI of the circuits

Condition	Output power (Po)	Input power (Pin)	Efficiency (%)	EMI (dBuV)
Without	91.936W	189.693W	48.47	106.49
RLD	90.927W	188.672W	48.19	107.66
RCD	95.565W	193.495W	49.39	101.05
RCD+RLD	94.755W	192.670W	49.18	101.2
RCD+RLD (improved)	51.514W	100.813W	51.1	100.32

4.3 Justification

By referring to Table 4, we can see the comparison for efficiency and EMI of the different circuits. It is proved that EMI emission is most reduced by using integrated RCD and RLD snubber circuit. The only thing left that to be improved is the efficiency. In order to improve the efficiency, at first, the proposed method is by using the synchronous rectifier with parallel Schottky diode. Unfortunately, this method is not successful because it requires a device which is not yet created in PSPICE library. The proposed device should be N-Channel MOSFET Motorola MTD20N03HDL but this type of MOSFET not available in PSPICE library.

Trial has been done to import the related component into PSPICE library with the help from technician, but it still not working. As another alternative, efficiency is increased by increasing the load resistance, R_{load} from 100Ω to 200Ω. By this method, the efficiency of the circuit is slightly increasing about 2.08%. However this method is not 100% successful because there is a change in input power, P_{in}. Thus, it needs further study for the future work.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

A simulated result of efficiency and EMI is compared between the circuit without snubber, the circuit with integrated RCD and RLD snubber and the circuit with integrated RCD and RLD snubber (improved). We can conclude that the improvement made for the efficiency of the circuit with integrated RCD and RLD snubber is 2.63% higher compare to the converter without snubber and 1.92% higher compared to the converter with RCD+RLD snubber before improvement. For EMI, the RCD-RLD snubber (improved) circuit could reduce 6.17 dBuV of EMI at 1MHz from the circuit without snubber and 0.88 dBuV from the improvement circuit.

5.2 Recommendation

As to end the project presentation, it is therefore important to suggest some improvements and recommendations for the benefit of the project in the future undertaking. In any cases at all, engineers are known to improvise and modify to better the system. Therefore, the recommendations suggested are as follows:

- Proposed components should be imported into the PSPICE library for the simulation purposes.
- Efficiency of the circuit should be still increase at least up to 10%.
- EMI conducted emission could be reduce more for better circuit performance and efficiency.
- Experimental approach is needed to compare the simulated result with the experimental results.

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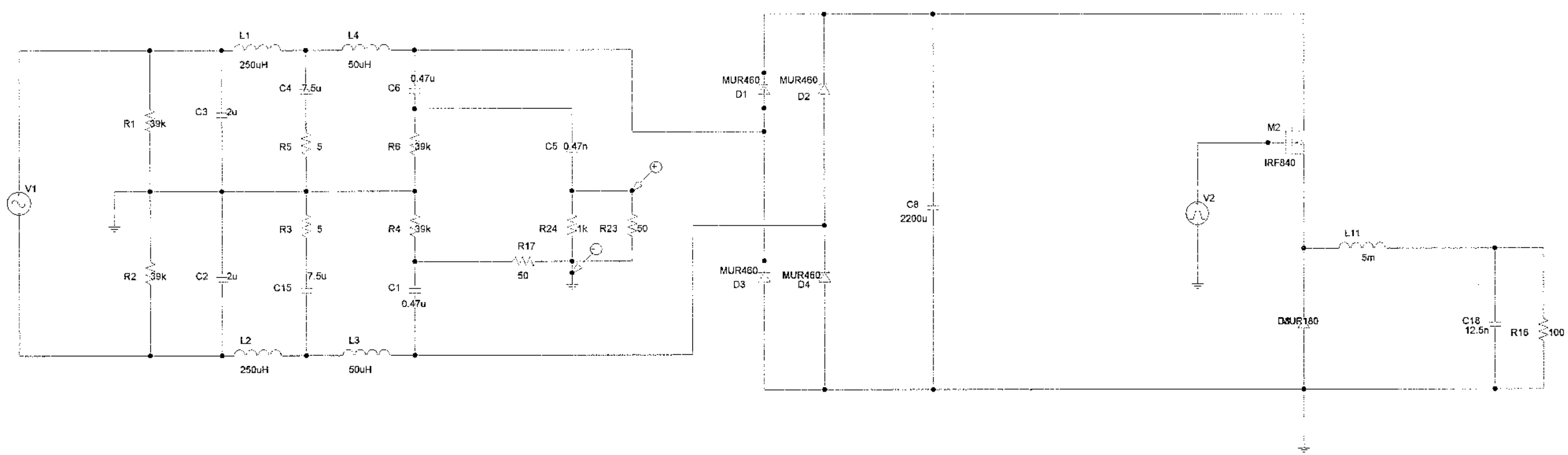
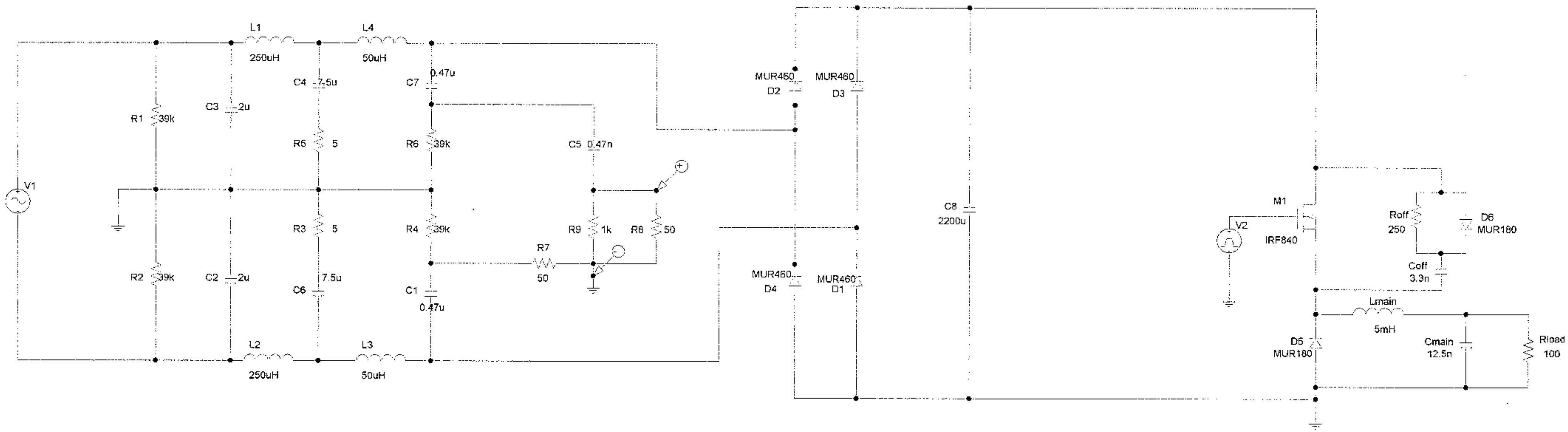
APPENDICES

APPENDIX A
EMI SIMULATION CIRCUIT FOR BUCK CONVERTER WITHOUT SNUBBER

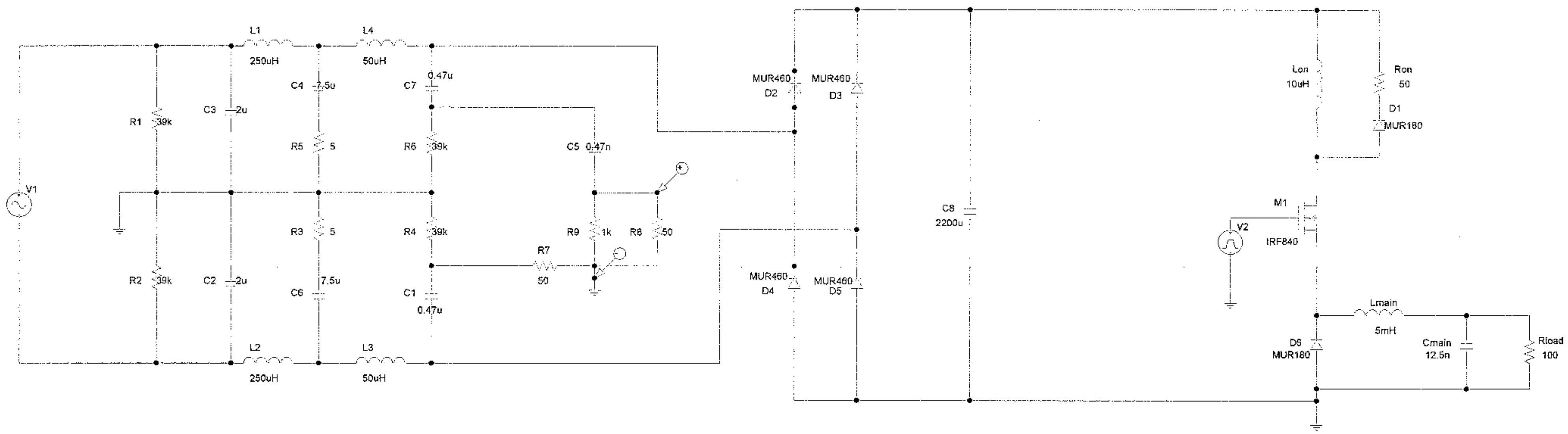

L1
250uH
L4
50uH
V1
R1
39k
R2
39k
C3
2u
C2
2u
C4
7.5u
R5
5
R3
5
C15
7.5u
C6
0.47u
R6
39k
R4
39k
C1
0.47u
C5
0.47n
R24
1k
R23
50
R17
50
L2
250uH
L3
50uH
MUR460
D1
MUR460
D2
MUR460
D3
MUR460
D4
C8
2200u
M2
IRF840
V2
L11
5m
MUR180
C18
12.5n
R16
100

APPENDIX B

EMI SIMULATION CIRCUIT FOR BUCK CONVERTER WITH RCD SNUBBER


V1
R1 39k
R2 39k
C3 2u
C2 2u
L1 250uH
L2 250uH
C4 7.5u
R5 5
R3 5
C6 7.5u
L4 50uH
L3 50uH
C7 0.47u
R6 39k
R4 39k
C1 0.47u
R7 50
C5 0.47n
R9 1k
R8 50
MUR460 D2
MUR460 D3
MUR460 D4
MUR460 D1
C8 2200u
V2
M1 IRF840
Roff 250
D6 MUR180
Coff 3.3n
Lmain 5mH
D5 MUR180
Cmain 12.5n
Rload 100

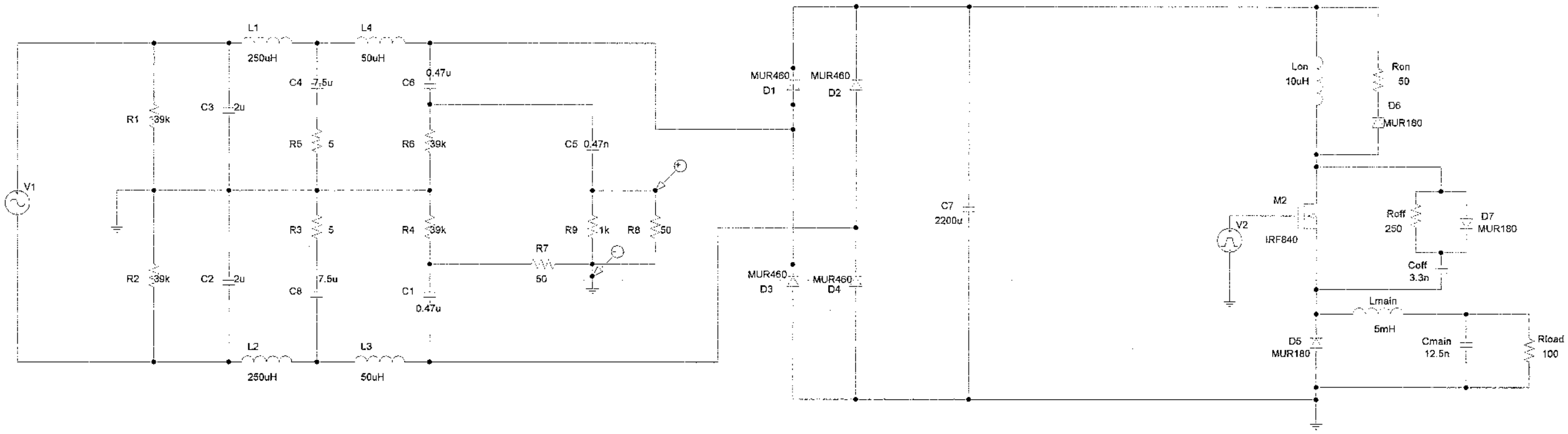
APPENDIX C
EMI SIMULATION CIRCUIT FOR BUCK CONVERTER WITH RLD SNUBBER CIRCUIT



V1
R1
39k
R2
39k
C3
2u
C2
2u
L1
250uH
L2
250uH
C4
7.5u
R5
5
R3
5
C6
7.5u
L4
50uH
L3
50uH
C7
0.47u
R6
39k
R4
39k
C1
0.47u
R7
50
C5
0.47n
R9
1k
R8
50
MUR460
D2
MUR460
D3
MUR460
D4
MUR460
D5
C8
2200u
Lon
10uH
Ron
50
D1
MUR180
M1
IRF840
V2
Lmain
5mH
D6
MUR180
Cmain
12.5n
Rload
100

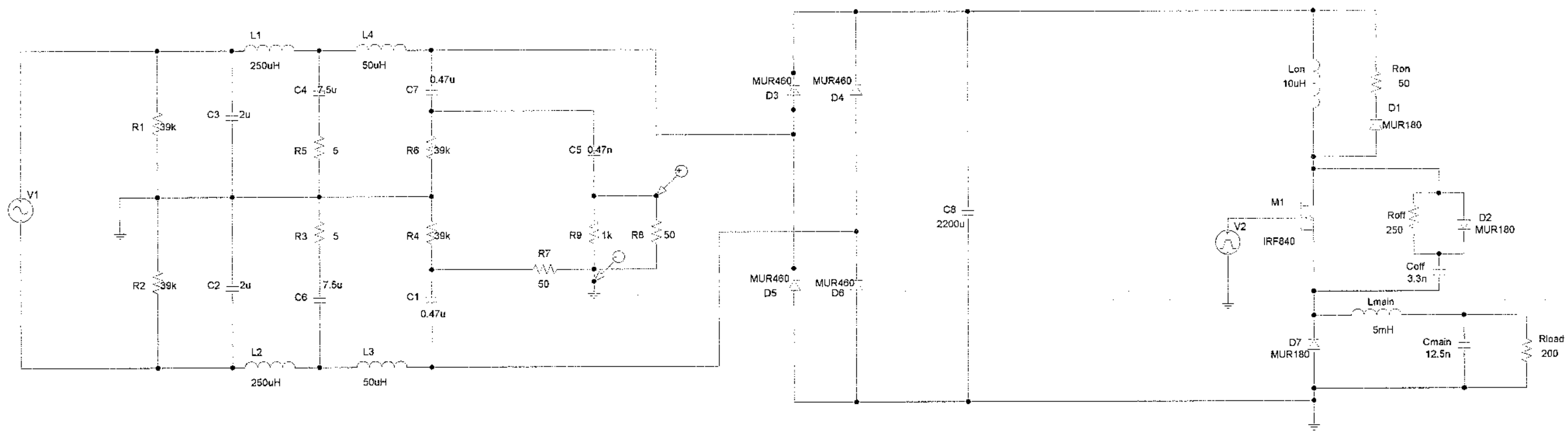
APPENDIX D

EMI SIMULATION CIRCUIT FOR BUCK CONVERTER WITH RCD AND RLD SNUBBER CIRCUIT


V1
R1 39k
R2 39k
C3 2u
C2 2u
L1 250uH
L2 250uH
C4 7.5u
R5 5
R3 5
C8 7.5u
L4 50uH
L3 50uH
C6 0.47u
R6 39k
R4 39k
C1 0.47u
C5 0.47n
R9 1k
R8 50
R7 50
MUR460 D1
MUR460 D2
MUR460 D3
MUR460 D4
C7 2200u
Lon 10uH
Ron 50
D6 MUR180
M2
IRF840
V2
Roff 250
D7 MUR180
Coff 3.3n
Lmain 5mH
D5 MUR180
Cmain 12.5n
Rload 100

APPENDIX E

EMI SIMULATION CIRCUIT FOR BUCK CONVERTER WITH RCD AND RLD SNUBBER (INCREASE LOAD RESISTANCE)


V1
R1 39k
R2 39k
C3 2u
C2 2u
L1 250uH
L2 250uH
C4 7.5u
R5 5
R3 5
C6 7.5u
L4 50uH
L3 50uH
C7 0.47u
R6 39k
R4 39k
C1 0.47u
R7 50
C5 0.47n
R9 1k
R8 50
MUR460 D3
MUR460 D4
MUR460 D5
MUR460 D6
C8 2200u
Lon 10uH
Ron 50
D1 MUR180
M1
IRF840
V2
Roff 250
D2 MUR180
Coff 3.3n
Lmain 5mH
D7 MUR180
Cmain 12.5n
Rload 200