DESIGN A COMPENSATOR FOR DC-DC CONVERTER

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"I hereby declared that I have read through this report and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

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نحمد الله العلي العظيم ونصلي على رسوله الكريم

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ABSTRACT

An open-loop DC-DC converter cannot regulate its output voltage due to varies in input voltage or changes at load. Compensator is used to overcome this problem so that the converter will produce a stable output voltage. This project presents a UC3525A IC based analog control design and implementation. The aim of this project is to develop loop compensation. For this purpose, the basic circuit configuration used is the buck converter. By the way, loop compensation frequency domain responses analysis and design process for a compensator is presented using MATLAB package. Within the aim to increases the loop phase, Type 3 compensator is used because the phase margin of the open loop DC-DC converter is less than the desired closed loop phase margin at the desired crossover frequency. The compensator block is responsible for providing sufficient gain to make the output voltage very nearly equal to the reference voltage (times a constant) and sufficient phase margin so that the output voltage doesn't ring or oscillate in response to a load step. At the same time, too much phase margin will cause the output voltage to respond too slowly to a load step. Finally, MATLAB based analog control design approaches presented here are finally validated with multiple test results from a prototype converter.

ABSTRAK

Penukar AT-AT gelung buka atau *open loop DC-DC converter* lazimnya tidak dapat mengatur voltan keluarannya disebabkan perubahan pada voltan masukan dan beban. Oleh itu, Pemampas atau *compensator* digunakan untuk mengatasi masalah tersebut dimana akan menghasilkan voltan keluaran yang stabil. Projek ini melibatkan rekebentuk dan perlaksanaan kawalan analog pada litar bersepadu UC 3525A. Objektif projek ini adalah merekabentuk gelung pampasan atau *compensation loop.* Litar asas yang digunakan adalah penukar langkah turun atau *buck converter.* Perisian simulasi MATLAB digunakan untuk membuat analisa terhadap sambutan domain frekuensi dan proses mereka bentuk gelung pampasan. Oleh kerana itu, pemampas tahap 3 digunakan untuk meningkatkan fasa gelung kerana jidar fasa atau *phase margin* penukar AT-AT gelung buka adalah rendah / kurang berbanding dengan jidar fasa gelung tertutup di frekuensi lintas atau *crossover frequency* yang dikehendaki. Gelung pampasan akan memastikan voltan keluaran adalah sama dengan voltan rujukan melalui penghasilan gandaan voltan dan jidar fasa dimana sambutan voltan keluaran tidak akan berayun pada langkah beban. Dalam masa yang sama, jidar fasa gelung tertutup yang terlalu tinggi akan menyebabkan sambutan voltan keluaran yang perlahan pada langkah beban. Seterusnya, pendekatan rekebentuk dan perlaksanaan kawalan analog MATLAB akan digunakan dalam perkakasan dengan beberapa siri analisa, eksperimen dan ujian.

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LIST OF ABBREVIATIONS & SYMBOLS

AC	-	Alternating Current
AM	-	Amplitude Modulation
BJT	-	Bipolar Junction Transistor
D	-	Duty Cycle
dB	-	Decibel
DC	-	Direct Current
DMM	-	Digital Multimeters
EA	-	Error Amplifier
EMI	-	Electromagnetic Interference
ESR	-	Equivalent Series Resistance
FM	-	Frequency Modulation
IC	-	Integrated Circuit
IGBT	-	Insulated Gate Bipolar Transistor
LED	-	Light Emitter Diode
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
MATLAB	-	Matrix Laboratory
PSpice	-	Simulation Program with Integrated Circuit Emphasized
PSM	-	Projek Sarjana Muda
PWM	-	Pulse Width Modulation
SIT	-	Static Induction Transistor
SMPS	-	Switch Mode Power Supply
TF	-	Transfer Function
THD	-	Total Harmonic Distortion
UTeM	-	Universiti Teknikal Malaysia Melaka
VOM	-	Volt-Ohm-Meters
^{0}	-	Degree
%	-	Percent
+/-	-	Plus or Minus

CHAPTER 1

INTRODUCTION

Basically, an open-loop DC-DC converter cannot regulate its output voltage due to varies in input voltage or changes at load. Compensator is used to overcome these problems so that the converter will produces a stable output voltage. The aim of this project is to develop loop compensation. For this purpose, the basic circuit configuration used is the buck converter. By the way, loop compensation frequency domain responses analysis and design process for a compensator is presented using MATLAB package.

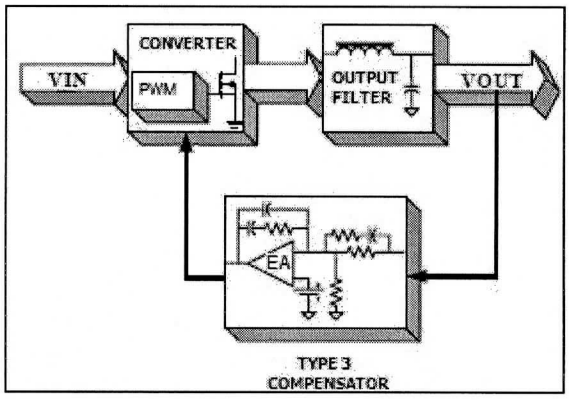

Figure 1.1: Project Block Diagram

Within the aim to increases the loop phase, Type 3 compensator is used because the phase margin of the open loop DC-DC converter is less than the desired closed loop phase margin at the desired crossover frequency. The compensator block is responsible for providing sufficient gain to make the output voltage very nearly equal to the reference voltage (times a constant) and sufficient phase margin so that the output voltage doesn't ring or oscillate in response to a load step. At the same time,

too much phase margin will cause the output voltage to respond too slowly to a load step. Finally, the stability of the design is tested with optima performances parameters for giving satisfying output.

1.1 Project Objectives

An open-loop DC-DC converter cannot regulate its output voltage due to varies in input voltage or changes at load. Compensator is used to overcome these problems so that the converter will produces a stable output voltage. The aim of this project is to develop type 3 compensator. For this purpose, carefully analysis of Buck converter operating frequency with a varying duty cycle is introduced. At the same time, loop compensation frequency domain responses analysis and design process for a Type 3 compensator is presented using MATLAB package. Within the slightly aim to alter the closed loop response to meet a given set of requirements, test a stability of the design with optima performances parameters may be taken into design oriented consideration.

1.2 Problem Statements

Within the aim of this project to enhance several problems that usually faced by an open loop DC-DC converter. Greatly consideration may be taken into account to accomplish this solution. Below list down the several problems are found in open loop DC-DC converter:

1. **Unstable Output Voltage**

Basically, an open loop DC-DC converter cannot regulate its output voltage due to varies in input voltages or change at load.

2. Instability System

To much or less phase margin an open loop DC-DC converter will cause the output voltage to respond too slowly to a load step, thus contribute instability condition of the system.

3. High Ripple and Harmonic Problem

Ripple and Harmonics that produced in open loop DC-DC converter also high thus contribute reduced in the output efficiency.

1.3 Scope of Works

The scope of this project is to develop loop compensation in a **frequency domain analysis** form to alter the closed loop response to meet given set of requirement. The compensator block will do this task:

1. Provide sufficient gain to make output voltage very nearly equal to the reference voltage (in this case assumed $Vref = 5V$)
2. Provide sufficient phase margin so that the output voltage doesn't ring or oscillate in response to a load step. A good target phase is about 55°, though 45° is usually acceptable and sometimes even40 °[1]
3. Reduction of noise due to feedback, in order a high noise contribute reduced system efficiency.

1.4 Project Methodology

To accomplish this task, overall project are divided in three phase stage. Each phase is planning according to time frame that is given previously. By the way, this project progress moved on the right track based on time frame and scope of work. For

[1] Feedback Loop Stabilization Section, Abraham I. Pressman, Switching Power Supply Design, McGraw Hill, 1996

further reference, please refer to project planning schedule attached together in this report.

Table 1.1: Project Methodology

1st Phase	Literature Review System Planning
2nd Phase	Frequency Domain Analysis Alter Closed Loop Response Determine System Stability
3rd Phase	Components Integration System Testing Final Documentation

Within the aim to settle down entire phase, an emphasize in design oriented procedures that understand Type 3 Compensator Design approach and demonstrates the goals of a Type 3 Compensator. Shortly, to compensate a DC-DC Converter, the following steps may be used as a general guide:

1. Determine characteristics of the output filter.
2. Choose a compensation network.
3. Calculate values for components in the compensation network.
4. Simulate stage.

These steps should be iterated until a suitable solution is reached.

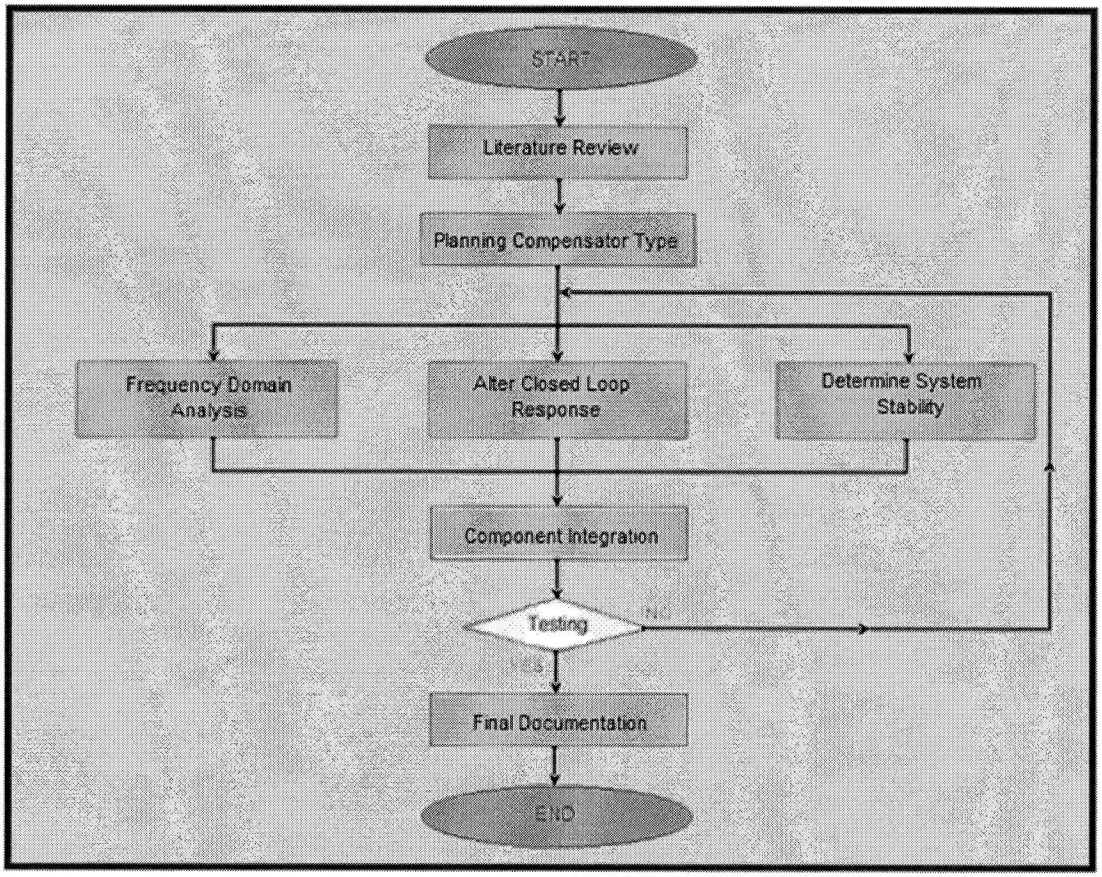

Figure 1.2: Project Work Flow

Regards the following project work flow, a hard effort step is to alter closed loop response because there are several things to keep in mind. For example, if a suitable solution is not reached after the initial iteration, instruct resort to plotting the design oriented transfer function on a Bode phase plot. The poles and zeros should be placed to attain the necessary phase margin (typically 45°- 90°, however 55° is preferable) at the desired $\omega_{crossover}$ (typically $1/5^{th}$"$1/10^{th}$ the switching frequency, however $1/5^{th}$ the switching frequency is preferable[2]). Once this is completed, a Bode amplitude plot may be constructed. The Bode amplitude plot may be used to determine the system gain necessary to reach 0dB at $\omega_{crossover}$.

[2] Feedback Loop Stabilization Section, Abraham I. Pressman, Switching Power Supply Design, McGraw Hill, 1996

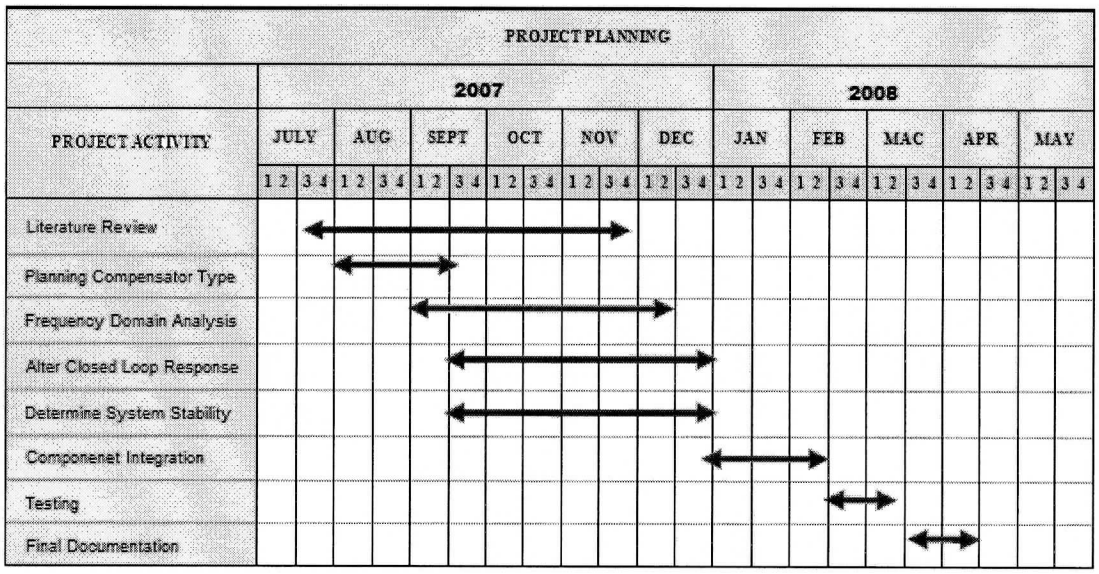

Figure 1.3: Project Gantt Chart

Below there are some effective steps to be follow to ensure this project can be done smoothly:

1. Planning

In this stage, I've been given choice to choose a project to be done. After make a choice for a project, discussion with supervisor about the project requirement and project scope have been done. As the result, greater decide that the scope of project for PSM-1 include finding a information, collecting data, circuit analysis and circuit design using simulation software. The result from simulation will continue at PSM-2 for develop the prototype. For PSM-2 this project more on prototype development and hand-on skill needed. Testing and troubleshooting process is done after finish installing the component on the circuit board.

2. Data collection

In this stage, entire data and information about DC-DC converter and compensator are collected. The data sheet and basic theory for the component such as inductor, capacitor, resistor, diode, MOSFET and some integrated circuit (IC) that used to generate PWM signal also find. After find all the information, read and understand the data is the most important thing for the next stage progression.

3. Circuit analysis and circuit design

Basic operation and theory of the circuit must be known before analyze and designing a circuit. The parameter of the project also must be state such as input voltage requirement, expected output, switching frequency and some other parameter before the component value can be calculates such as the inductor, capacitor and resistor. After all the value has been found out, the circuit can be draw and simulate in simulation software to get the first result from the calculation.

4. Simulation

MATLAB and OrCAD PSpice are the simulation software used to simulate the circuits that have been design in the previous step. Both software can show the output voltage, output current, total harmonic distortion (THD) and else. From the output waveform we can know whether the design is meet the requirements or vice versa. The result from simulation is compared to the theory calculation. For the best and accurate result, simulation must be done repeatedly.

5. Build-up prototype

In hardware prototype, there are four stages have been taken. The first step is to build the open loop buck converter circuit and filter circuit. The required component for this is MOSFET, diode, inductor, capacitor and resistor. The second stage is to build the signal or control circuit. To develop this circuit IC is needed to generate PWM signal. The IC that usually used is such as SG3524, UC3525, MAX8546, LT1027 and LM2593HV. The third step and this is an additional step is to build a snubber circuit. This circuit is to protect power transistor device from the spike voltage when switching process is in progress. Finally, build a compensation loop for provide sufficient gain, phase margin and reduce noise due to feedback for enhance system efficiency and stable output.

6. Testing and troubleshooting

This is the final stage before the result or output from the project is defined. After all the circuits are built, testing process is the important part to know the

functional and the output of the circuit. In many project design there are no accurate result get from the first testing so here we have proceed for troubleshooting process. This step is to define the problem and un-match value of the component. In this step several modifications and change to the circuit and adjust the value of the component meet. Finally, the testing and troubleshooting process is continuously until the expected result obtains and meets the desired requirements.

CHAPTER 2

LITERATURE REVIEW

2.1 DC-DC Converter

The three basic switching power supply topologies in common use are the buck, boost, and buck-boost. These topologies are non-isolated, that is, the input and output voltages share a common ground. There are, however, isolated derivations of these non-isolated topologies. The power supply topology refers to how the switches, output inductor, and output capacitor are connected. Each topology has unique properties. These properties include the steady-state voltage conversion ratios, the nature of the input and output currents, and the character of the output voltage ripple. Another important property is the frequency response of the duty cycle to output-voltage transfer function.

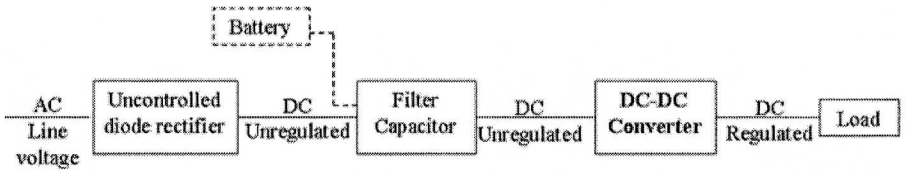

Figure 2.1: A DC-DC Converter System

The most common and probably the simplest power stage topology is the buck power stage, sometimes called a step-down power stage. Power supply designers choose the buck power stage because the output voltage is always less than the input voltage in the same polarity and is not isolated from the input. The input current for a buck

power stage is discontinuous or pulsating due to the power switch (Q1) current that pulses from zero to I_O every switching cycle. The output current for a buck power stage is continuous or non-pulsating because the output current is supplied by the output inductor/capacitor combination, the output capacitor never supplies the entire load current (for continuous inductor current mode operation). The steady state operation of the buck power stage in continuous-mode and discontinuous-mode operation with ideal waveforms given. The duty cycle to output voltage transfer function is given after an introduction of the PWM switch model. Figure 2.2 shows a simplified schematic of the buck power stage with a drive circuit block included. The power switch, Q1, is an n-channel MOSFET. The diode, CR1, is usually called the catch diode, or freewheeling diode. The inductor, L, and capacitor, C, make up the output filter. The capacitor ESR, RC, (equivalent series resistance) and the inductor DC resistance, R_L, are included in the analysis. The resistor, R, represents the load seen by the power stage output.

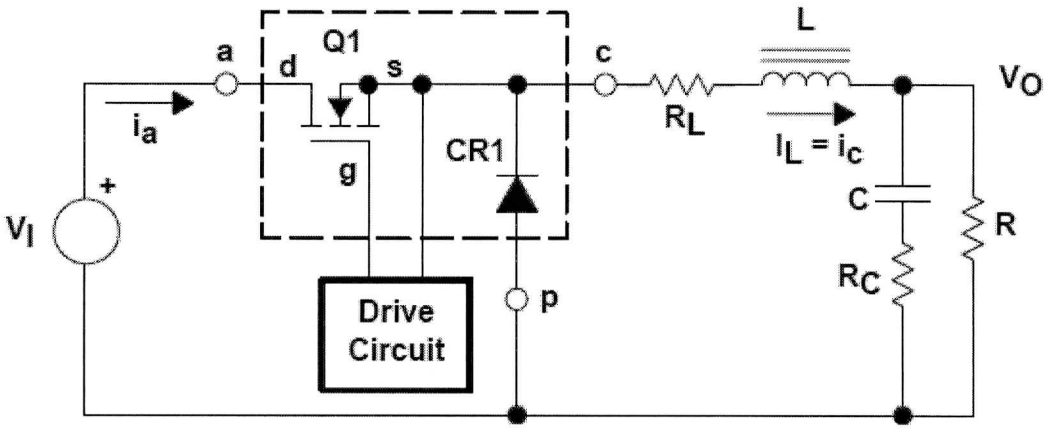

Figure 2.2: Buck Power Stage Schematic

During normal operation of the buck power stage, Q1 is repeatedly switched on and off with the on and off times governed by the control circuit. This switching action causes a train of pulses at the junction of Q1, CR1, and L which is filtered by the LC output filter to produce a dc output voltage, Vo.