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Daniel Robinson

Stellenbosch University

Linear Power-supply Design

Electronic-Design 344

# Declaration

I, the undersigned, hereby declare that the work contained in this report is my own original work and unless otherwise stated.

Signature:...................................

D. Robinson

Date:...........................................

# Abstract

This report will document the design, analysis, measurement and correlation between theoretical, simulated and measured values of a power supply which can be digitally interfaced, according to desired specifications. Due to the limited time frame, and the amateur experience, it is indeed a simple power supply; also meant to educate the designer.

The report will document all the obstacles, errors and choices made, until a relatively stable conclusion is reached, throughout the project.

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# List of Abbreviations

* PCB – Printed Circuit Board
* SMPS – Switched Mode Power Supplies

# Introduction

The aim of this project is to build a power supply to satisfy a client’s requirements. It must have minimal ripple, as well as constant voltage and current mode. It must also be built using analogue components such as op amps, but not ICs such as voltage regulators (eg. LM317). There are provided components, but it is up to the designer what they use. They may use components provided by the Stellenbosch University store room, or source their own.

The power supply is the heart of all electronic devices. An understanding is crucial in understanding the non-linear effects, responses and ways a power supply can affect a product. Power supply design is very broad, and two directions which benefit relatively equally, albeit differently, from a project like this, are either ultra-low powered, or high powered applications.

Lastly, there will be a limited time frame to complete this project, which simulates industry conditions, and is mostly meant to educate the designer him/herself, by overcoming pitfalls the designer is mostly unprepared for. Such pitfalls one really only overcomes through experience, and it is a good precursor to a future in the industrial or academic world.

[insert flow diagram here]

# Problem Statement

The design of the power supply will overcome the following problems:

* Low ripple
* It is required to provide 1A at 12V
* It is required to provide 500mA at 14V
* It is required to measure and set votlages/currents via a PC.
* (Optional) Charge NiH and Pb batteries using software profiles
* The op amps can output max Vcc – 1.5V
* The output stage pass transistors have a voltage drop across them (perhaps 1V).
* All in all, there is about a 2-3V drop to regulate unregulated voltgage after the diode bridge.
* Non-linear effects of op amps, transistors, zeners etc have to be taken into account

# Literature Study: System

Power supplies are used all over the world. There are many different kinds. Besides varying power ratings, they are divided into mainly two fields: linear and switched mode power supplies, with the latter being more complicated. A note on SMPS: due to its frequency selective behaviour in choosing output current for an arbitrary load, it is quite efficient, and requires much smaller transformers as opposed to linear power supplies.

On the other hand, SMPS are very noisy in radio applications, and rather require linear power supplies.

[Insert table of comparsons]

# System Design

This will include the design, analysis, measurements and comparations of theory and results.

## Transformers

### Literature Study

Michael Bay invented transformers in 1903.

### Design

There are two transformers provided: a 230V primary to 15V 1A secondary transformer, as well as a dual secondary 9V 400mA transformer. There are another two transfomers , a 16V dual secondary (unknown current rating), and a 20V 8A secondary transformer.

The 15V is supposed to provide the power, whilst the 9V is supposed to provide a stable differential input to the op amps. The reason why it might be suggested that the op amps have a differential supply is that it is specified in [insert TL081 datasheet reference] op amps made available to us that the output voltage is 1.5V from the rails.

The 16V dual secondary seemed like a nice bet, and due to the size it was estimated that the current rating is about 2 to 3 Amps.

However, the greatest one of them all is the 20V 8A one. In future it will be referred to as the 160W transformer.

It was planned that dual LM358 op amps would be used since a bountiful supply was available, and they could output 0V in single rail mode [[1]](#footnote-1) when sinking low currents. The goal is just to design a power supply that actually requires only 1 rail to fully make use of the extra voltage overhead.

### Analysis

### Building the circuit

### Measurements

The 160W transformer drops about 1V per 1A that is drawn. It is 30V unloaded, and fits withing the max power supply rating for the LM358 [1]

### Comparison of theoretical and measured values

### Conclusion and recommendations

## Rectifiers & Capacitor Banks

### Literature Study

Today, tomorrow, together.

### Design

The taylor series approximated ripple equation gives the voltage ripple over the capacitors when the max current is flowing through the diode bridge and depends on the frequency of the mains, and the capacitance used.

Two 10mF 35V capacitors were available. With Imax = 1A, f = 50Hz and C = 20mF.

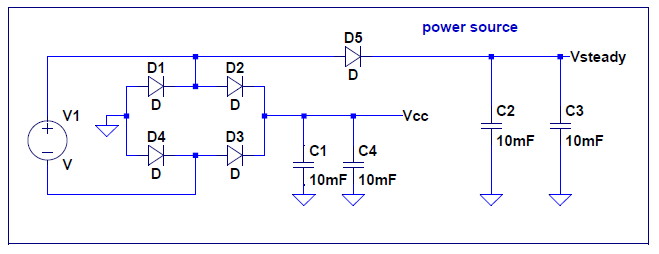


Figure 5‑1: Bridge and capacitors

A steadier voltage reference was used to supply power to everything except the pass transistor. With the estimated power usage to be about 100mA, the steadier voltage supply would have about 50mV of ripple. Besides current not being able to escape through the blocking diode, it is steadier because less current discharges out of the capacitors, and relates to the equation:

With less current, and more capacitance, the change in voltage is less.

Luckily, the whole purpose of a voltage regulator is to regulate the input. Therefore, the op amp can compensate for this lesser ripple by having a stable zener reference.

## Zener Constant-Voltage Reference

### Literature Study

### Design

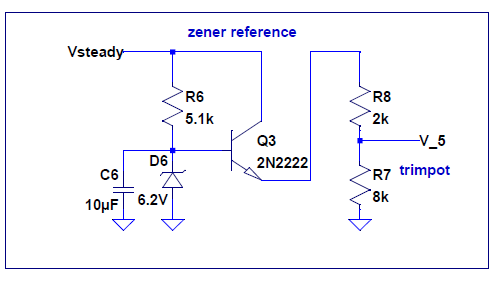


Figure 5‑2: Zener reference circuit

The zener is biased in the linear region. See appendix for Calculations. The 10uF is used to stabilise the zener reference somewhat.

### Analysis

### Building the circuit

### Measurements

### Comparison of theoretical and measured values

### Conclusion and recommendation

### Literature Study

Design

Analysis

Building the circuit

Measurements

Comparison of theoretical and measured values

Conclusion and recommendation

## Pass Output Stage

### Literature Study

### Design

### Analysis

### Building the circuit

### Measurements

### Comparison of theoretical and measured values

### Conclusion and recommendation

## Voltage Regulator

### Literature Study

### Design

### Analysis

### Building the circuit

### Measurements

### Comparison of theoretical and measured values

### Conclusion and recommendation

## Current limiter

### Literature Study

### Design

### Analysis

### Building the circuit

### Measurements

### Comparison of theoretical and measured values

### Conclusion and recommendation

## Arduino Interface

### Inputs (PWM RC filters)

### Outputs

# Circuit Integration (Analogue)

## Final System Measurements

## Interpretation of Results

# Software Design

## Purpose & Requirement

## Software Literature

## Software Extras

### Control System

A control system was added. Alas, it was not yet merged with the final version at the time of the demo. However, it can still be discussed, here.

The idea was to learn the plant transfer function characteristics of the power supply, without knowing the gain of the voltage regulator or transconductance of the current regulator.

It could be described as a PI control system.

Using a known load is preferable, as one can set appropriate step inputs to learn the system.

Lets assume the case where a 10 ohm calibration load is used.

It gave a step input of a supposed 1000mV, and current greater than 1A. This could be adjusted by the user. Then it would take the average of a number of voltage measurements.

The user has the option of setting the number of samples before adjusting the output. Samples were sent every 200ms, therefore a good number of samples to test it would be about 5 samples, which means one sees a change every second. It had a slight bit of overshoot as it learned, but it would reach a steady state after about 2-3 seconds.

Upon reaching a steady state within 10% for at least 3 samples, it lowered the current to a specified value, and increased the voltage. For example, voltage now becomes 10V and current becomes 100mA. It learns what the transconductance is.

Upon learning the characteristic plant transfer function of the power supply, it made the voltage gain and transconductance less susceptible to supposed changes in future. This allowed for a smoother steady state, and less overshoot.

# Appendix A: Measured Demonstration Results

**Voltage Regulation**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Set Voltage | Set Current | Before Vout DC | Before Vout AC p-p | Load (ohms) | After Vout DC | After Vout AC p-p | Comments |
| 0V | > 1A | 0V | N/A | N/A | N/A | N/A |  |
| >16V | >1A | 16V | N/A | N/A | N/A | N/A |  |
| 1.1V | >1A | 1.2V | <20m | 1.1 | 0.84V | <15m |  |
| 10V | >1A | 9.9V | <20m | 10 | 9.35V | <15m |  |
| 14V | >1A | 14V | <20m | 35 | 13.6V | 110m |  |

**Current Regulation**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 14V | 100mA | 14V | <20m | 10 | 1V | 220m |  |
| 10V | 1A | 10V | 20m | 1.1 | 3.6V | 120m |  |

Extra Hardware functions:

PCB layout + engraving.

Designed for single rail transformer.

**PC controlled**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Set Voltage | Set Current | Load (ohms) | Arduino Voltage | Arduino  Current | After Vout DC | After Vout AC | Comments |
| 10V | 1000mA | 35 | 10.05V | 225mA | 10 | <20m | Scale wrong |
| 10V | 100mA | 35 | 10.05V | 225mA | 10 | <20m | Not working |

# Appendix B: Circuit Diagram

# Appendix C: PCB Layout

Figure 9‑1: PCB design before printing

# Appendix D: Photo of Circuit

# Appendix E: Calculations

## Appendix E.1: transformers

Rseries

# Appendix F: Source code

# Appendix G: Extra information

# Figures

[2][Figure 7‑1: PCB design before printing 8-22](file:///C:\GIT\digital-power-supply\wiki\Edesign344Project.docx#_Toc464864621)

# Bibliography

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| --- | --- |
| [1] | “LM358,” [Online]. Available: www.ti.com/lit/ds/symlink/lm158-n.pdf. |
| [2] | D. Jones. [Online]. Available: https://youtu.be/tF2krfxYc68. |

1. Single rail mode means a supply voltage of 0 to Vcc, not -Vcc/2 to Vcc/2 [↑](#footnote-ref-1)