

Final

by Kristian Payne

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BSc (Hons) Electrical and Electronic Engineering

PSDE6015: Electronic Design

Assignment: Regulated Power Supplies

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1. EXECUTIVE SUMMARY

This report details the process of designing a power supply to satisfy a customer's requirements through a top down design method to ensure that all parts of the power supply were designed appropriately. The design was supported by values and figures that were calculated from appropriate formulae and graphical methods while using information supplied by manufacturers through data sheets. Manufactured and purchasable components were then selected to be used with consideration of the customer requirements and calculated value tolerances. The design process was effectively completed with the results suiting the customer's requirements.

2. RESEARCHING REQUIREMENTS AND COMPLIANCE OF THE SPECIFICATION

1.1 PRODUCT DESIGN SPECIFICATION

1.1.1 Customer physical requirements

This power supply is needed to provide a supply to several components in an electrical panel on a small furnace.

1.1.2 Operational and physical requirements

Electrical

$$\begin{aligned} \text{Input voltage} &= 240V \\ \text{Output Voltage } (V_o) &= 24V \pm 0.1V \\ \text{Output Current } (I_o) &= 2A \end{aligned}$$

Safety

The power supply will need to be enclosed in a case that is not easily removed without tools and have a rating of IP40 for all its terminals to protect anyone from electric shock when the panel is live with the door open.

Operating environment

The power supply will be fitted inside of an electrical panel that is mounted on the back of a furnace, this will protect the power supply from oil, dust and other contaminants. The power supply must be able to operate in temperatures of up to 65°C, in a dry environment, with or without the use of external cooling. As The max temperature of 40°C is caused by the panel location and due to the possibility of other components inside the panel radiating heat.

Service life

The power supply must be able to run for extended amounts of time whenever the electrical panel is powered up meaning the power supply must be cool during operation to avoid overheating.

Size

The power supply must be of a size that is able to be mounted to DIN rail and fit inside the electrical panel without any modifications.

3. DESIGN METHOD, CHOICES AND CALCULATIONS

4.1 DESIGN METHOD

When designing this power supply, the top down design method was used. The top down method (Also known as stepwise) is a method of designing something by braking down a system into small parts to make the overall system easier to understand. This is done by creating an overview of how the system functions and then identifying all the small parts of the system that make it function. Then all these smaller parts are looked at in greater detail, eventually understanding how the system is completely made up of smaller parts.

This power supply design was split up into small parts to help understand what is achieved all the way through its process. At a basic level the power supply takes an AC supply in and outputs a controlled DC supply. When this process is looked at in more detail it can be described as: An AC supply in, stepped down to a lower voltage, converted to DC, smoothed, regulated and then outputted as a DC supply. This process can then be related to the components that conduct it: A transformer, a rectifier, a capacitor and a regulator. These components can then be looked at in more detail to find their ratings, parameters and configurations which complete the process.

4.2 POWER SUPPLY PERFORMANCE REQUIREMENTS

Input voltage = 240V
Output Voltage (V_o) = $24V \pm 0.1V$
Output Current (I_o) = 2A
Max Ambient Temperature = 65°C



Figure 1: Top down design sections for power supply

Regulator requirements:

Output Voltage (V_o) = $24V \pm 0.1V$
Output Current (I_o) = 2A, (Limited)
Max Ambient Temperature = 65°C

IC Regulator Selection

The regulator that has been selected for the power supply is the Motorola MC1723C. This is because it meets all of the performance requirements. The MC1723C is a positive or negative voltage regulator that is designed to deliver a load current of up to 150 mADC. For the design of the power supply an NPN boost circuit configuration (Figure 2) has been chosen to obtain the required 2A output. This configuration uses an NPN external pass element which is the most economical approach.

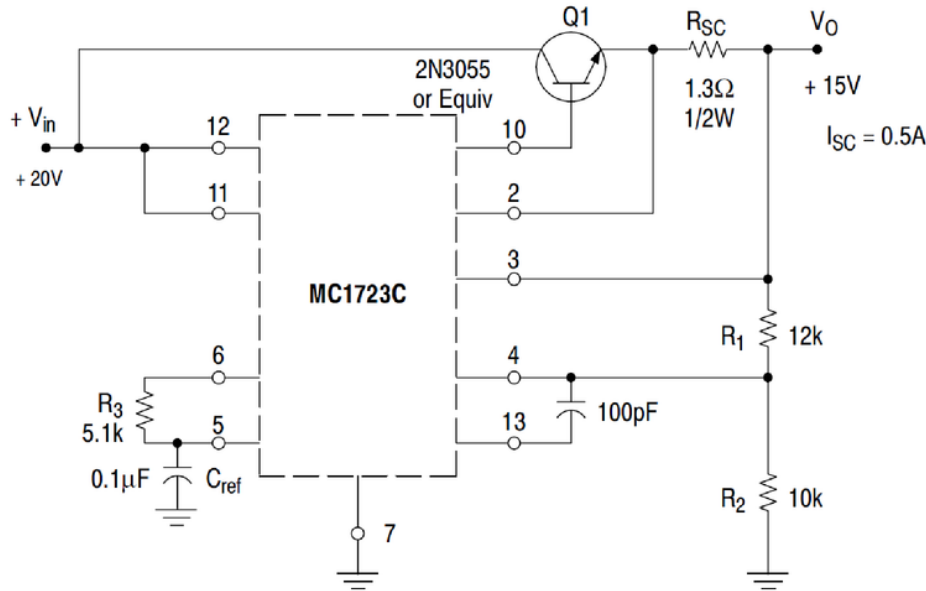


Figure 2: MC1723C NPN boost configuration (ON Semiconductor, 2002)

Calculation of component Values

(Values from MC1723C data sheet) (Motorola, 2005)

$C_{ref} = 0.1 \mu f$ (For low noise operation)

$$R_1 + R_2 = 10K\Omega$$

$$R_1 = 7.12K\Omega$$

$$R_2 = 2.88K\Omega$$

$$I_{SC} = I_o$$

$$R_{SC} = \frac{0.66}{I_{SC}}$$

$$R_{SC} = \frac{0.66}{2} = 0.33\Omega$$

$$R_3 = R_1 \parallel R_2 = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_3 = \frac{(7120 \times 2880)}{7120 + 2880} = 2051\Omega$$

$$R_3 = 2.05K\Omega$$

Calculation of Input Voltage (Vin)

When determining Vin, the MC1723C has two constraints. The device requires $Input(V_{in}) - output(V_o)$ to be greater than or equal to 3V, and Vin must be greater than or equal to 9V but must be less than or equal to 40V.

With the regulator circuit in the NPN boost configuration:

$$\begin{aligned}V_{in} - V_o &= [V_{in} - (V_o + 2\varphi)] \\ \varphi &= V_{BEon} \approx 0.6V \\ V_{in} &\geq (V_o + 2\varphi + 3V) = 24 + 1.2 + 3 = 28.2 \\ \therefore V_{in} &\geq 28.2V\end{aligned}$$

V_{in} is Greater than 9V and less than 40V so the MC1723C can be used.

4.3 SELECTION OF SERIES PASS ELEMENT (Q1)

Q1 Transistor requirements:

$$\begin{aligned}V_{CEO} &\geq V_{in} & V_{CEO} &\geq 28.2V \\ I_{c(max)} &\geq I_{SC} & I_{c(max)} &\geq 2 \\ P_{D(Max)} &\geq V_{in} \times I_{SC} & P_{D(Max)} &\geq 56.4W \\ \theta_{JC} & \text{to allow heatsinking}\end{aligned}$$

A 2N3055 transistor is selected as a suitable device for Q1 as it meets all the above requirements.

$$\begin{aligned}V_{CEO} &= 60V \\ I_{c(max)} &= 15A \\ P_{D(Max)} &= 115W \\ \theta_{JC} &= 1.5^\circ C/W\end{aligned}$$

4.4 CAPACITOR INPUT FILTER DESIGN

$$VC_{Dc}(Vin\ regulator) = 28.2V$$

$$V_{ripple}(pp) = 3.2V$$

$$V_m = 39$$

$$f = 50hz$$

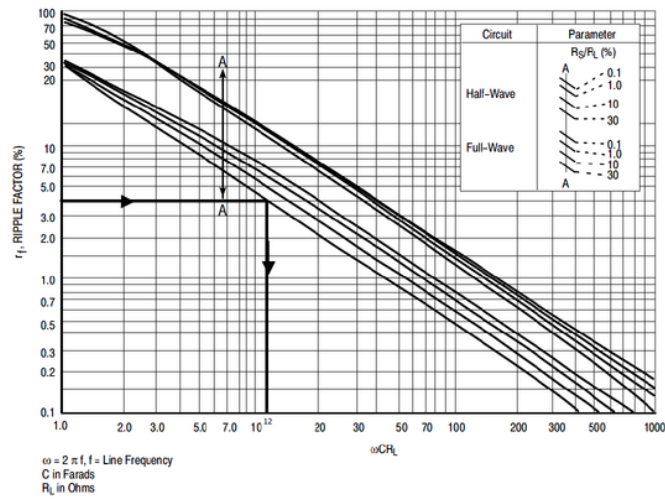


Figure 3: RMS ripple voltage for capacitor-input circuits(ON Semiconductor, 2002)

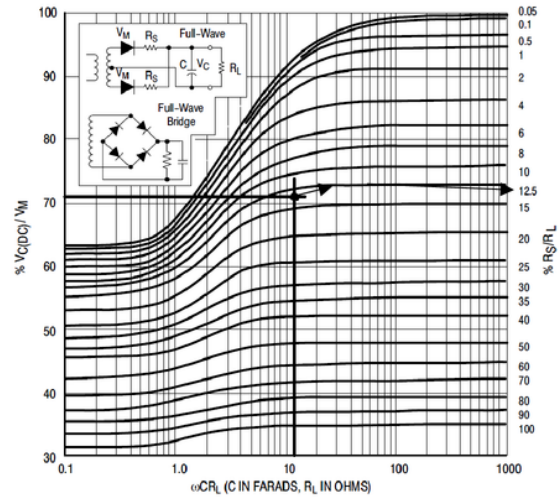


Figure 4: Relation of alternating peak voltage to direct output voltage(ON Semiconductor, 2002)

Minimum Capacitor Values

From figure 3 a range of minimum capacitor values can be determined to obtain enough ripple attenuation.

$$\text{Ripple factor } (r_f) = \frac{V_{\text{ripple}}}{2 \times \sqrt{2 \times V_{C_{Dc}}}} \times 100\%$$

$$r_f = \frac{3.2}{2 \times \sqrt{2 \times 28.2}} = 4\%$$

$$\omega C R_L \text{ Found from figure 3} = 12$$

$$\frac{V_{C_{Dc}}}{V_m} = \frac{28.2}{39} = 0.72 = 72\%$$

$$\text{From figure 4: } \frac{R_s}{R_L} = 12.5\%$$

$$R_L = \frac{V_o}{I_o} = \frac{24}{2} = 12$$

$$\frac{R_s}{R_L} = 12.5\% = 0.125$$

$$\frac{R_s}{12} = 0.125$$

$$R_s = 0.125 \times 12 = 1.5$$

$$* \text{ Check } * \frac{1.5}{12} = 0.125$$

Capacitor size(C) calculation

$$C = \frac{\omega C R_L}{2\pi f \times \left(\frac{V_{C_{Dc}}}{I_o}\right)} = \frac{\omega C R_L}{2\pi f \times (R_L)}$$

$$C = \frac{12}{2 \times \pi \times 50 \times 12} = 3.183 \times 10^{-3} F = 3183 \mu F$$

Capacitor selection

A Würth ATG8 3300 μ F 20% 35VDC 7.5mm Radial Alum. Electrolytic Capacitor was chosen to be used as the smoothing capacitor for the power supply as it has a rating of 3300 μ F.

4.5 RECTIFIER DESIGN

Average current per Diode ($I_{F(avg)}$) = $\frac{I_o}{2}$ For full wave rectification

$$I_{F(avg)} = \frac{2}{2} = 1A$$

n = 2 for full – wave rectification

$$n\omega CR_L = 2 \times 16 = 32$$

$$\frac{R_S}{n \times R_L} = \frac{1.5}{24} = 0.0625 = 6.25\%$$

$$I_{F(peak)} \times I_{F(avg)} = 5.9$$

$$I_{F(peak)} = \frac{5.9}{I_{F(avg)}} = \frac{5.9}{1} = 5.9A$$

$$PIV \text{ for full wave circuit} = 2 \times V_m = 2 \times 39 = 78V$$

$$\frac{V_m}{R_S} = \frac{39}{1.5} = 26A$$

Rectifier Selection

A Diotec P1000B Rectifier Diode 100V 10A is chosen to make up the rectifier for the power supply.

4.6 TRANSFORMER DESIGN

$$\text{Secondary leg RMS Voltage } (V_S) = \frac{(V_m + n \times 1)}{2}$$

$$V_S = \frac{39 + (2 \times 1)}{\sqrt{2}} = 29v$$

$$\text{Secondary resistance} = R_S = 1.5 \Omega$$

$$I_{rms} = \text{rms rectifier current}$$

$$\text{rms rectifier current} = 2.5A \text{ (From figure 8 – 4)}$$

$$\text{Secondary RMS current} = \sqrt{2} \times I_{rms} = \sqrt{2} \times 2 = 2.83A$$

$$\text{Transformer } V_a \text{ rating} = V_S \times I_{rms} \times \sqrt{2}$$

$$V_a \text{ rating} = 29 \times 2 \times \sqrt{2} = 82VA$$

4.7 HEATSINK DESIGN

(Values from 2N0355 data sheet) (ST Microelectronics, 2013)

$$P_d = V_{in} \times I_{SC}$$

$$P_d = 28.2 \times 2$$

$$\theta_{Sa} = \frac{T_j - T_a}{P_d} - (\theta_{JC} + \theta_{CS})$$

$$\theta_{Sa} = \frac{200 - 40}{28.2 \times 2} - (1.5 + 1.6) = 1.24^\circ\text{C/W}$$

4. TESTING, RESULTS AND ANALYSIS

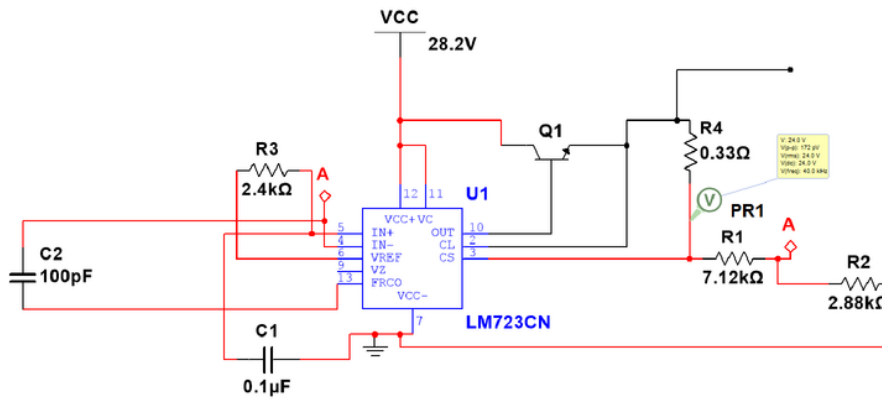


Figure 5: Multisim simulation of regulator circuit

Figure 5 shows a simulation of the regulator circuit, with all calculated regulator component values used. This circuit has an input of 28.2V and an output of 24V which is exactly what it needs to output according to the design specification.

5. CONCLUSIONS

The power supply was designed using a top down method to split the power supply into a transformer, a rectifier, a capacitor and a regulator. Then looking at the requirements of each component, values and parameters were calculated using formulae and graphs. This method was very effective as it made sure that all values that were required for subsequent steps were calculated ready. The values that were calculated and the components that were selected all fitted the design specification, and achieved the given electrical, thermal and physical customer requirements.

As the power supply was not physically produced it would be difficult to see If the product would encounter any problems which would affect its ability to meet the customer requirements. To improve the design/testing process, the power supply should be made and then tested by installing it in the environment specified in the customer brief.

6. REFERENCE LIST

Giles, M., 1980. *Audio/Radio handbook*. Santa Clara: National semiconductor conductor.

Motorola, 2005. *MC1723 Data Sheet*. [Online]

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ST Microelectronics, 2013. *2N3055 Data Sheet*. [Online]

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Final

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

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ENGAGEMENT WITH LITERATURE

 There was little evidence of further reading and research and although there was a short reference list there was no evidence of any in-text referencing. Your references list relied on a small selection of mainly datasheets and course notes

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KNOWLEDGE AND UNDERSTANDING

 The knowledge and understanding of the subject demonstrated by this assignment was reasonably detailed and mainly accurate. There were very few gaps in your knowledge of the basic concepts and your understanding of the higher level concepts was demonstrated to a limited degree - you could have explained in more detail how the circuit evolved. Further work – Your explanations need to be more detailed and written with a greater emphasis on critical evaluation rather than description.

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COGNITIVE AND INTELLECTUAL

 There was a brief testing section, but you should have tested each block as you built it. When building complex circuits you should test each block to ensure it meets the specification, otherwise when you test the overall circuit you will have big problems fault finding. The conclusions were mainly descriptive and the report contained many unsubstantiated facts. You could for example have

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included a much more detailed evaluation of the circuit performance and compared this with the established concepts from research.

PRACTICAL APPLICATION



The application of your practical skills for this task was generally rudimentary; you used the resources appropriately when designing the circuit and you used appropriate options for testing and evaluating the circuit performance - albeit to a limited fashion. Testing generally lacked a lot of the required detail however and you should have included a comprehensive set of results for each stage.

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TRANSFERABLE SKILLS FOR LIFE



Your written report was reasonably well presented in terms of content and layout and was mostly structured in a coherent way, however you should endeavour to use the available word count more effectively in future - you only used half of the available words.

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