

Phillip Rowe

by Phillip Rowe

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Supplies

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1. Executive summary

In this assignment a specification from a customer will be written in order to produce a functional power supply. The power supply will need to be designed and then adapted in order to meet the customer's needs. The power supply components will be calculated in order to get starting results, then fine-tuned on multisim. A critical analysis will be given in order to explain the purpose of fine tuning values on multisim. The power supply will then be tested against the customer's design specification and then suitable components will be chosen, giving reasons for each component choice. Data sheets will be analysed to ensure that all ethical needs and codes of practice are met.

*ES is too short for L6,
needs to cover each
section and give the
reader an overview of
the entire report*

2. Researching requirements and compilation of the specification

During a consultation with the customer, a strict design specification was agreed upon. The power supply must be portable as it will be taken too many locations on the customer's site. Since the power supply needs to be portable, then it must be as lightweight as possible, which should be no heavier than 7.5kilograms. The customer has requested the power supply to have 110v AC input, with 24v DC output and an operating current of 1Amp. The box of the power supply must be rated to at least IP67 and be robust with an impact rating of at least IK07. Since the power supply will be taken into some explosive atmospheres the customer has insisted that the power supply must comply with ATEX 95 (94/9/EC) and ATEX 137 (1999/92/EC) which are the compliances for equipment to enter an explosive atmosphere. The power supply will also need to comply with BS 7430 which is the code of practice for earthing. The customer has also requested that a type B RCBO rated at 4Amps or less be fitted to the power supply, this is for protection of the user and also the equipment that will be powered by the power supply. Finally, the customer has requested that the power supply should be built using components with efficiency rating of nothing less than 95%. This is due to ethical choices the customer has taken on.

*Block diagram of system is
always good to start with*

Design method, choices and calculations

In order to build a power supply, each section of it needs to be split up and built in order to reach the final outcome. Each section has been built using mathematical equations in order to choose real life components.

Regulator

For this power supply the regulator must have the following performance requirements:

Output voltage, $V_o = 24v$

Output current, $I_o = 1A$

Max ambient temperature, $T_a \leq 150^{\circ}C$

Now a series of calculations will be produced in order to find suitable values for the required performance of the regulator.

$C_{ref} = 0.1\mu F$ taken from the data sheet. As seen in Appendix 1. This is for low noise operation

$R1+R2 = 25K\Omega$ – These two values added up should normally be between 10 K Ω -100 K Ω , these are generally used as optimum values as normally any lower resistance will draw too much current and if the resistance is higher then the current will drop too low.

$$R2 = \frac{C_{ref}}{V_o} \times (R1 + R2)$$

$$R2 = \frac{7.2}{24} \times (25000) = 7.5K\Omega$$

$$R1 = (R1 + R2) - R2$$

$$(25K\Omega) - 7.5K\Omega = 17.5K\Omega$$

$$R_{sc} = \frac{0.6}{I_{sc}} = \frac{0.6}{1} = 0.6\Omega$$

When calculating R_{sc} the 0.6 is the voltage between the base-emitter junction which is between 2-3.

$$R3 = R1 || R2$$

$$R3 = \frac{R1 \times R2}{R1 + R2} = \frac{17.5K \times 7.5K}{17.5K + 7.5K} = 5250\Omega$$

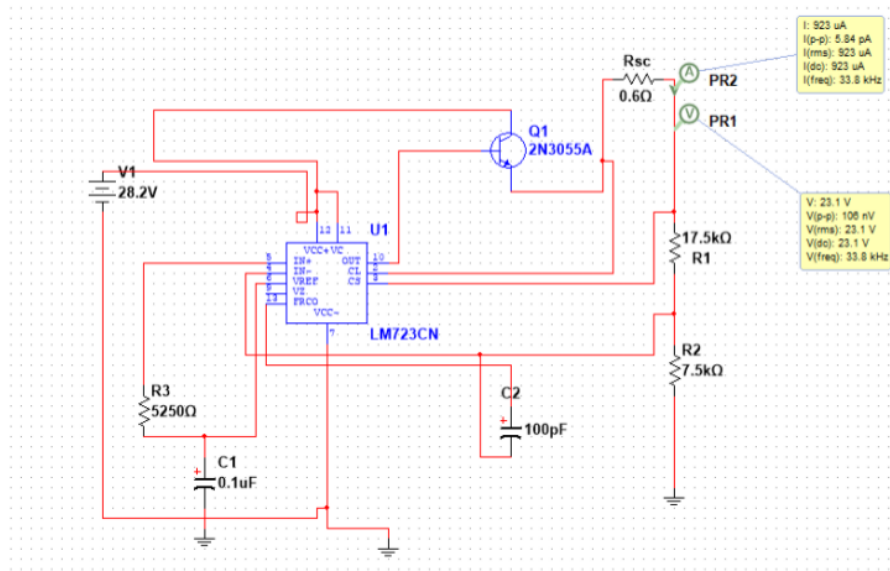
The final part of the regulator is to determine the input voltage (V_{in}).

$$V_{in} = \geq V_o + 2\phi + V_{min}$$

V_o = Output voltage, 2ϕ = Base, emitter junction value taken from data sheet allowing for both base/emitter volt drops and V_{min} is minimum input-output voltage differential. As seen in appendix 1.

$$= 24 + 1.2 + 3 = 28.2v$$

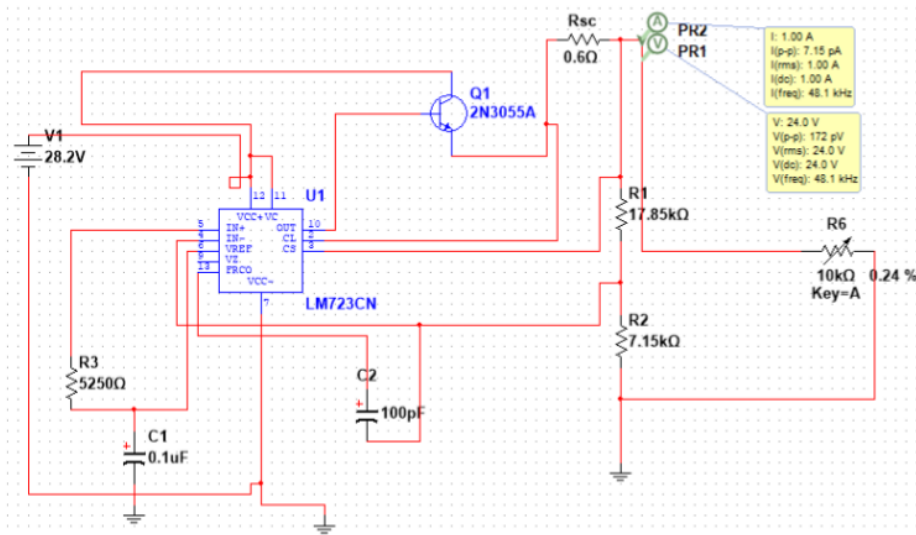
Following below in figure 1 is the regulator circuit built with no load.



Regulator

As shown in the above figure the output current is 923 μA and the output voltage is 23.1v. Since these output figures do not meet the specification, the balance between R1 and R2 can be modified in order to meet the desired specification.

By varying the ratio of R1 and R2 the perfect values were found in order to meet the speciation, this is represented below in figure 2. This figure also shows that this regulator meets the specification.



- Optimal regulator

Now that the optimum values have been found for R1 and R2, a graph was made in order to show the optimum load value. Below in figure 3 are the voltage and current readings that were measured whilst altering the load resistance.

OHMS	voltage	current
0	0.103	1.03
2	2.05	1.03
4	4.1	1.02
6	6.15	1.02
8	8.19	1.02
10	10.2	1.02
12	12.3	1.02
14	14.3	1.02
16	16.4	1.02
18	18.4	1.02
20	20.4	1.02
22	22.5	1.02
24	24	1
26	24.7	0.948
28	24.7	0.882
30	24.7	0.824
32	24.7	0.772
34	24.7	0.727
36	24.7	0.686
38	24.7	0.65
40	24.7	0.618

Figure 3 - Table of results for voltage/current graph

Following below in figure 4 is the graph which was plotted in order to what a small and big load will do to the output voltage and current. The low resistance represents a large load and a high resistance represents a small load. A vertical line was drawn in order to find the best load resistance for the regulator, this value is about 240 ohms.

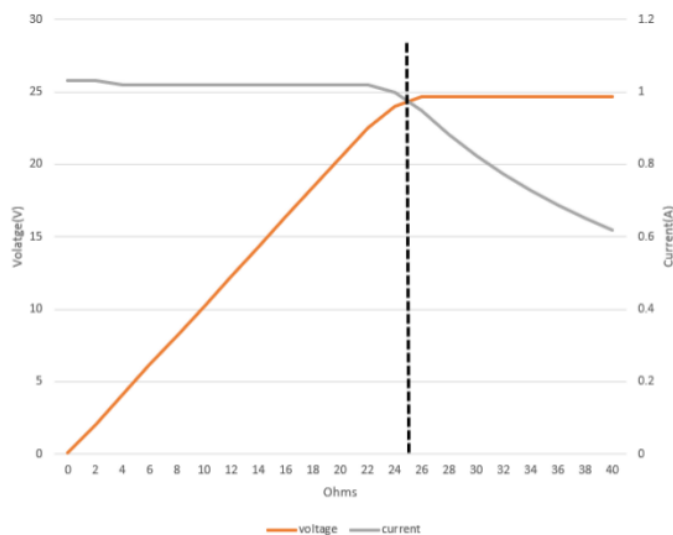


Figure 4 - Voltage/current

graph

From investigating the relationship between R1+R2 the optimum conditions have been found and the ratio of R1+R2 is:

R1= 17.85K R2= 7.15K

This is illustrated in figure 5 as the output design specification of the regulator has been met.

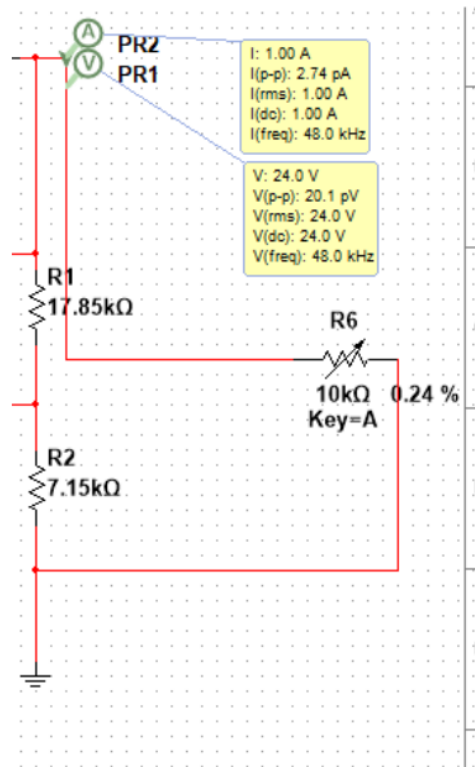


Figure 5 - Optimum values for R1+R2

Capacitor, transformer and rectifier ratings

Now that the regulator has been built, the ratings for the rectifying bridge, transformer and smoothing circuit will be calculated. The following ratings will be used in order to complete the calculation.

$V_C(Dc) = 28.2v$

$V_{Ripple(pp)} = 3v$

$V_m = 40v$

$$I_o = 1A$$

$$F = 50Hz$$

$$Ripple\ rejection = \frac{Ripple\ out}{Ripple\ in}$$

$$= 74 = 10^{\frac{-74}{20}} = 1.995^{-4}$$

Now a range of minimum capacitor values will be calculated in order to obtain a suitable ripple attenuation.

$$rf = \frac{V_{ripple(pp)}}{2\sqrt{2} V_c(DC)}$$

$$rf = \frac{3}{2\sqrt{2} \times 28.2} \times 100\% = 3.76\%$$

Now that rf has been calculated, 2 values for ωCR_L can be measured using the graph in figure 6.

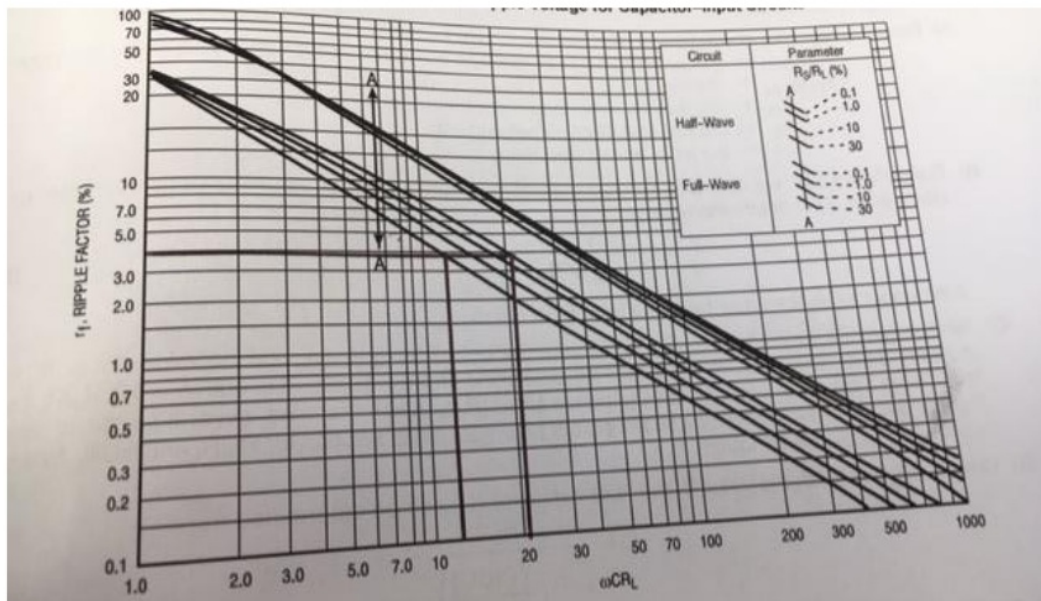


Figure 6 - Schade curve for ωCRL

The two measured values obtained from the graph in figure... were 13 and 21. A value in between the both of these will be used for the calculations meaning a final value of 17 will be used for ωCR_L

Now in order to measure R_s/R_L a percentage must be found for $\frac{V_c}{V_m}$

$$\frac{V_c}{V_m} = \frac{28.2}{40} \times 100 = 70.5\%$$

In figure 7, 70.5% has been used on the graph in order to determine R_s/R_L . The results taken from the graph is that $R_s/R_L = 15\%$

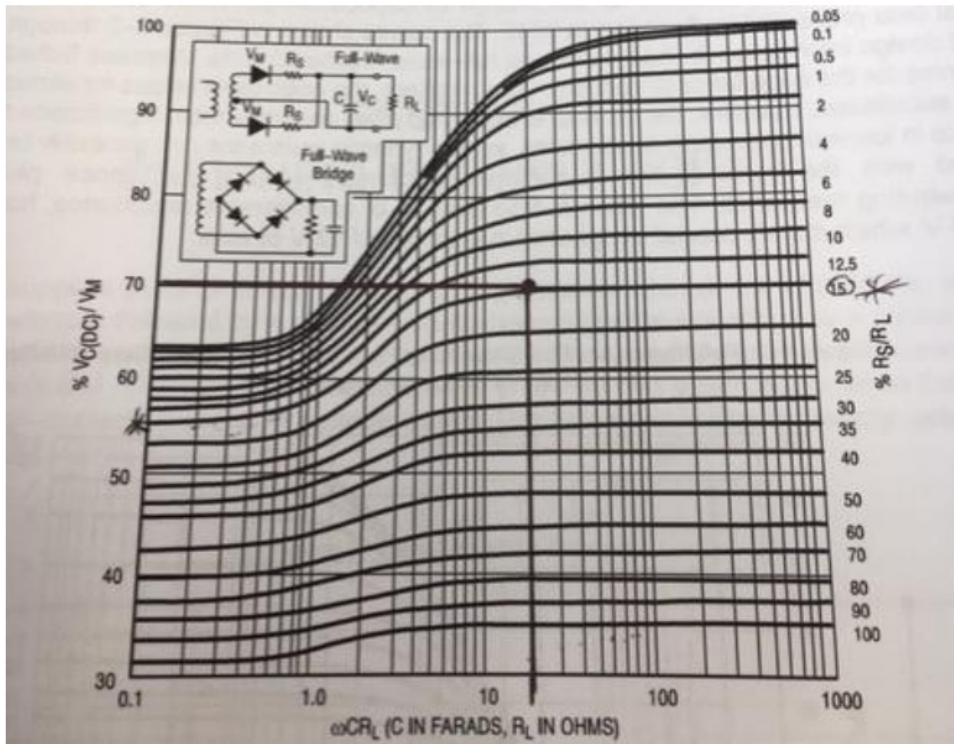


Figure 7-Schade curve for R_s/R_L

Now R_s/R_L will be calculated.

$$\frac{R_s}{R_L} = 20\% \text{ or } R_s = 0.2 \times R_L = 0.2 \left(\frac{V_c(DC)}{I_o} \right) = 0.2 (28.2)$$

$$RS = 0.15 \times \frac{28.2}{1} = 4.23\Omega$$

$$RL = \frac{VC}{IO} = \frac{28.2}{1} = 28.2\Omega$$

Now the correct size capacitor will be calculated for the smoothing circuit.

$$C = \frac{\omega CRL}{2\pi f \left(\frac{VC(DC)}{Io} \right)}$$

$$C = \frac{17}{2\pi f \left(\frac{28.2}{1} \right)} = 1.918 \text{ } mf$$

Rectifier

The rectifier circuit is made in order to rectify the incoming AC into rough dc. In order to build the circuit, the following values need to be found:

IF(avg)

IF(rms)

IF(peak)

PIV

ISurge

For full wave rectification it can be said that:

$$IF(avg) = \frac{Io}{2} = \frac{1}{2} = 0.5A$$

In order to determine IF(rms), the graph in figure 8 was used. Since this is a full wave rectifier circuit, the value for ωCRL which is 17 must be multiplied by 2 to give $n\omega CRL = 34$. So by using the graph the value for IF(rms) = 2.2A

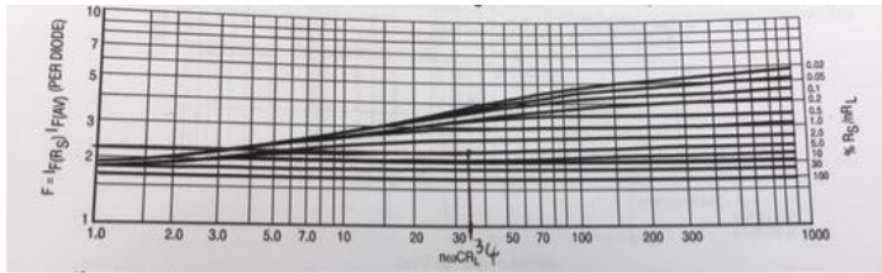


Figure 8 -

Schade curve for $IF(rms)$

In order to calculate the peak value for IF, the graph in figure 9 was used. Since this is a full wave rectifier circuit, the value for ωCR_L which is 17 must be multiplied by 2 to give $\omega CR_L = 34$. The graph was used then in order to determine the value of IF to be 6Amps.

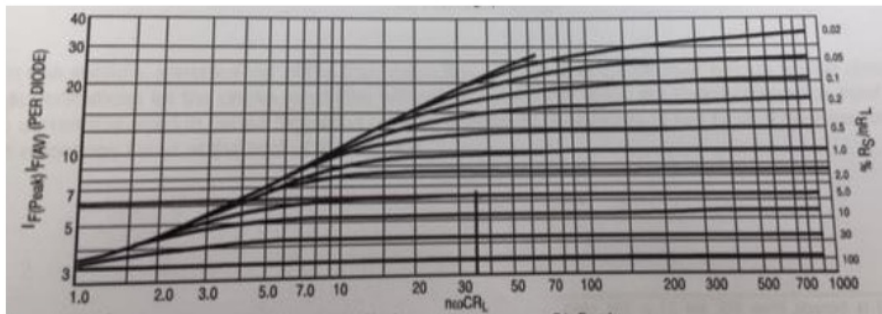


Figure 9-

Schade curve for $IF(peak)$

The true value of IF peak would be calculated as followed:

$$IF(peak) = 0.5 \times 6 = 3A$$

PIV is firstly calculated by using the following formula:

$$PIV = V_m \times 2 = 40 \times 2 = 80v$$

It is noted that a safety margin of 20-50% should be added due to possibility of line transients.

Therefore:

$$PIV = 96v$$

The surge current can now be calculated.

ESR is the minimum equivalent series resistance of the filter capacitor from its data sheet. This is $1\ \Omega$

$$I_{surge} = \frac{V_m}{R_s \times ESR}$$

$$I_{surge} = \frac{40}{4.23 \times 1} = 9.46A$$

Transformer

The transformer specification will now be calculated so that in order to meet the design specification. The following values will be calculated:

V_S = Secondary leg RMS voltage

Transformer turns ratio

R_S = Total resistance of the secondary

I_{rms} = Secondary RMS current

Transformer VA rating

The secondary leg RMS voltage was calculated as followed, since this is a full wave rectification circuit n will be known as '2'.

$$V_S = \frac{V_m + (n)1}{\sqrt{2}}$$

$$V_S = \frac{40 + (2)1}{\sqrt{2}} = 29.698\ RMS$$

The turns ratio for the transformer can be worked out by using the following equation:

$$Turns\ ratio = \frac{V_{in}}{V_{out}}$$

$$\text{Turns ratio} = \frac{110}{28.2} = 3.9:1 \text{ Step down}$$

The transformer secondary resistance can be said to be the same as the value of R_S , therefore:

$$\text{Transformer secondary resistance} = R_S = 4.23 \, \Omega$$

Secondary RMS current is equal to the I_{RMS} of the rectifier circuit, therefore:

$$\text{Secondary } I_{rms} = I_{RMS} = 2.2A$$

Finally, the transformer VA was determined by using the follow:

$$VA = 2 \times V_S \times I_{rms}$$

$$= 2 \times 29.698 \times 2.2 = 130.67 \, VA$$

Heatsink

The heatsink will be used in order to dissipate excessive heat and protect components. The type of heatsink needed was calculated by using the following calculation:

$$\theta_{SA} = \left(\frac{T_J - T_A}{PD} \right) - (\theta_{JC} + \theta_{CS})$$

Operating range = $T_A = +50$

Operating and storage junction temp range = $T_J = +70$

Power dissipation - PD - for T_A above 25 = 1.25w

Thermal resistance junction – junction to case - JC = 1.52

Therefore $C_s = 0.1$

$$\theta_{SA} = \left(\frac{70-50}{1.25} \right) - (1.52 + 0.1) = \leq 14.38 \, ^\circ\text{C/W}$$

3. Component selection

Now that all of the values for the components have been selected, suitable components will be chosen in order to build the power supply. All components have been selected and their data sheets have been referenced. All of the links are in the reference list.

Firstly, the transistor which will be used for the regulating circuit will be the 2N3055A. The regulator circuit needs to be able to deal with a worst case over current of 9.6A and overvoltage of 40 volts. With reference to data sheet (Industries, 2013) it can be seen that this transistor is capable of operating normally with up to 15A and 60V which is well above the specification. The component is also well within the temperature operating range whilst also remaining on the cheap side as the customer's specification requires.

The resistors which are needed in order to build the power supply are hard to purchase individually and the customer has acknowledged this, so they have requested in the design specification that they are supplied with multiple spares of resistors in case of failures. The data sheet can be found with reference (spares, 2018). All of the resistors in the book are rated at 2Watts, this means they are capable to deal with the maximum current the regulator may take with regards to overcurrent. These resistors also have a 1% tolerance which increases the accuracy of output current and voltage that is able to be achieved.

The two capacitors which are needed for the power supply circuit are 100µF and 100nF. (spares C. R., 2020) This capacitor is able to tolerate the voltage which may flow through the capacitor. This is also the case with (KEMET, 2019) this capacitor will tolerate the overvoltage which may flow through the capacitor. Both capacitors also have a low level of tolerance which will help during the smoothing phase of the power supply.

The transformer datasheet has been compared to the specification with reference to (Spares, 2017) the Comparing the data sheet to the design specification it is a more than suitable selection. The step down voltage is 115V to 24V which is more than acceptable, the maximum current the transformer can take is 10A which is above the surge current so in the event of a surge the transformer will not break. Finally the transformer is only 2500 grams so it is very lightweight as the customer requested.

The heatsink chosen with reference to the data sheet (spares H. R., 2015), this is rated at 17.9°C/W and is small, compact and lightweight with dimensions which will fit within the power supply enclosure easily.

The enclosure which has been chosen is (Spares B. R., 2020) this enclosure is IP67, IK09 and also ATEX rated as the customer has requested. The dimensions of 180x180x100 will allow all of the components to fit inside with some allowed space still free. The transformer will take up the most space and its dimensions are only 59 x 57 x 50mm.

Finally for the component and user protections RCBO rated at 3 amps has been chosen. This also has a 30ma trip to protect the user in the case of an earth fault. All of the components selected are rated higher than 3amps this will protect them all in the event of overcurrent and short circuit events. Datasheet can be found with reference to (EATON, 2020)

Using all of the data sheets, the total weight of each component has been added up in order to give a final weight of the power supply as followed. The total weight is 6.4KG.

- Heatsink – 700g
- Enclosure – 1500g
- RCBO – 1000g
- Resistors – <10g
- Capacitors – 200g
- Transformer – 2500g
- Transistor – 400g

4. Multisim and analysis

Since all of the component values have been calculated, the power supply circuit was now built on multisim in order to simulate the power supply working. Shown in figure 10 is the final power supply design. The switch in the circuit represents the switch on the socket where the customer will plug in the power supply, the fuse represents the RCBO due to it not being in multisim.

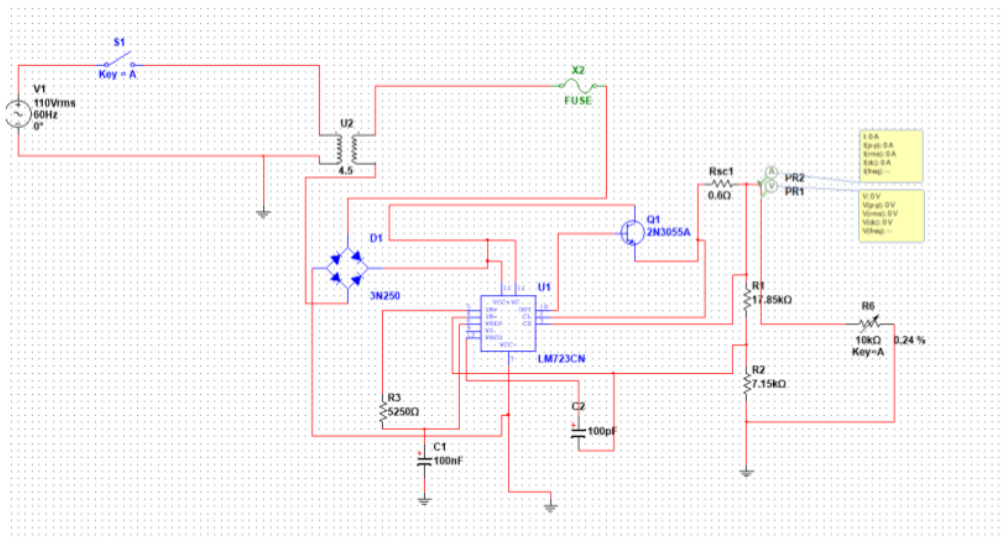


Figure 10 - Final power supply design

The switch was then closed and the circuit started to rectify and produce an output voltage and current for the given load. Following below in figure 11 shows the output voltage and current of the power supply. Referring to the design specification this meets the exact requirements that has been requested.

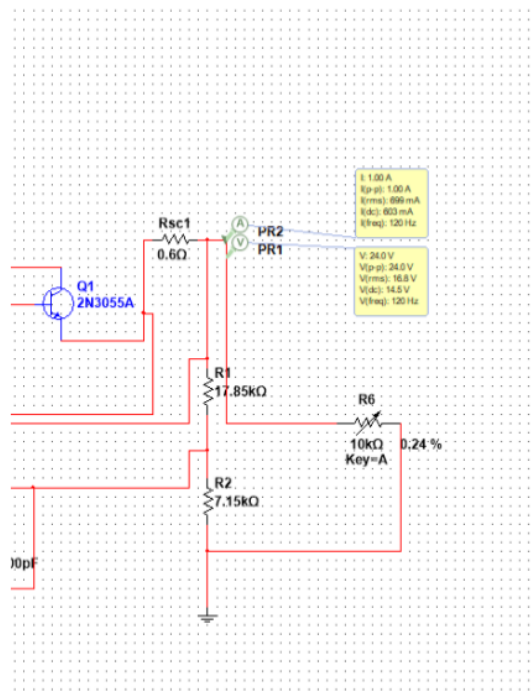


Figure 11- Power supply results

As seen in figure 12 is the voltage and current which is entering the bridge rectifier. When the calculations were carried out the voltage needed in the bridge rectifier was calculated to be 28.2v and in figure 12 it is 28.3v which correlates the theory to the practical.

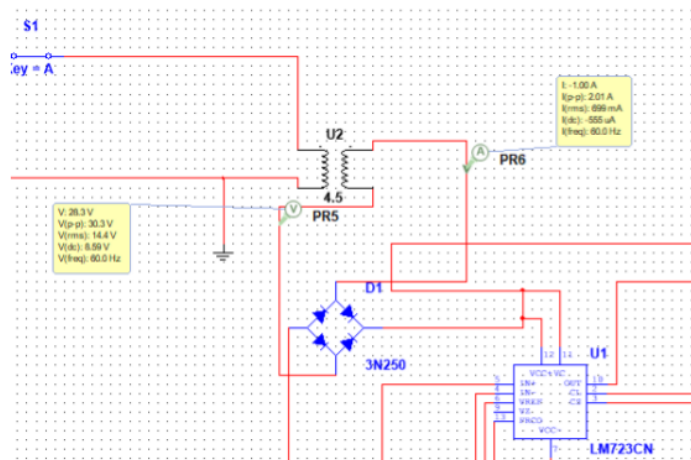


Figure 12 - Transformer voltage

Figure 13 shows the voltage which is coming out of the bridge rectifier which then goes into the transistor. Comparing the two it can be seen that there is a small voltage drop of 1.3 volts from the bridge rectifier.

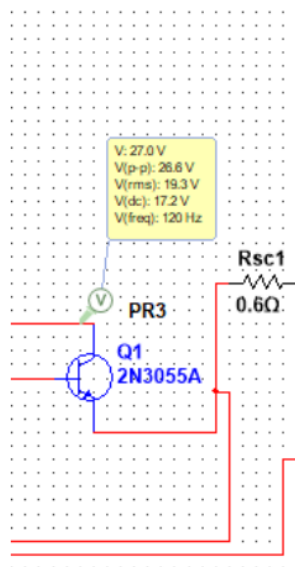


Figure 13 - Rectifier voltage

Following below in figure 14 is a table of comparison. Analysing the table, it can be said that the theoretical values are very close to the realistic values used. Looking firstly at R1+R2 the starting calculated values are very close to the final values which were used, the reason they could be different is to small rounding errors and tolerances with components when the multisim was built. Comparing the transformer peak to peak current which can be seen in figure.... There is a small difference of 1amp, this can be due to theory calculations neglecting things like inductance and resistance. Also since the tables were used in order to get the peak value some small error could have been introduced during that process.

Comparison	Theory (Calculated)	Multisim measured
Vin (Input into the rectifier)	28.2v	28.3v
R1	17.5k	17.85k
R2	7.5k Ω	7.15k Ω
Transformer IF peak	3A	2A
Voltage secondary (Transformer)	29.698	28.3v

Figure 14 - Table of comparison

5. Conclusions

To draw a conclusion on the assignment, the design specification has been met. The power supply was built in an enclosure which is lightweight and compact, it also was within the required weight range that the customer requested. The power supply also complied with all codes of practice such as ATEX and BS 7430, this was down to the careful selection of the components used. The power supply when built on multisim, was proved to give the required values out as requested in the specification meeting all of the electrical power requirements. The electrical and component protection levels have been met by the careful selection of components which can handle overcurrent and over voltage. To conclude on the theoretical results, it can be clearly seen that they give good starting values whilst building a power supply. This was proven when the values for $R1+R2$ were calculated in the regulator circuit, they were very close to their optimal final figures but needed fine tuning to find the correct balance in order to meet the specification. The theoretical results calculated for the transformer secondary voltage matched up very closely with the calculated result which means that, that the power supply was performing like the theory predicted. One discrepancy between the theory and practical presented was with the value of the capacitor. Much like when calculating the resistor values, the smoothing capacitor needed fine turning in order to meet the required specification. The overall conclusion can be made that the theoretical calculations can be used in order to find base starting values for a power supply circuit, however the recommendation would be to simulate the power supply circuit first in order to get final values. Multisim does present an issue with the simulation of a power supply, this is due to the component values being hard to find and purchase in the real world. The example of this can be used with the resistors, a nearest preferred value would need to be used in order to build the power supply which would then coherently, alter output values of the power supply.

6. Harvard Referencing

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7. Appendix

Characteristics	Symbol	Min	Typ	Max	Unit
Input Voltage Range	V_I	9.5	—	40	Vdc
Output Voltage Range	V_O	2.0	—	37	Vdc
Input–Output Voltage Differential	$V_I - V_O$	3.0	—	38	Vdc
Reference Voltage	V_{ref}	6.80	7.15	7.50	Vdc
Standby Current Drain ($I_L = 0$, $V_{in} = 30$ V)	I_{IB}	—	2.3	4.0	mAdc
Output Noise Voltage ($f = 100$ Hz to 10 kHz) $C_{ref} = 0$ $C_{ref} = 5.0$ μ F	V_n	— —	20 2.5	— —	μ V(RMS)
Average Temperature Coefficient of Output Voltage ($T_{low} < T_A < T_{high}$)	TCV_O	—	0.003	0.015	%/°C
Line Regulation ($T_A = 25^\circ\text{C}$) $\left\{ \begin{array}{l} 12 \text{ V} < V_{in} < 15 \text{ V} \\ 12 \text{ V} < V_{in} < 40 \text{ V} \end{array} \right.$ ($T_{low} < T_A < T_{high}$) $12 \text{ V} < V_{in} < 15 \text{ V}$	Regline	— — —	0.01 0.1 —	0.1 0.5 0.3	% V_O
Load Regulation (1.0 mA $< I_L < 50$ mA) $T_A = 25^\circ\text{C}$ $T_{low} < T_A < T_{high}$	Regload	— —	0.03 —	0.2 0.6	% V_O
Ripple Rejection ($f = 50$ Hz to 10 kHz) $C_{ref} = 0$ $C_{ref} = 5.0$ μ F	RR	— —	74 86	— —	dB
Short Circuit Current Limit ($R_{SC} = 10$ Ω , $V_O = 0$)	I_{SC}	—	65	—	mAdc
Long Term Stability	$\Delta V_O/\Delta t$	—	0.1	—	%/1000 Hr.

(Appendix 1) (Motorola, 1996)

FINAL GRADE

GENERAL COMMENTS

Instructor

72/100

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Text Comment. ES is too short for L6, needs to cover each section and give the reader an overview of the entire report

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Text Comment. Block diagram of system is always good to start with

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GRADING FORM: CSG-RUBIC

PHILLIP ROWE

72

RESEARCH-INFORMED LITERATURE



You have identified some components but it wasn't clear if these met the electrical AND physical specification

6

KNOWLEDGE AND UNDERSTANDING



The knowledge and understanding of the subject demonstrated by this assignment was generally very good. There were few gaps in your knowledge of the basic principles and your understanding of the higher level concepts was demonstrated to a high degree. You have demonstrated a competent critical understanding of the main concepts and expanded

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your knowledge beyond that contained in the course notes.

ANALYSIS



Your analysis of the task was generally very good, both in class and as shown in this assignment. You have demonstrated sound critical analysis skills and your approach to the task was logical. You carried out a detailed evaluation of the results and included a good conclusion relating the practical results to researched theory. The conclusions demonstrated very good cognitive skills and the ability to interpret quantitative and qualitative data without error.

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PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally very good. You used the resources appropriately when designing the circuit and you used appropriate options for testing and evaluating the circuit performance. You managed to design an effective circuit that functioned within the specification and achieved this by only asking for assistance when appropriate thus demonstrating some advanced problem solving skills. Your results were comprehensive and allowed for a detailed conclusion to be attempted.

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SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in

working individually and also collaboratively. Your written report was generally good and contained most of the required detail, it was also written in a coherent and logical way. The available word count was in the main effectively used.