

PSDE6015, Assignment 1

by Michael Lewis

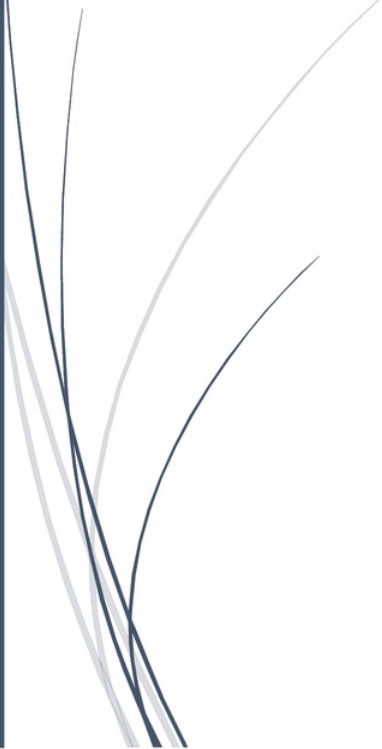
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PSDE6015

Electronic Design

Assignment 1 – PSU design



Mike Lewis
COLEG SIR GAR

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1. Introduction

The overall aim of this assignment is to design a power supply unit (PSU) for a customer. The customer has written a list of specifications, which must be incorporated into the final product.

The PSU is powering a panel consisting mainly of solenoids, which is in a deep freezer with an average temperature of -18°C . However, the solenoids are only activated intermittently for short periods of time.

- Convert 230V AC to 12V DC
- The system must operate in temperatures as cold as -18°C
- Deliver a maximum current of 2A.
- Short circuit protection.
- Stable output voltage over a reasonable range of loads

The customer has requested detailed analysis of the system to be provided to ensure the PSU meets specification: Design schematics, simulation data and proof of detailed testing and analysis.

2. Background research

The simple explanation of the basic principles of a power supply is not going to be included in this report (Other than brief explanation on p20). This is because all people involved in this project (author, client, technicians) have been trained to a higher-than BTEC level 3 standard in electronic engineering, and are expected to have a grasp of the simple principles/circuit surrounding a PSU.

One of the major concerns when designing and building an electronic/electrical system for a customer is the safety and hazards of the system. These risks and potential hazards must be eliminated or reduced to ensure the safety of the customer and technicians who may have to perform maintenance on the product.

Shown in Figure 1 is a list of some of the main hazards associated with electronic/electrical equipment. The risks listed on the table should be minimised as much as reasonably possible. The sources column on the table gives an insight into what may be causing each of the main risks. All of the researched information regarding safety will be used throughout all aspects of the project.

Hazard	Main risk	Source
Electric shock	Electrocution, injury due to muscular contraction, burns	Accessible live parts
Heat or flammable gases	Fire, burns	Hot components, heatsinks, damaged or overloaded components and wiring
Toxic gases or fumes	Poisoning	Damaged or overloaded components and wiring
Moving parts, mechanical instability	Physical injury	Motors, parts with inadequate mechanical strength, heavy or sharp parts
Implosion/explosion	Physical injury due to flying glass or fragments	CRTs, vacuum tubes, overloaded capacitors and batteries
Ionising radiation	Radiation exposure	High-voltage CRTs, radioactive sources
Non-ionising radiation	RF burns, possible chronic effects	Power RF circuits, transmitters, antennas
Laser radiation	Damage to eyesight, burns	Lasers
Acoustic radiation	Hearing damage	Loudspeakers, ultrasonic transducers

Table 9.1 Some safety hazards associated with electronic equipment

Figure 1: Hazards associated with electronic equipment#

(Williams, 2005, p. 293)

As a relatively large current is being switched in the PSU, the build-up of heat in some components is an issue that will almost certainly have to be dealt with. The diagram in Figure 2 is a generalised model of how heat generates and dissipates, along with an equation showing the relationship between the various parameters of the model. The equations and theory will be used in this project to calculate the value of heatsink on the component in question.

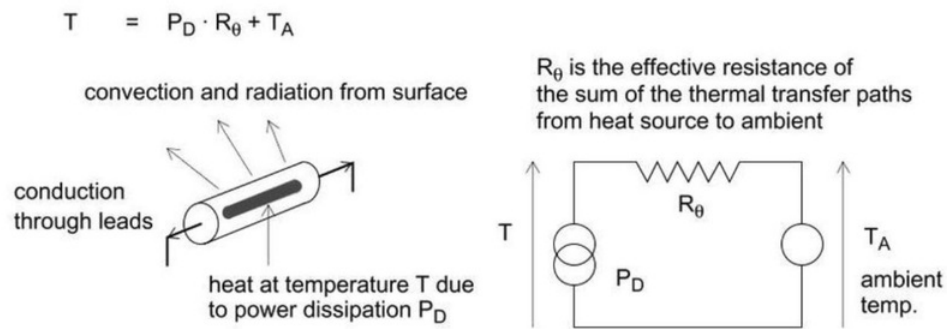


Figure 2: General model of heat dissipation

(Williams, 2005, p. 314)

Unfortunately, the majority of the background research for this project consisted of countless datasheets used to select components and extract information. These have not been entirely excluded from the report, but are in more appropriate sections throughout the whole report: mainly in the form of diagrams, graphs and other snippets. All datasheets that relate to the components chosen are referenced in the appropriate section of the report. See the 'component choices' section on p13.

3. Design method, choices and calculations

Calculations

The input voltage and frequency are known values of 230VAC at 50Hz respectively.

Regulator

Specification: $V_{out} = 12V, I_o = 2A, V_{rip} = 1.2mV$

$$Line\ reg = V_{in} - V_o = > 3V \rightarrow V_{in} = 3 + V_o = > 15V$$

$$Rip\ In_{pp} = \frac{Rip\ out}{dB} = \frac{1.2mV}{10 \frac{-74}{20}} = 6V_{pp}$$

$$V_c = V_{in} + 0.5Rip\ in + 30\% = 15 + 3 + 30\% = 19.5V$$

30% is used instead of 10% as the system allows for a large ripple in.

Capacitor

$$Ripple\ factor\ (Rf) = \frac{\frac{1}{2}Ripple\ in}{2 * \sqrt{2} * V_c} * 100\% = \frac{3V_{pp}}{2 * \sqrt{2} * 19.5} * 100\% = 5.44\%$$

$$V_m = V_c + 50\% = 19.5 + 50\% = 29.25V$$

$$\frac{V_c}{V_m} * 100\% = \frac{19.5}{29.25V} * 100\% = 66.6\%$$

From the graph in Figure 5, $\omega CR_L \cong 10$ to 16. The following calculations will use a ωCR_L value of 13.

See Figure 3 for annotated Sharde curve. The red lines indicate the values calculated earlier. A line closest to the point where the 2 red lines intersect is followed to give the value of $\% \frac{R_s}{R_L} = 20\%$.

$$\frac{R_s}{R_L} = \frac{V_c}{I_o} = \frac{19.5}{2} = 9.75\Omega$$

$$R_s = 0.2R_L = 0.2 * 9.75 = 1.97\Omega$$

$$C = \frac{\omega CR_L}{2\pi f R_L} = \frac{13}{2\pi * 50 * 9.75} = 4.2mF$$

A suitable capacitor with a rating of 4.7mF was sourced which will be used in the final product. The capacitance rating is slightly higher than calculated, but proved through testing that the capacitor that was chosen does not impact the performance/functionality of the system. See ‘

Figure 14 shows the oscilloscope output waveform of transformer input/output. Figure 13 shows the oscilloscope connections.

Figure 15 shows the oscilloscope waveforms for the bridge rectifiers input and output, coloured purple and red respectively. As the capacitor is in the circuit the output from the bridge rectifier is being smoothed. If the capacitor was removed, the output would be 'lumpy', as previously mentioned. The waveform also shows that the voltage being supplied to the regulator meets requirements (20VDC-Unregulated), and thus will enable the regulator to deliver the specified voltage.

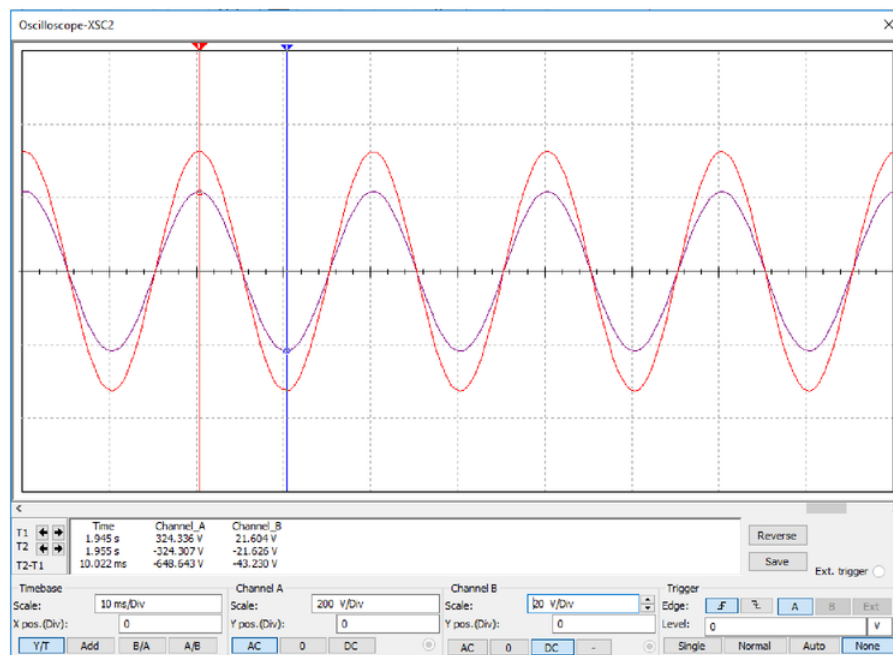


Figure 14: Transformer Oscilloscope input/output

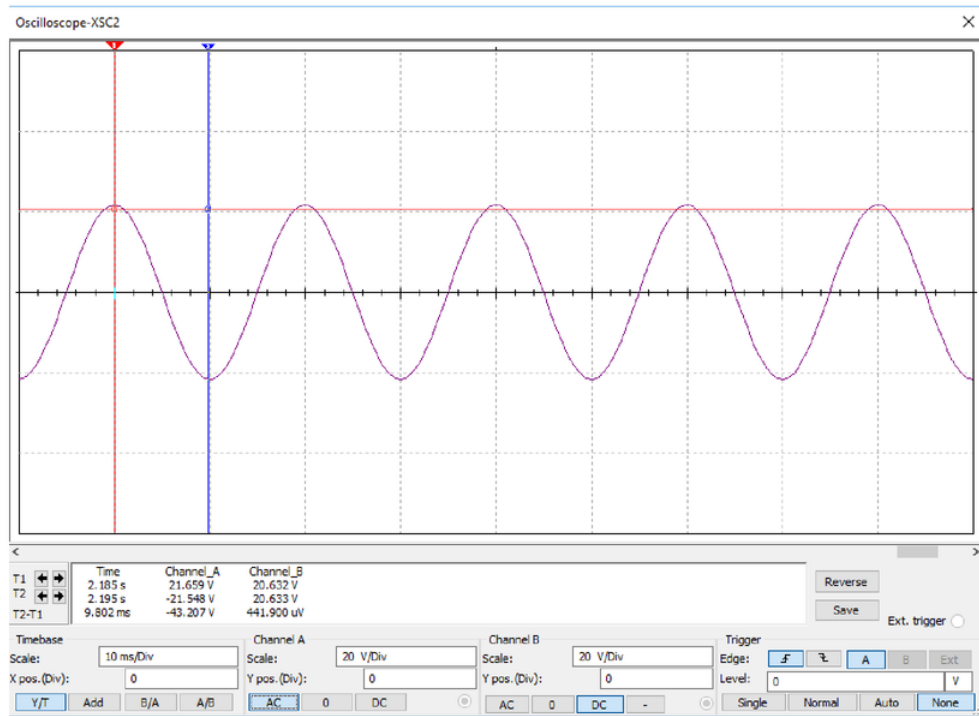


Figure 15: Bridge rectifier Input/output waveform

Testing and improving the design' section of the report for more detail.

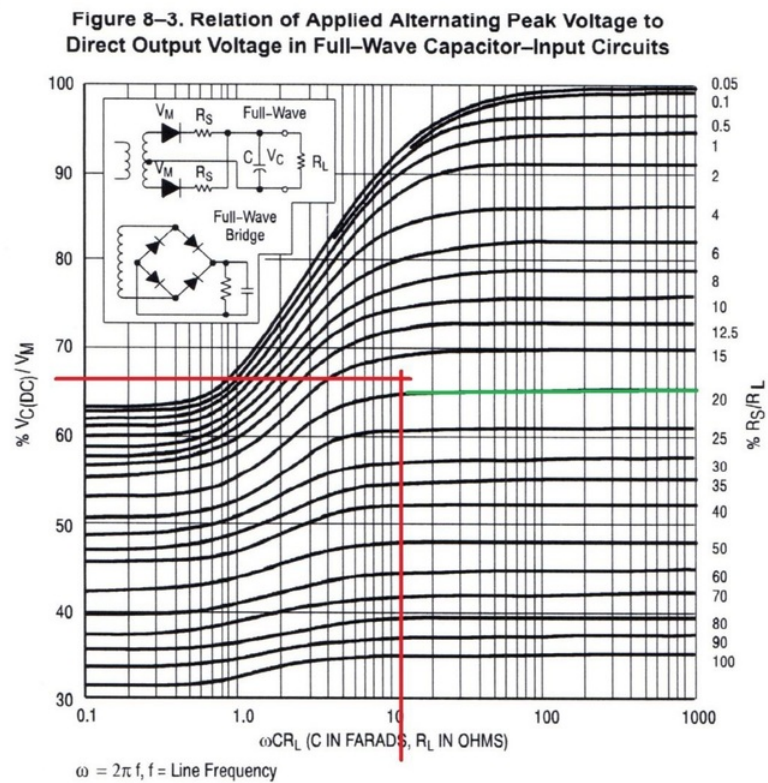


Figure 3: Sharde curve 1

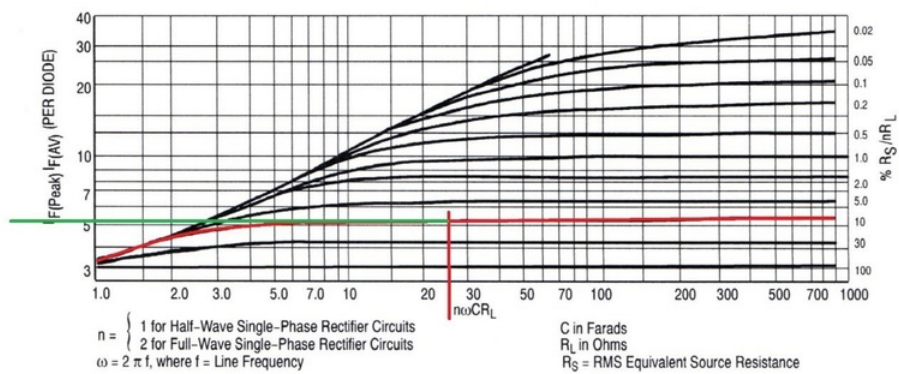


Figure 4: Sharde curve 2

Figure 8-5. Root-Mean-Square Ripple Voltage for Capacitor-Input Circuits

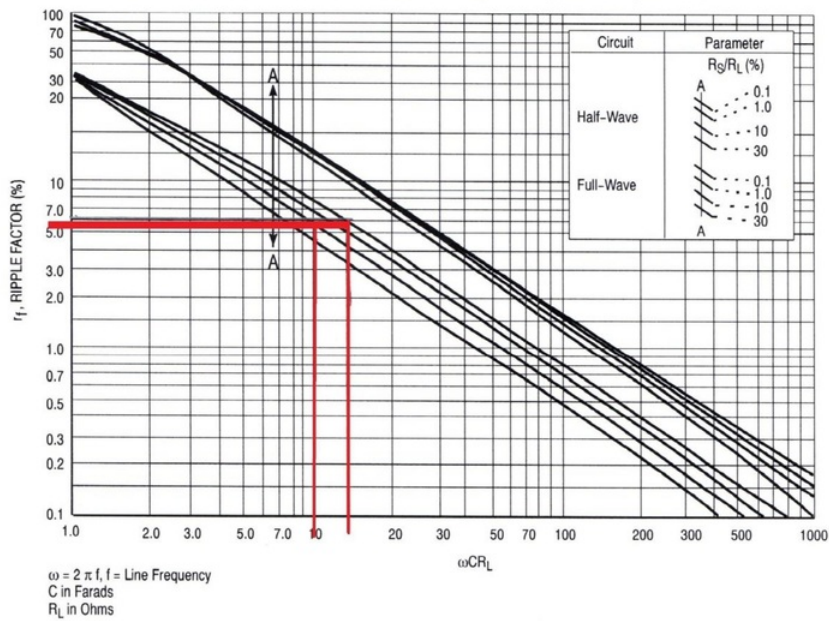


Figure 5: Sharde curve 3

Rectifier

$$I_f(avg) = \frac{I_o}{2} = \frac{2}{2} = 1A$$

$$I_f(rms) = I_f(avg) * 2 = 2A$$

$$I_f(peak): n = 2, \quad \frac{R_s}{R_L} = 0.2, \quad \omega CR_L = 13$$

$$\text{Because } n = 2: \frac{R_s}{nR_L} = 0.1 \text{ or } 10\%, \quad n\omega CR_L = 26$$

The above values were used in conjunction with the Sharde curve in Figure 4 to find $I_f(peak)$. A line was drawn from the intersecting point and a value of roughly 5.2A was obtained. To find the true value of $I_f(peak)$, the following equation was used:

$$I_f(peak) = 5.2 * I_f(avg) = 5.2 * 1 = 5.2A$$

$$PIV = V_m = 29.25 \text{ (50V used for safety)}$$

$$I_{surge} = \frac{V_m}{R_s + ESR} \text{ (ESR is ignored)} = \frac{V_m}{R_s} = \frac{29.45}{1.975} = 14.9A$$

Transformer

$$V_s = \frac{V_m + n(1)}{\sqrt{2}} = \frac{29.25 + 2}{\sqrt{2}} = 22V_{rms}$$

$$\text{secondary resistance} = R_s = 1.975$$

$$\text{secondary RMS current} = I_f(rms) * \sqrt{2} = 2 * \sqrt{2} = 2.8A$$

$$VA \text{ rating} = V_s I_{f(rms)} (\sqrt{2}) = 22 * 2 * \sqrt{2} = 62VA$$

Heatsink

The output current of 2A max for the PSU is switched through the transistor. To allow the transistor to operate safely, the heat generated by the transistor has to be dissipated. The transistor has a maximum collector current rating of 3A.

The maximum junction temperature was chosen as:

$$T_j(max) = 100$$

The case-to-heatsink thermal resistance θ_{cs} was found from a standard table based on the package and use of heatsink compound:

$$\theta_{cs} = 1.0C/W$$

The following values were specified in the datasheet as:

$$P_d = 40W$$

The P_d rating has to be de-rated based on the junction temperature. With a junction temp of 100C the new P_d value is 16W. See Figure 6 for derating curve. The graph was taken from the components datasheet.

$$P_d = 16W$$

$$\theta_{jc} = 3.125C/W$$

Using these values, the heatsink-to-ambient thermal can be calculated, which will be used to select the heatsink:

$$\theta_{SA} = \frac{T_j - T_A}{P_d} - \theta_{cs} - \theta_{jc} = \frac{100 - (-18)}{16} - 3.125 - 1 \leq 3.25 C/W$$

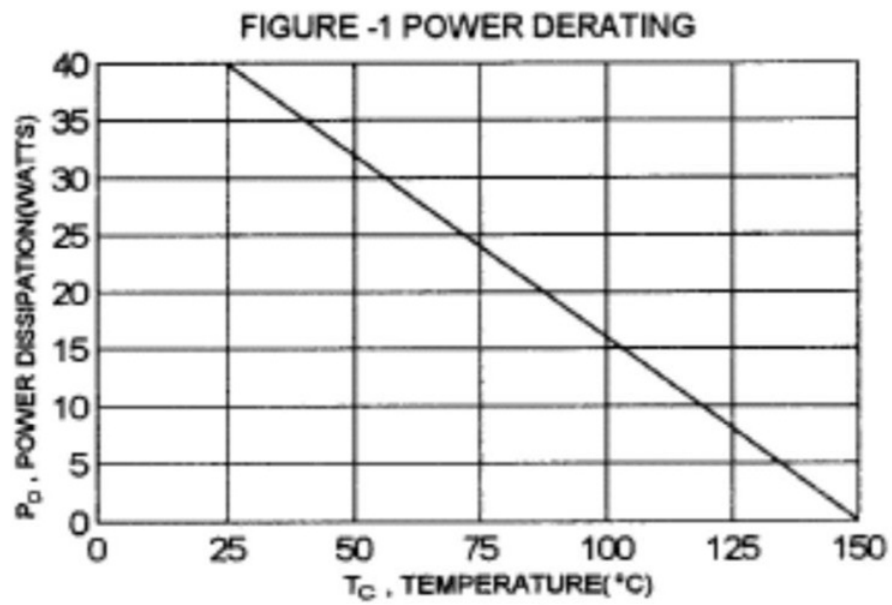


Figure 6: Pd derating

Some of the calculations are not going to be incredibly accurate, if some values were obtained using printed graphs. There is expected error caused by manually using a printed graph. This is why components are slightly overrated in most cases to avoid any errors which could potentially cause a problem in the final design.

Component choices

All the components used in the PSU were selected using the following criteria:

- Size, shape & weight suitable for application
- Suitable operating temperature range
- Price reasonable for its application
- Suitable for the Electrical/thermal ratings as calculated in the 'calculations' section

For the reasons listed above, detailed explanations of exactly why each component has been chosen was omitted due to being superfluous. The following section is the final parts list, along with price and link to RS website for chosen component (Priced per single component purchased).

Parts list of suitable components

Capacitor



Aluminium Electrolytic Capacitor 4700µF 50V

Price per unit: £1.745

Link: <https://uk.rs-online.com/web/p/aluminium-capacitors/7111526/>

Datasheet: <http://docs-europe.electrocomponents.com/webdocs/1581/0900766b81581713.pdf>

(RS pro, n.d.)

Bridge rectifier



KBU4D-E4/51, Bridge Rectifier, 4A 200V

Price per unit: £3.45

Link: <https://uk.rs-online.com/web/p/bridge-rectifiers/6294475/>

Datasheet: <http://docs-europe.electrocomponents.com/webdocs/154c/0900766b8154c20f.pdf>

(Vishay, 2014)

Transformer



Price per unit: £17.05

Link: <https://uk.rs-online.com/web/p/toroidal-transformers/6718980/>

Datasheet: <http://docs-europe.electrocomponents.com/webdocs/157a/0900766b8157a9ba.pdf>

(RSpro, n.d.)

Voltage regulator



LM723CN Linear Voltage Regulator

Price per unit: £0.768

Link: <https://uk.rs-online.com/web/p/linear-voltage-regulators/7140837/>

Datasheet: <http://pdf.datasheetcatalog.com/datasheet/stmicroelectronics/4553.pdf>

(STMicroelectronics, 1998)

High-power resistor



Radial Fixed Resistor 300mΩ ±5% 50W

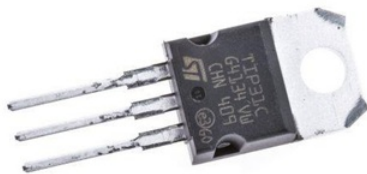
Price per unit: £8.32

Link: <https://uk.rs-online.com/web/p/through-hole-fixed-resistors/8098730/>

Datasheet: <http://www.arcolresistors.com/wp-content/uploads/2013/05/AP851-2-13.18.pdf>

(Arcol, 2013)

Transistor



TO-220 TIP31C NPN Transistor, 3 A

Price per unit: £0.784

Link: <https://uk.rs-online.com/web/p/bipolar-transistors/4859755/>

Datasheet: <http://docs-europe.electrocomponents.com/webdocs/135f/0900766b8135f8a7.pdf>

(STMicroelectronics, 2006)

Heatsink



HEATSINK FOR TO220

Price per unit: £1.358

Link: <https://uk.rs-online.com/web/p/heatsinks/8934942/>

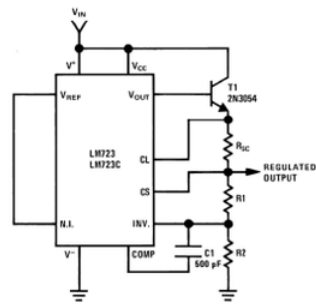
Datasheet: <http://docs-europe.electrocomponents.com/webdocs/14c9/0900766b814c94f4.pdf>

(Ohmite, n.d.)

Design method

The first thing considered in the design was the voltage regulator circuit. The output voltage and current from the regulator is known, the regulator circuit must be designed first to find out the required input voltage to the regulator.

The circuit shown in Figure 7 is a configuration that allows enough current to satisfy the initial specification. This is achieved by using a bypass transistor controlled by the voltage regulator.



Typical Performance

Regulated Output Voltage	+15V
Line Regulation ($\Delta V_{IN} = 3V$)	1.5 mV
Load Regulation ($\Delta I_L = 1A$)	15 mV

Figure 19. Positive Voltage Regulator (External NPN Pass Transistor)

Figure 7: Voltage regulator

(Texas Instruments, 2013)

The calculations for the regulator (Section 3) show that an input voltage equal or greater than 19.5VDC is needed. The values of the resistors in the regulator circuit have to be calculated to suite the specification. According to the initial specification, the output voltage and current is 12V and 2A respectively. All of the following tables and equations relating to the regulator are from the manufacturers datasheet. See Figure 9, Figure 10, Figure 11 & Figure 12 for the values and equations used in the following calculations;

$$12 = \left(7.15 \times \frac{R1 + R2}{R2} \right)$$

Let $R2 = 7 \text{ Ohms}$ (Tweaked value until 12v was achieved)

$$12 = 7.15 \times \frac{R1 + 7}{7}$$

$$12 \times 7 = 7.15 \times (R1 + 7)$$

$$84 = 7.15 \times (r1 + 7)$$

$$84/7.15 = r1 + 7$$

$$11.75 = r1 + 7$$

$$R1 = 11.75 - 7 = 4.75 \text{ ohms}$$

$$I_{\text{limit}} = 2A$$

$$R_{sc} = 0.3 \text{ Ohms}$$

$$V_{\text{sense}} = 2 * 0.3 = 0.6 \text{ Transistor volt drop}$$

From equations: $R1 = 4.75, R2 = 7, R_{sc} = 0.3$

The values of $R1$ and $R2$ were tweaked slightly to achieve the desired output voltage of 12V. The short circuit resistor will remain the same, as changing this value ensures only 2A are drawn when the output terminals are shorted out. This is the reason a high wattage resistor was selected, because it's capable of allowing 2A of current @12VDC through without damage to the component.

The completed simulated regulator is shown in Figure 8. The simulation shows the values that were tweaked to reach as close to 12VDC as possible. Also shown in the previously mentioned figure is the output voltage of the regulator: Which is within specifications with a load of 50Ohms. See section 4 on p21 for voltage regulation over a range of loads.

The voltage source shown in Figure 8 is used to avoid convergence errors in Multisim. The value of the voltage source is 19.5V, as calculated earlier. A ripple of 0.5Vpp was added to the voltage source to simulate input ripple.

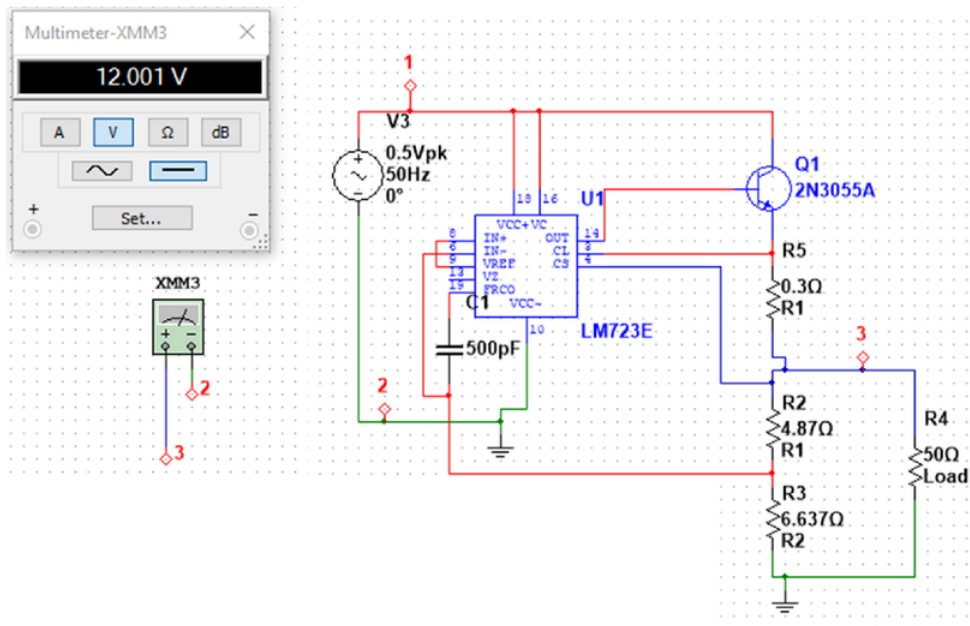


Figure 8: Regulator circuit

Outputs from +7 to +37 volts
(Figure 17 Figure 19 Figure 20
Figure 21 Figure 24 Figure 27)

$$V_{OUT} = \left(V_{REF} \times \frac{R1 + R2}{R2} \right)$$

Figure 9: Regulator Vout calc

Current Limiting

$$I_{LIMIT} = \frac{V_{SENSE}}{R_{SC}}$$

Figure 10: Regulator Current limit

Positive Output Voltage	Applicable Figures	Fixed Output ±5%		Output Adjustable ±10% (1)			Negative Output Voltage	Applicable Figures	Fixed Output ±5%		5% Output Adjustable ±10%		
		R1	R2	R1	P1	R2			R1	R2	R1	P1	R2
+3.0	Figure 4, Figure 19, Figure 21, Figure 24, Figure 27 (Figure 19)	4.12	3.01	1.8	0.5	1.2	+100	Figure 22	3.57	102	2.2	10	91
+3.6	Figure 4, Figure 19, Figure 21, Figure 24, Figure 27 (Figure 19)	3.57	3.65	1.5	0.5	1.5	+250	Figure 22	3.57	255	2.2	10	240
+5.0	Figure 4, Figure 19, Figure 21, Figure 24, Figure 27 (Figure 19)	2.15	4.99	0.75	0.5	2.2	-6 ⁽³⁾	Figure 18, (Figure 25)	3.57	2.43	1.2	0.5	0.75
+6.0	Figure 4, Figure 19, Figure 21, Figure 24, Figure 27 (Figure 19)	1.15	6.04	0.5	0.5	2.7	-9	Figure 18, Figure 25	3.48	5.36	1.2	0.5	2.0
+9.0	Figure 17, Figure 19, (Figure 19, Figure 21, Figure 24, Figure 27)	1.87	7.15	0.75	1.0	2.7	-12	Figure 18, Figure 25	3.57	8.45	1.2	0.5	3.3
+12	Figure 17, Figure 19, (Figure 19, Figure 21, Figure 24, Figure 27)	4.87	7.15	2.0	1.0	3.0	-15	Figure 18, Figure 25	3.65	11.5	1.2	0.5	4.3
+15	Figure 17, Figure 19, (Figure 19, Figure 21, Figure 24, Figure 27)	7.87	7.15	3.3	1.0	3.0	-28	Figure 18, Figure 25	3.57	24.3	1.2	0.5	10
+28	Figure 17, Figure 19, (Figure 19, Figure 21, Figure 24, Figure 27)	21.0	7.15	5.6	1.0	2.0	-45	Figure 23	3.57	41.2	2.2	10	33
+45	Figure 22	3.57	48.7	2.2	10	39	-100	Figure 23	3.57	97.6	2.2	10	91
+75	Figure 22	3.57	78.7	2.2	10	68	-250	Figure 23	3.57	249	2.2	10	240

Figure 11: Regulator resistor value table

Reference Voltage		6.95	7.15	7.35
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Figure 12: regulator reference voltage

(STMicroelectronics, 1998)

The circuit leading up to the regulator can now be designed to supply the regulator circuit with at least 19.5VDC. The rest of the circuit is a standard PSU design:

- Transformer steps 230AC down to 15.3VAC (Figure 13 XMM5, Figure 14)
- The bridge rectifier flips the negative half cycle of the sine wave.
- The capacitor smooths the 'lumpy' DC coming from the bridge rectifier.
- The output from the capacitor is unregulated, relatively smooth DC.
- The DC value of 20.3V (Figure 13 XMM4) shows the DC that will supply the regulator

In reality, the circuit would not be split into 2. But due to the limits of the simulation software, this was not possible. However, the simulation is still accurate as the output voltage from one circuit has been simulated onto the regulator circuit.

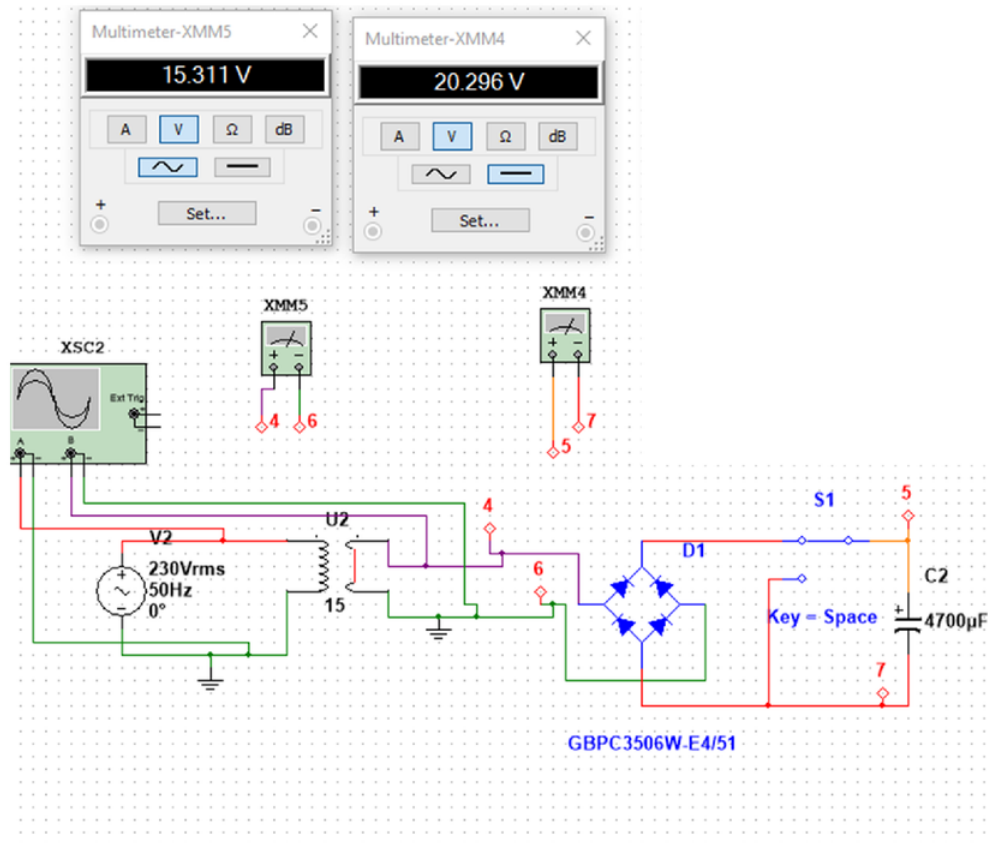


Figure 13: Regulator circuit 2

In the physical design, a transformer with a higher output was used, 18V instead of 15V. The testing section shows that supplying the regulator with more voltage that calculated does not affect the output voltage (Within reasonable limits). Only underrating the transformer would affect the output voltage of the regulator.

Figure 14 shows the oscilloscope output waveform of transformer input/output. Figure 13 shows the oscilloscope connections.

Figure 15 shows the oscilloscope waveforms for the bridge rectifiers input and output, coloured purple and red respectively. As the capacitor is in the circuit the output from the bridge rectifier is being smoothed. If the capacitor was removed, the output would be 'lumpy', as previously mentioned. The waveform also shows that the voltage being supplied to the regulator meets requirements (20VDC-Unregulated), and thus will enable the regulator to deliver the specified voltage.

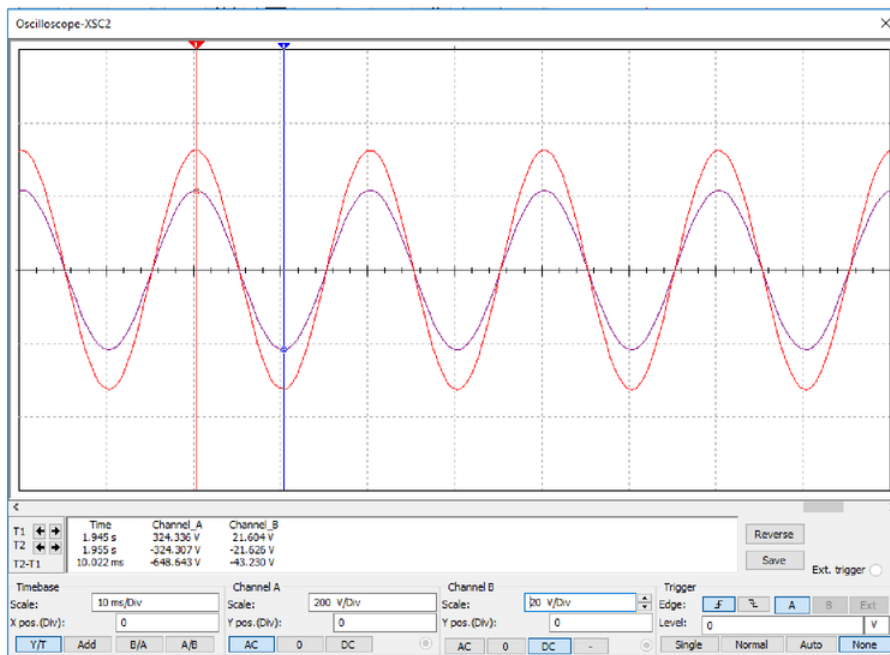


Figure 14: Transformer Oscilloscope input/output

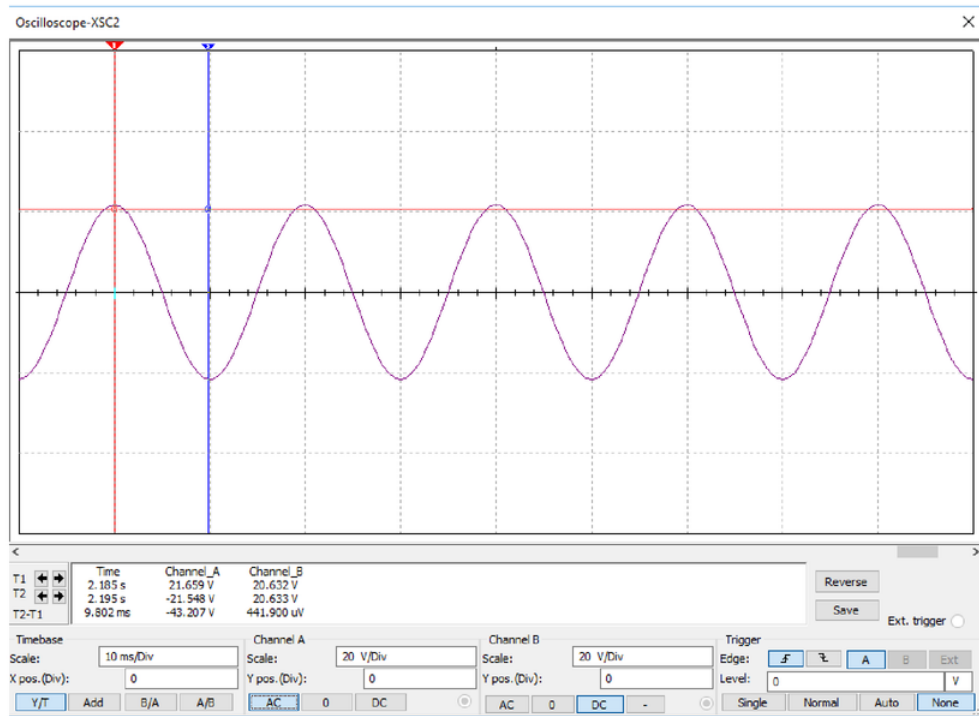


Figure 15: Bridge rectifier Input/output waveform

4. Testing and improving the design

Testing

The circuit has been fully designed and produced a working power supply. Before the design can progress into a physical build, the functionality of the design has to be fully tested. The main tests being performed will be line and load tests.

Line test (Figure 16): The input voltage to the regulator will be varied from 0 to 30VAC, showing the output voltage of the regulator at each voltage level. This shows the relationship between regulator input and output. The load for this test was a constant value of 500hms. The graph shows the point at which the regulator outputs 12VDC, shown as a blue line at 15V input. However, this is not taking ripple into consideration. This is why the calculated value of 19.5V input is used, as explained in detail in section 3. The graph also proves that the regulator will still maintain 12vDC output with input voltage far higher than the calculated value. This is one of the reasons the transformer used in the build was higher rated than calculated.

The test was performed using the parameter sweep in Multisim.

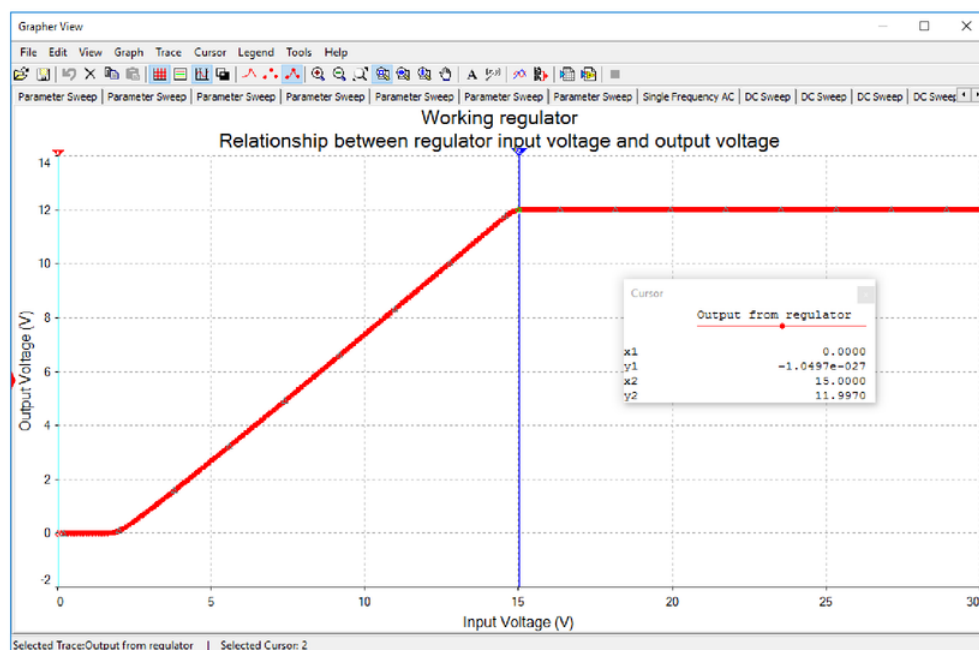


Figure 16: Regulator Input/output relationship

Load test (Figure 17): The load test varies the resistance of the load within a certain range, 0 to 600hms. The output current is plotted on the same graph to show the relationship between load resistance and output current. The graph clearly shows the relationship between output current/voltage and the resistance of the load. This test also confirms that when the outputs are shorted out (00hms), the power supply will not exceed the current limit of 2A.

The final test performed on the PSU was to ensure that the regulator will consistently output a steady 12VDC when the input voltage contains a ripple. Figure 18 shows a realistic example of a slight amount of input ripple being removed by the regulator. As the circuit was designed to accept a large amount of input ripple (See section 3), a more dramatic example of the regulator removing input ripple is shown in Figure 19.

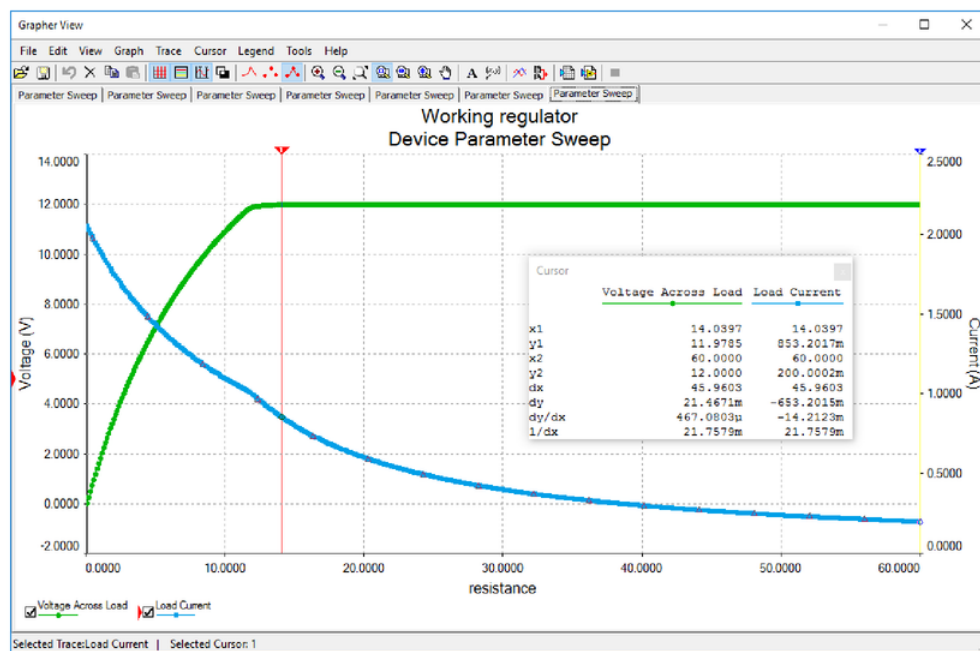


Figure 17: Load test

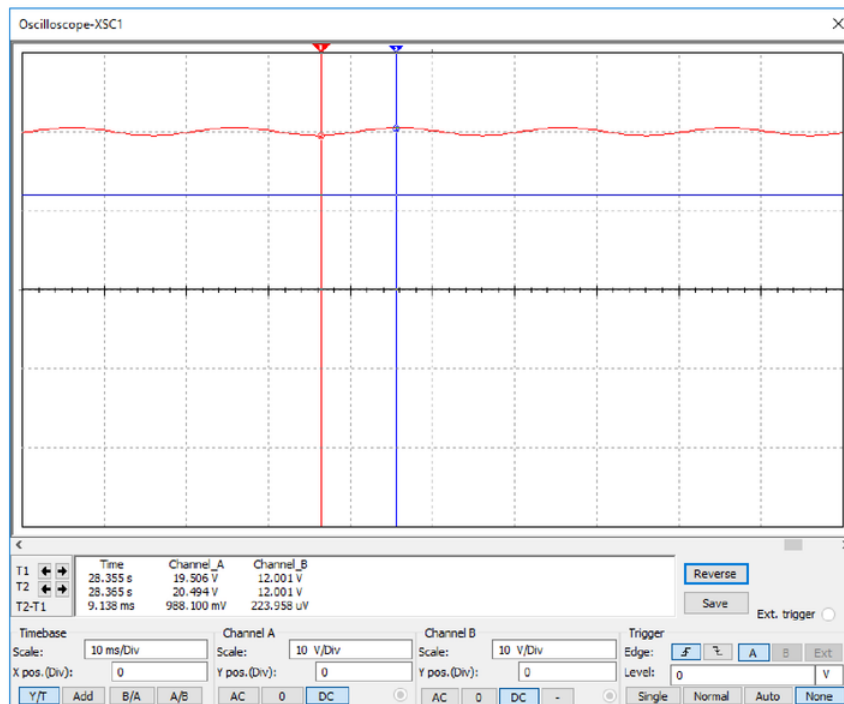


Figure 18: ripple test 1

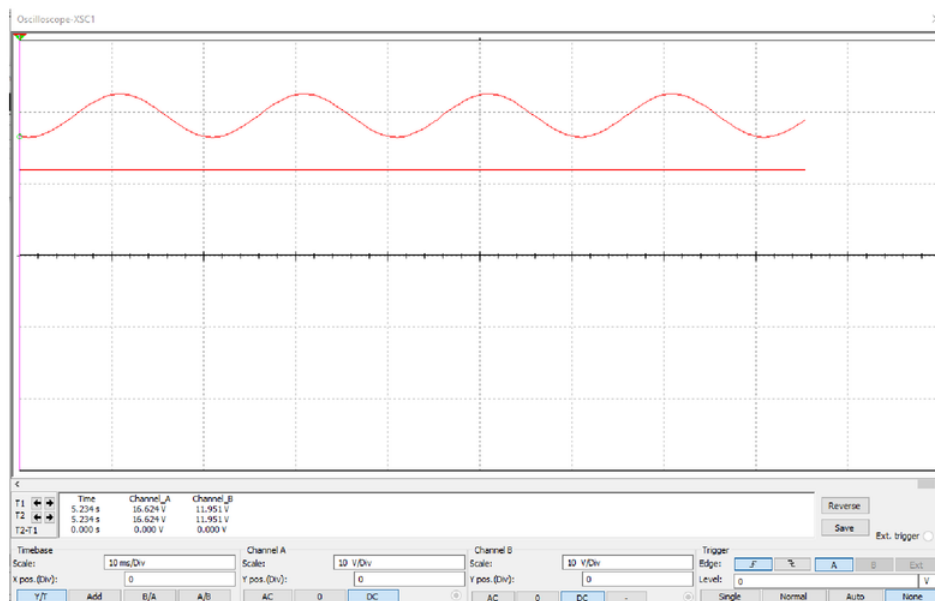


Figure 19: ripple test 2

Improving the design

Throughout the whole design process small changes have been made to improve the design of the product. Tweaking component values to meet the specification makes up the majority of the improvements.

The over-rating of the transformer also improves the design to allow even more input ripple to the regulator, as well as enabling the 230VAC input voltage to vary slightly without effecting the output voltage. If the rating of the transformer was too low, then a slight dip in the mains voltage could cause the regulators input to dip below 15V, thus causing the regulator to output less than 12VDC. Shown best in the diagram in Figure 16.

5. Conclusion

The overall aim of this assignment was to design a power supply unit (PSU) for a customer, based off a list of specifications:

- Convert 230V AC to 12V DC
- The system must operate in temperatures as cold as -18C
- Deliver a maximum current of 2A.
- Short circuit protection.
- Stable output voltage over a reasonable range of loads

These criteria were all met and the PSU was thoroughly tested to ensure the product was suitable for the customers application. The customer had requested detailed analysis of the system to be provided to ensure the PSU meets specification. The results have been included throughout the report.

The design and testing of the PSU was completed with no major problems.

The background research was essential in this project as certain equations and values were essential in designing a system suited to a specification. The datasheets for each component had to be sourced and studied for the same reason.

Insight into the design of a system based on a specification was also gained from the project, for example; Calculated values are often used as a baseline or starting point, with the final values tweaked slightly to ensure that the specification is met. Also, another problem arises when designing a circuit using printed graphs. Some of the calculations are not going to be incredibly accurate as there is expected error caused by manually using a printed graph. This is why components were slightly overrated in most cases to avoid any errors which could've potentially cause a problem in the final design.

6. Reference list and bibliography

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7. Annex

There are no appendices for this project. All relevant information has either been included or properly referenced throughout the report.

PSDE6015, Assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

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GRADING FORM: CSG-RUBIC

MICHAEL LEWIS

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RESEARCH-INFORMED LITERATURE



There was little evidence of further reading and research either in power supplies in general or on the choice of components. You have included minimal information on the choice of component with little technical detail. You needed to show why you chose the component you did and why alternatives were not suitable. Your interpretation and understanding of the additional research was satisfactory. Your references list was short for this the task.

2

KNOWLEDGE AND UNDERSTANDING



The knowledge and understanding of the subject demonstrated by this assignment was generally good. The design was well explained and well executed. There were very few gaps in your knowledge of the basic principles and your understanding of the higher level concepts was demonstrated. You could have explained in more detail how you chose the final component for each stage.

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ANALYSIS



Your explanation of the design process was good, however the conclusions lacked some detail. You could have evaluated the choice of the various components, specified whether the solution met the specification and suggested ways to improve the solution. You have however demonstrated good analytical skills and your approach to the task was logical. Further work – in your conclusion, you should relate the results to the original specification and to accepted theory.

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PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally very good. You used the resources available in MultiSim appropriately when designing the circuit and you used appropriate options for testing and evaluating the circuit performance. You managed to design an efficient circuit that functioned within the specification and achieved this by only asking for assistance when appropriate. Your results were comprehensive and allowed for a

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good conclusion to be attempted.

SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was of an appropriate length, you could however be more efficient with your word count. You had 3500 to play with and only used 3100, some of what you did write was unnecessary. The report however was not well presented, and the order of your design explanation didn't make much sense.

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