

1809802

by Mason Morgan

Submission date: 27-Feb-2022 07:31PM (UTC+0000)

Submission ID: 172229826

File name: 13695_Mason_Morgan_1809802_179513_1865809842.pdf (1.1M)

Word count: 3411

Character count: 18078

60-65

Course: BSc (Hons) Electrical and Electronic Engineering
Module: SGEE6005 Electronic Design
Assignment: Regulated Power Supply Design
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Date submitted: 28th February 2022
Word count: 3000
Currently: 3072

- ① NO CITATIONS OR A CITATION LIST. EVEN WITH TECHNICAL DATA YOU NEED TO CITE YOUR SOURCES.
- ② THE DESIGN METHOD WAS REASONABLY COMPLETE, BUT SOME CALCULATIONS DIDN'T MATCH YOUR CIRCUIT AND SOME OF THE SCHEME CURVES WERE MISSING.
- ③ TESTING WAS DONE AND SHOWED THE POWER SUPPLY WORKED TO SPEC.
- ④ COMPONENT SELECTION WASN'T COMPLETE AND DIDN'T REALLY EXTEND INTO THE ENVIRONMENTAL CONDITIONS THE SUPPLY WILL OPERATE IN.
- ⑤ SOME VALID CONCLUSIONS.

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1. Executive Summary

PAST TENSE

This assignment has been written to investigate new items of consumer electronics. It is the student's job to design a power supply unit as part of this job.

The student must design, simulate, and evaluate a power supply using advanced design methodologies. The design must consider the electrical, physical, and thermal requirements.

The tasks can be broken down into the following:

1. The specification for the design will be communicated between the customer and the designer
2. With relevant and valid documents, the voltage regulator can be designed which will take into consideration over-voltage protection and short-circuit protection.
3. The input stage can then be designed which uses Schade curves to determine the most suitable components
4. The thermal management system must be created using the appropriate literature and datasheets.
5. The design will finally be tested, evaluated, and critically analysed.

Once the design of the power supply has been completed an overall conclusion can be constructed which will allow the reader to understand what has been found and any similarities that be discovered.

Also, recommendations can then be thought of to improve the design for next time.

All relevant information discovered or used throughout the course of this task will be cited and listed using Harvard.

NOT A CONVENTIONAL ES.

2. Researching requirements and compilation of the specification

From the specification and criteria set a power supply must be designed, the power supply criteria must meet a product application. Specifically, a power supply of 240VAC must be converted to a 24VDC supply which will power an electrical instrument on a production line, this instrument being powered will be a photovoltaic cell. The conversion of supplies will happen inside the main control panel however, the photovoltaic cell with the trailing 24VDC supply will be mounted in the field and will need to be suitable for use in a hazardous area.

VAC Input	: 240V
Input Frequency	: 50Hz
VDC Output	: 24V
IDC Output	: 1.8A
Temperature Rating	: 10 – 40 degrees
Ingress Protection (IP) Rating	: IP65
Enclosure	: Electrical Panel

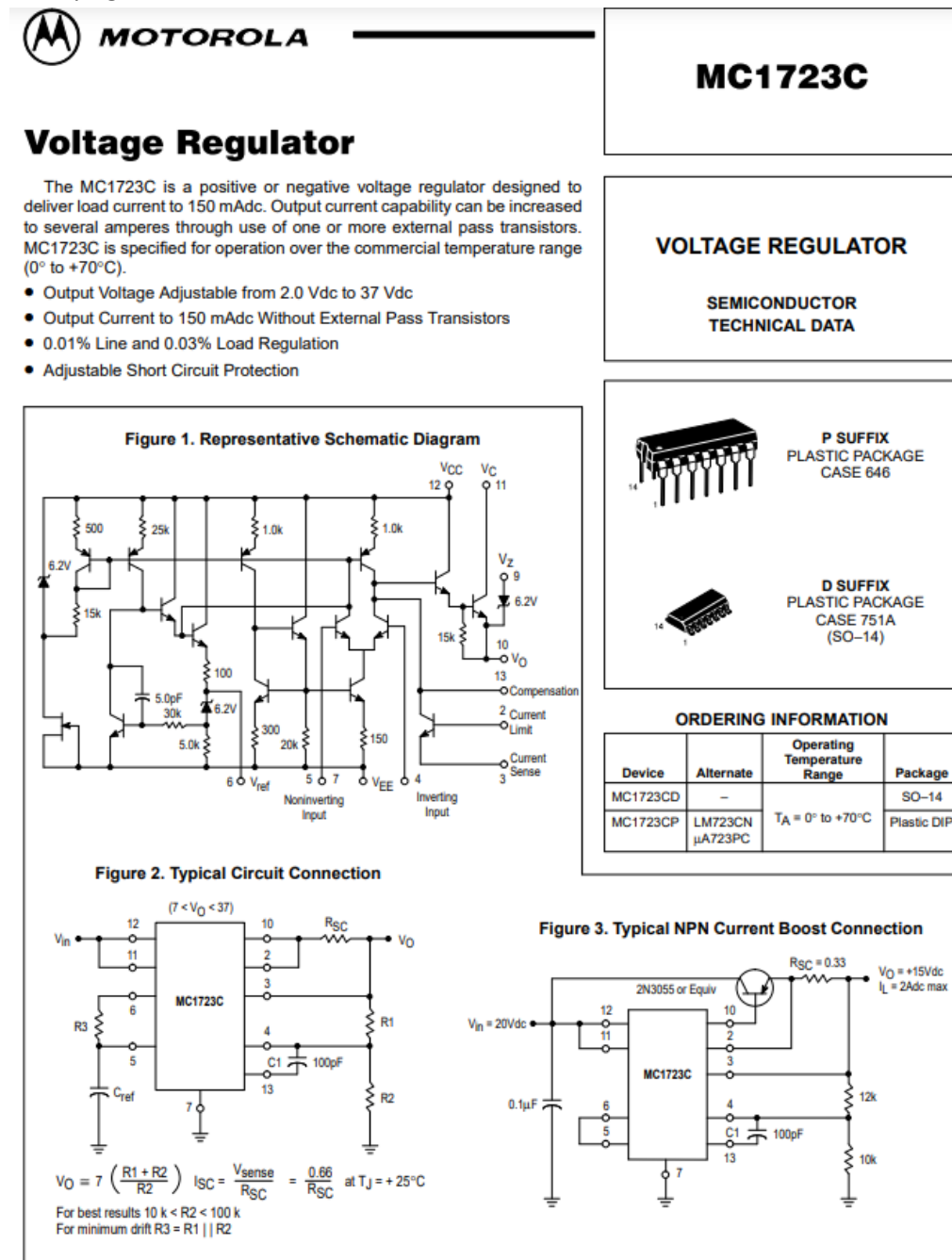
As discussed previously, the power supply to the sensor requires a 24VDC supply with an input current rating of 1.8 Amp. The 24VDC supply cable runs from the control panel and through channels of conduit and trunking, made of on the end of the cable is a removable female 4 pin termination point which adapts to a male 4 pin termination point which runs straight to the sensor, the reason for this being easy disconnection of sensor if damage or faults occur saving both time and money. The sensor has a low current rating due to quick communication between the physical input which transforms into a quick electrical data transmission signal (4 – 20mA).

There will be additional criteria that the sensor must meet to the environment that it has been placed in. The sensor will be subjected to dust and powder molecules from the mixture, there will also be a lot of heat within that area like heat forming tools for stretching the material running through the sensor. The supply will need to be able to function between 2 due to the nature of the enclosure and heat generated by components. The sensor must be subject to the ingress protection of IP65 or above.

YOU ARE DESIGNING A POWER SUPPLY, NOT A SENSOR!

3. Design method, choices, and calculations

During the first stages of the design stage a suitable chip was chosen, the chip that was chosen was a MC1723C in NPN transistor boost configuration. A copy of the MC1723C can be seen below illustrated by figure 2.



ONLY SHOW RELEVANT INFO, NOT THE ENTIRE PAGE.

Figure 1: MC1723C micro controller chosen

The integrated chip is not designed to be able to regulate high amounts of current, thus why the transistor added does increase the current output but only to approx. 150mA.

The above circuit has been used to help design a circuit which can output a positive signal of 24VDC. It can be seen from figure 2 that the voltage regulator uses pin 12 to supply the transistor with a 240V supply.

Specifically, one of the reasons why the LM723NC chip was selected was because of its temperature protection which will meet the needs for the environment that it'll be placed in. The chip allows a minimum of 0 degrees with a maximum of 70 degrees, the product application will be used in an environment varying between 10 degrees and 40 degrees.

The circuit transistor can determine when the voltage drops below a certain value and this in-turn decides what state it is. This is a very tactical way of protecting instruments and components at later stages of the circuit. As shown in figure 1 if the volt drop exceeds 0.66V the transistor will no longer conduct.

Figure 3 below shows a zoomed in image capturing a typical NPN current boost connection. From the diagram it clearly states that the RSC is equivalent to 0.33 Ω .

THIS IS AN EXAMPLE FROM THE DATASHEET. YOU NEED TO CALCULATE YOUR OWN VALUE

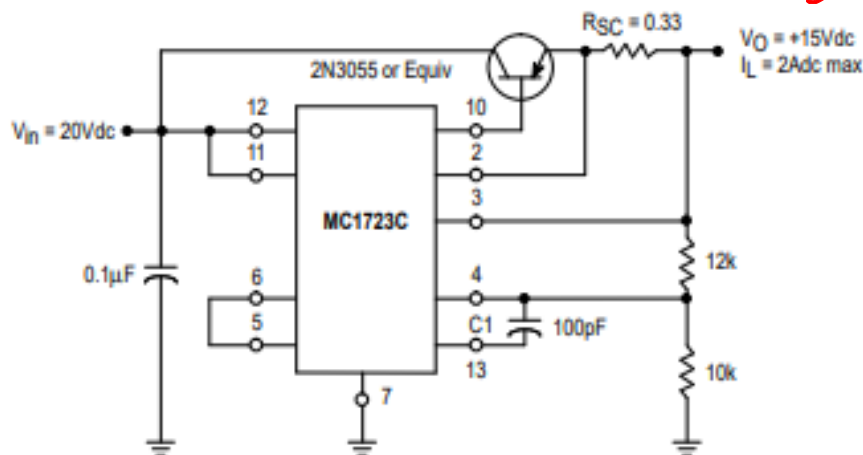


Figure 2: NPN Current Boost Connection

It's clear that this component is the limiting factor of the current flowing through the circuit, and it can now be determined that by adjusting the value of the resistor will affect the current flowing through the circuit, by increasing the value will decrease the current value and vice-versa.

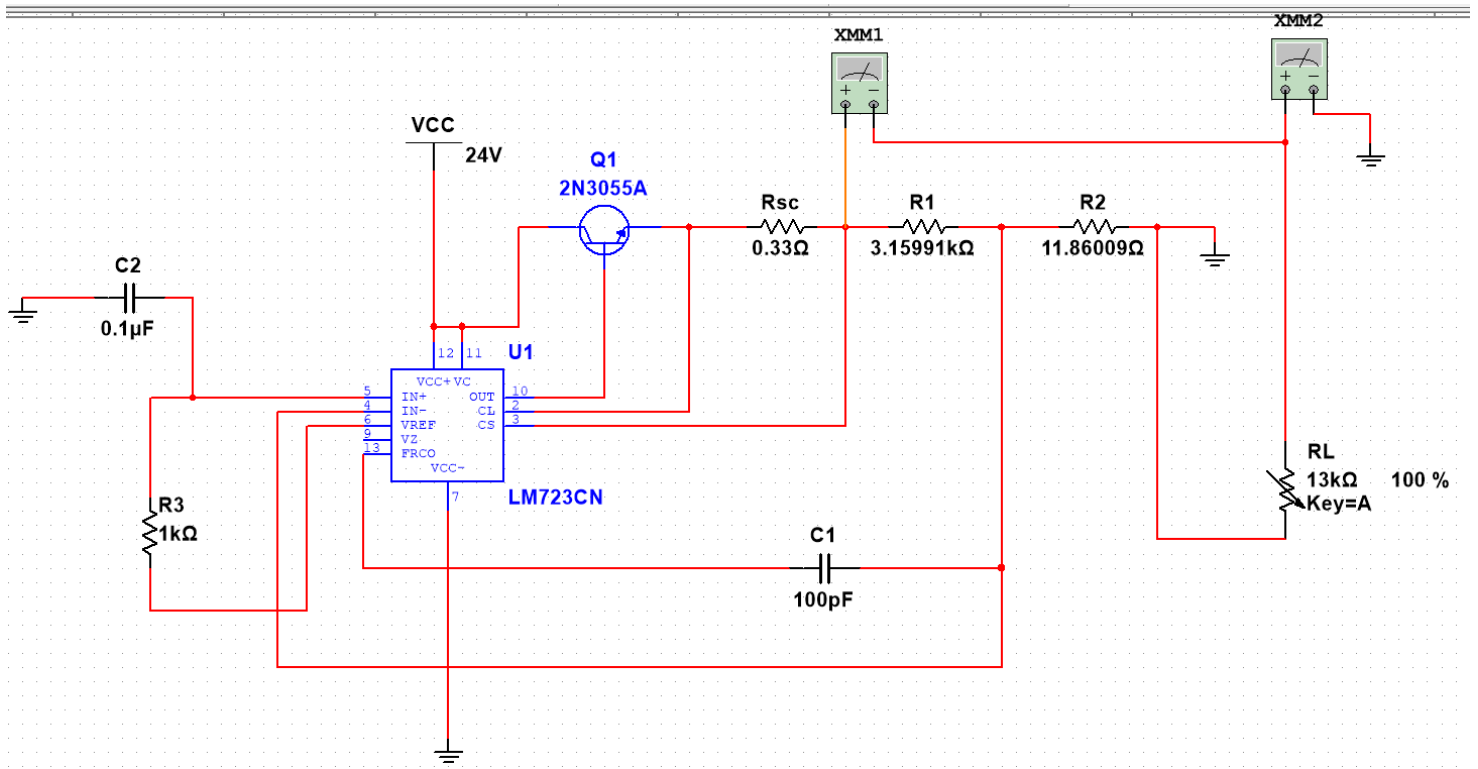


Figure 3: Multisim regulator circuit

Figure 1 was a great help in constructing the multisim circuit in figure 4 above. The layout and configurations could be used to manipulate in a specific way to meet the product application. The component values will later be determined through calculations which will be placed in the multisim circuit.

3.1. Determination of component values

Once the values were calculated they were adjusted to determine more accurate values for the circuit.

Firstly, C_{ref} is chosen to be 0.1 μ f for low noise operation.

An equation can firstly be written as $R1 + R2$.

$$R2 = \frac{V_{ref}}{V_{out}} (R1 + R2)$$

$$= \frac{7.15}{24} (25k)$$

$$= 0.30 (25k)$$

$$= 7500 \Omega$$

V_{ref} is a 7.0V specific characteristic of this IC.

$$R1 = 25k - 7500 = 17.5k \Omega$$

A value for the base-emitter junction voltage drop is divided by the sensing current.

$$R_{SC} = \frac{0.60}{1.8} = 0.33 \Omega$$

THE RESISTOR VALUES DO NOT MATCH YOUR CIRCUIT.

Calculated with these in parallel $R3 = R1 \parallel R2 = 2.7k \Omega$

The input voltage is determined by considering losses such as transistor volt drops.

3.2. Determination of Input Voltage

There are two basic constraints on the input voltage, these are the device limits for minimum and maximum V_{in} and the minimum input-output differential. These limits are found on the device data sheet to be:

$$24V < V_{in} < 40 V \text{ and } (V_{in} - V_o) > 3.0 V$$

For the configuration of figure 3 – 5A, $(V_{in} - V_o)$ is given by:

$$(V_{in} - V_o) = [V_{in} - (V_o + 2)] > 3.0 V, \text{ where } V_{BEon} = 0.6 V$$

Therefore, ultimately:

$$V_{in} > V_o + 2 + 3 V = 24 + (2 \times 0.6) + 3$$

$$V_{in} > 28.2 V$$

To simplify the design of the input supply, V_{in} is chosen to be 24 V average with a 3 Vpp ripple at full load and up to 30V at no load.

The MC1723C has a typical ripple rejection ratio of -74db, as given on its datasheet.

*YOU JUST CALCULATED
IT MUST BE GREATER
THAN 28V !!*

3.3. Design of the Input Stage

This part of the design determines capacitor and rectifier values through calculations and graph references.

To calculate the ripple, the ripple rejection value of -74dB was taken from the regulator datasheet.

$$\text{Ripple Rejection} = \frac{\text{ripple out}}{\text{Ripple in}} > -74\text{dB} = \frac{1\text{mv}}{\text{Ripple in}} > \left(10^{\frac{-74}{20}}\right) = \frac{1\text{mv}}{\text{Ripple in}} > \text{Ripple in} = 5.011\text{V}$$

As 5.011V is the ripple maximum, a value of 2.5V ripple peak to peak is chosen to allow for tolerance up to the max.

V_{in} was 24V earlier?

$V_{in} = \left(V_{in} + \frac{1}{2}V_{in}\right) = 40\text{V}$ This is a value used for the input to the capacitor.

Schade curves are used to obtain the design information for the capacitor filter and rectifier.

An equation can be used to determine the range of minimum capacitor values to obtain sufficient ripple attenuation, see below:

$$r_f = \frac{V_{\text{Ripple(pp)}}}{2\sqrt{2}V_{C(\text{DC})}} \times 100\% \quad r_f = \frac{3}{2 * \sqrt{2} * 35} * 100\%$$

WHERE DID 35 COME FROM?

$$r_f = 3.03\%$$

Equation 1: ripple factor equation w/ final answer

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

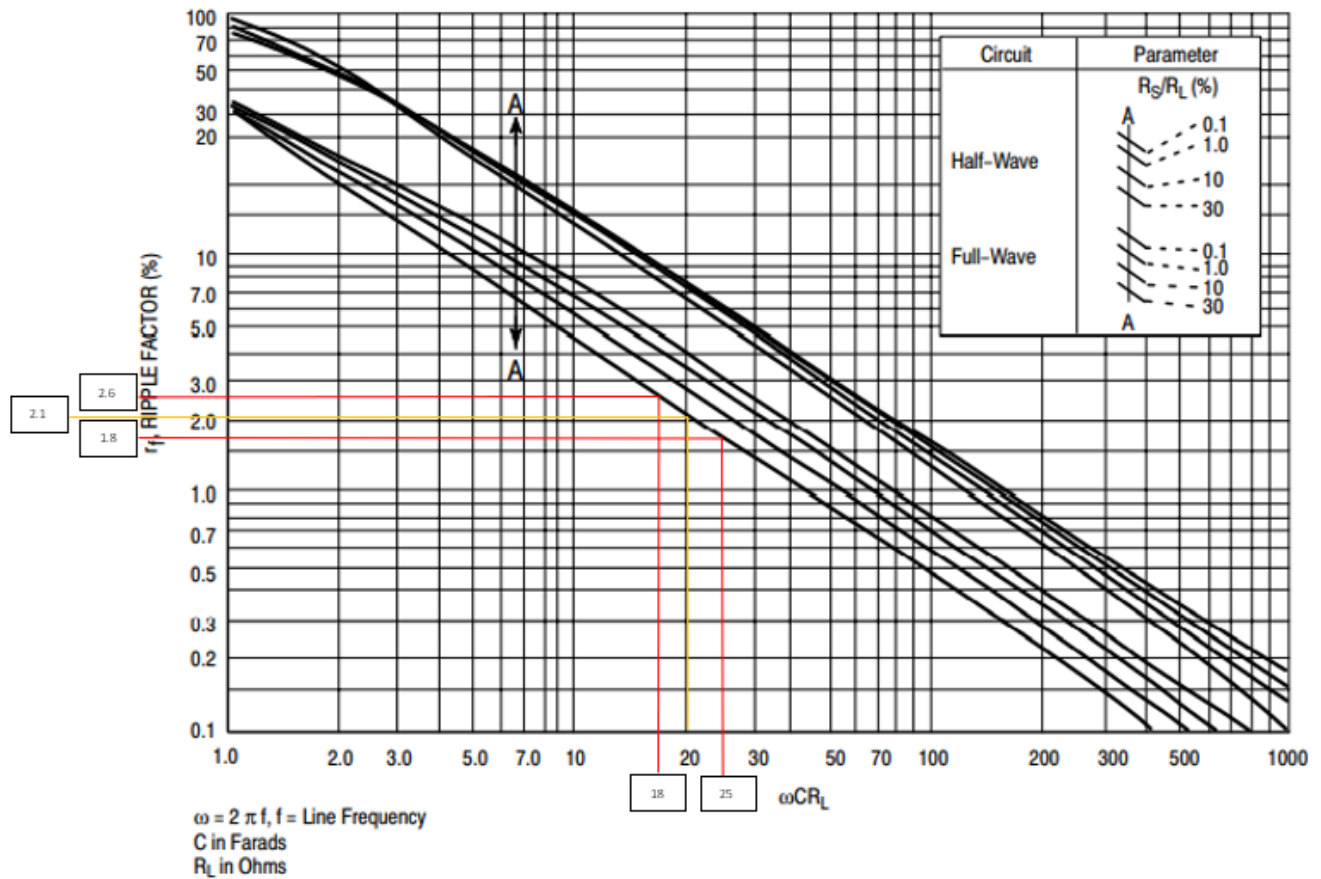


Figure 4: Graph displaying Root-Mean-Square Ripple Voltage for Capacitor-Input Circuits

As shown by figure 5, the graph shows different values plotted along the y & x axis. The y axis shows the ripple factor in percentage whilst being measured with a value of r_L , a value of 2.1 has been determined whilst having a minimum value of 1.8 and maximum of 2.6. The x axis measures ωCR_L and values of 18 and 25 have been plotted with an average figure of 20. With the average ripple value being 2.1 being plotted this is then used to plot the ωCR_L .

*THE SCHEME CURVES
ARE MISSING.*

As shown in figure 6, It can be seen that $\frac{V_c}{V_m} > \frac{24}{35} = 0.680\%$ or 68%

It can then be drawn on the curve that R_s / R_L is equal to the value of 68% thus a final value of 15% can be used.

From these values derived it can be said that $C = \frac{\omega C R_L}{2\pi f(\frac{V_c}{I_o})} > \frac{20}{2\pi 50(\frac{28.2}{2.0})} = 4.515\text{mF}$ for the filter capacitor.

$$R_s = 0.15 \times R_L \text{ therefore } R_s = 0.15 \times \left(\frac{28.2}{2}\right) = 2.115\text{ ohms and } R_L = 14.1\text{ ohms}$$

It can then be said that the average current I_{AVG} is half the output current so 1Amp. As it is a full wave, $WCRL$ is doubled. $20 \times 2 = 40$

It can be then determined that $IF_{RMS} = 2.3$ and $IF_{Peak} = 5.3 \times I_{avg} = 5.3A$

$$I_{surge} = \frac{V_m}{R_s + ESR} > \frac{40}{2.115} = 18.9A$$

$$\text{Peak Inverse Voltage, PIV} = V_m \times 2 > 35 \times 2 = 70$$

It was important that values were calculated for the transformer, the following equations are:

$$V_s = \frac{V_m + 2}{\sqrt{2}} > \frac{35 + 2}{\sqrt{2}} = 26.2V_{rms}$$

$$\text{Ratio} = \frac{V_{in}}{V_s} > \frac{240}{26.2} = 9.16:1$$

$$VA \text{ rating} = 2 \times V_s \times I_{rms} > 2 \times 26.2 \times 2.3 = 120.52 VA$$

The best location for the power supply to be placed was via DIN rail mounted. This meant that a supply could be picked up easily whilst being contained in a safe environment. The transformer was sourced from RS components and the link, code and datasheet can be seen below.

3.4. Thermal management system // Heatsink Calculations

Shown below are the equations used to calculate the heatsink.

$$T_J = T_A + P_D \theta_{JA}$$

Where, $P_D = V_{in} \times I_{SC}$

$$\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}$$

As discussed previously the transistor is used to boost the current. Obviously when increasing the current, you generate more waste heat through the components. Thus, a heatsink will be required to disperse the heat more effectively and keep the high amounts of heat to a minimum.

To be able to understand what specification the heatsink needs to be constructed to a value for the thermal insulation must be derived, to do this a value for the JC must be found from the transistor used in the circuit, the transistor used is the 2N3055 NPN.

From the datasheet on the transistor, a value of 1.5 degrees Celsius has been given, this can be seen in figure 9.

Table 3. Thermal data

Symbol	Parameter	Value	Unit
$R_{thj-case}$	Thermal resistance junction-case max	1.5	°C/W

Figure 5: Thermal resistance for the 2N3055 NPN transistor

Moving forward a value needs to be sourced for the θ_{SA} . To be able to determine this answer the following equations must be answered.

$$T_J = T_A + P_D \theta_{JA}$$

This equation can be rearranged to a more suitable one:

$$\theta_{JA} = \frac{T_J - T_A}{P_D},$$

Using the above equation, it can now be substituted into the original equation which makes,

$$\theta_{JA} = \frac{T_J - T_A}{P_D} - \theta_{CS} - \theta_{JC}$$

To calculate this formula answers for T_A & P_D can be sourced from the specification to determine the performance of the heatsink.

For the T_A (Ambient Temperature)

For the P_D (Power Dissipated)

To calculate the Power Dissipated, the following equation can be used:

$$P_D = (24V \times 1.8A) = 43.2W$$

From the information so far, the following equation can be rearranged:

$$\theta_{JA} = \frac{T_J - T_A}{P_D} > \frac{200 - 30}{43.2} = 3.935$$

$$\theta_{SA} = 3.935 - 0.28 - 1.52 = 2.135^\circ\text{C}/w$$

WHERE DID ALL
THESE NUMBERS
COME FROM?

To use the 2N3055G NPN transistor, a suitable physical product must be provided. The following transistor used has been sourced from RS Components and a datasheet for this component can be seen in figure 10 below.

[Heatsink, 2 \(Forced\) °C/W, 2 \(Natural\) °C/W, 46.4 x 46.4 x 33.3mm, Bolt On, Horizontal, Vertical | RS Components \(rs-online.com\)](#)

Heatsink, 2 (Forced) °C/W, 2 (Natural) °C/W, 46.4 x 46.4 x 33.3mm, Bolt On, Horizontal, Vertical

RS Stock No.: 176-3942 | Brand: RS PRO



Available to back order when stock is available

−

500

+

Units

Back order

Price Each (In a Box of 50)
£1.139
(exc. VAT)

Units Per unit

[View all Heatsinks](#)

Specifications

Attribute	Value
Length	46.4mm
Width	46.4mm
Height	33.3mm
Dimensions	46.4 x 46.4 x 33.3mm
Thermal Resistance	2 (Forced) °C/W, 2 (Natural) °C/W
Mounting	Bolt On, Horizontal, Vertical
Colour	Black
Series	RS AW294
Material	Aluminium
Package Type	TO-3
Finish	Black Anodized

A good choice.

Figure 6: Heatsink used

The reasoning for choosing this style of heatsink is because it is identical to the TO-3 package. The heatsink will be contained inside the electrical panel along with the transformer and other components. As previously calculated the heatsink features a thermal resistance of 2.135 degrees C/W without forced air flow, less than the required 2.135 degrees C/W when fixed with an insulator and heatsink compound.

3.5. Enclosure and Physical constraints

The processing machine in which the supply cable will be run to offers lots of space to work with in its environment and in the control panel. As previously mentioned, the supply used will be 240VAC and will be run directly through a circuit breaker to protect the circuit. Seeming like the supply is already inside an enclosure and stepped down to a 24VDC supply inside there's no need for further containment. The area is exposed to excessive amounts of powder which used for creating the product mixture run through the machine, thus it is necessary to have precautions in place for this. The distribution panel does have an extraction unit which allows only clean air to be circulated throughout however it may be useful to enclose the supply inside an Ex-d and Ex-tb enclosure for added protection.

An example of an ideal enclosure can be seen below by figure 11.

IP65 Polycarbonate Modular Enclosure with Transparent Door and DIN Rail - 182x180x110mm - 542-408

Manufacturer: SPELSBERG

Manufacturer Part No: 542-408

Order Code: EN83970

Also Known As: GTIN UPC EAN: 4013902140084

Technical Datasheet: [542-408 Datasheet](#)

Price: £29.75 (£35.70 Inc. VAT)

Quantity	Price
1+	£29.75 (£35.70)
3+	£28.40 (£34.08)

Product Overview

- UL listed
- Polycarbonate base & cover
- Integral seals
- Dust and moisture proof
- IP65 rated
- Corrosion and maintenance-free

Figure 7: Correctly rated enclosure used for housing supply

The enclosure has been selected because it is capable of being DIN rail mounted, it's compact, it allows space for more than just 1 circuit breaker to be added in case of future modifications or additions, it is compact enough as an enclosure to fit inside the main distribution panel and it is rated to IP65.

YOU HAVEN'T SOURCED THE TRANSFORMER,
RECTIFIER OR CAPACITOR.

4. Testing, results, and analysis

From all the information gathered previously it can now be compiled into a multisim circuit shown below by figure 12.

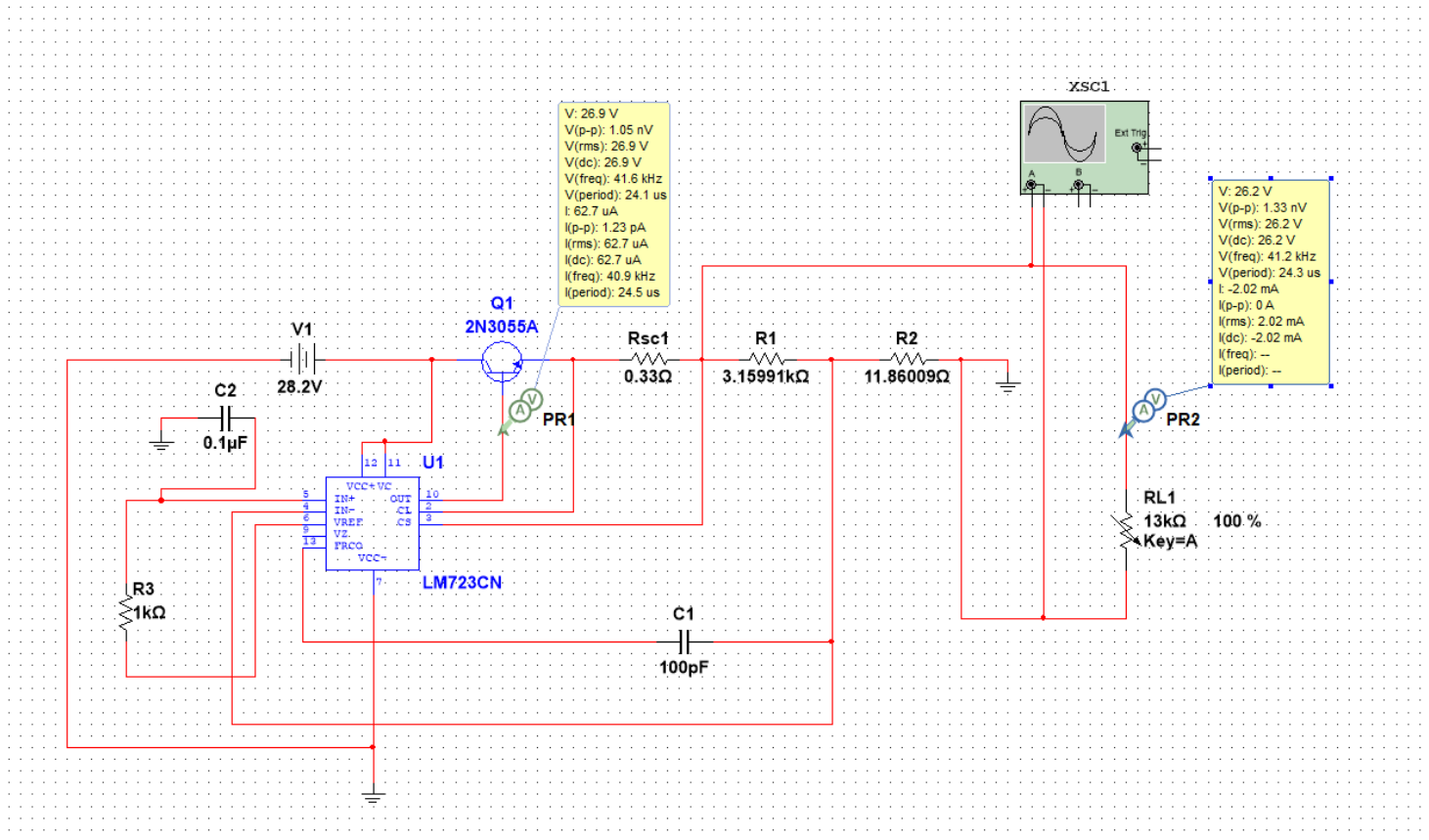


Figure 8: Regulator circuit

There have been minor changes to the circuit since further calculations have been recorded. The output provided a voltage of 26.2V. Resistor values for R1 & R2 have been selected to show 3.2k ohms & 11.9k ohms.

The data tips which have been attached above show a current value of 2.02Amps.

	A	B	C
1			
2			
3	Percentage	Voltage (V)	Current (A)
4	0	0.000133117	1.024
5	5	0.665405	1.024
6	10	1.33	1.023
7	15	1.995	1.023
8	20	2.659	1.023
9	25	3.323	1.023
10	30	3.987	1.022
11	35	4.65	1.022
12	40	5.313	1.022
13	45	5.975	1.021
14	50	6.637	1.021
15	55	7.299	1.021
16	60	7.96	1.021
17	65	8.621	1.02
18	70	9.282	1.02
19	75	9.942	1.02
20	80	10.602	1.019
21	85	11.261	1.019
22	90	11.856	1.013
23	95	11.989	0.00970787
24	100	12.051	0.00927031
25			
26			

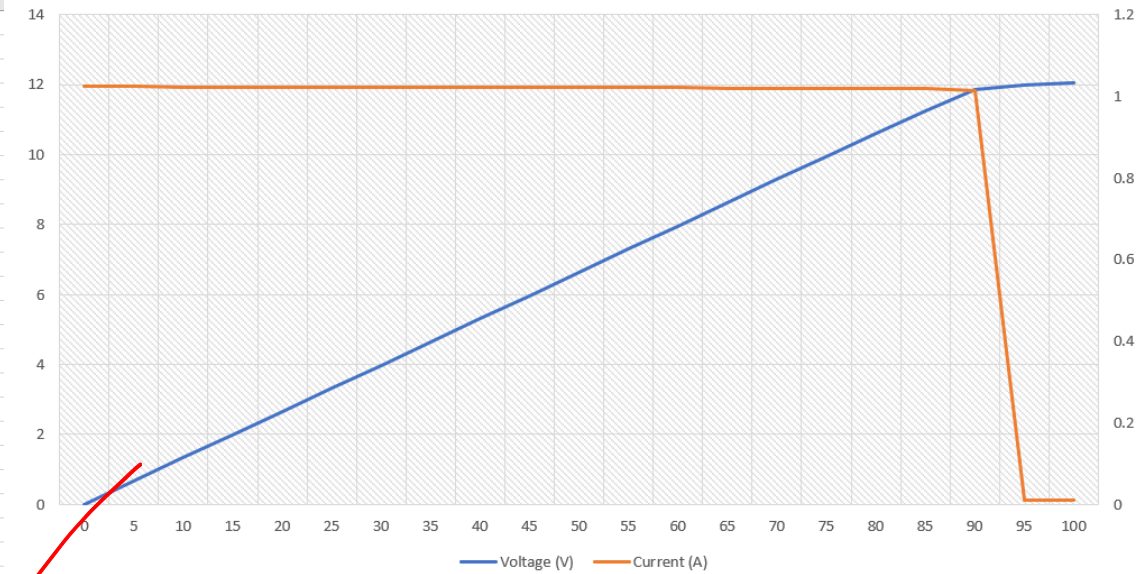


Figure 9: Current against Voltage under a variable resistance of 13k ohms (0 – 100)

The graph above illustrated by figure 13 shows the trend of both Current & Voltage under a varying resistor set at 13K ohms whilst being adjusted upwards from a percentage of 0 to 100.

The results from the graph show that the voltage starts off at the lowest value whereas the current is at its maximum value when the resistor is at 0%. Quickly, the voltage trend almost reaches its maximum value at around 85% of the variable resistor being adjusted whilst the Current value is still more or less the same as what it was at 0%. Coincidentally it's noticeable that once the Voltage value surpasses the Current value the Voltage begins to level out or Plato, whereas the Current value immediately drops once the Voltage is higher. The Current value rapidly decreases until it reaches almost 0Amps by which point the maximum value of 13K ohms is across the resistor.

The graph shows that the results are successful as both the Current and Voltage readings are close to that of the values displayed on the multisim circuit previously.

Moving forward from the graph and the regulator circuit once happy with the values from the data tips, the regulator circuit could then be combined with an additional transformer to represent the 240VAC being stepped down to the DC voltage feeding the regulator circuit. Figure 14 shows the regulator with the additional transformer attached.

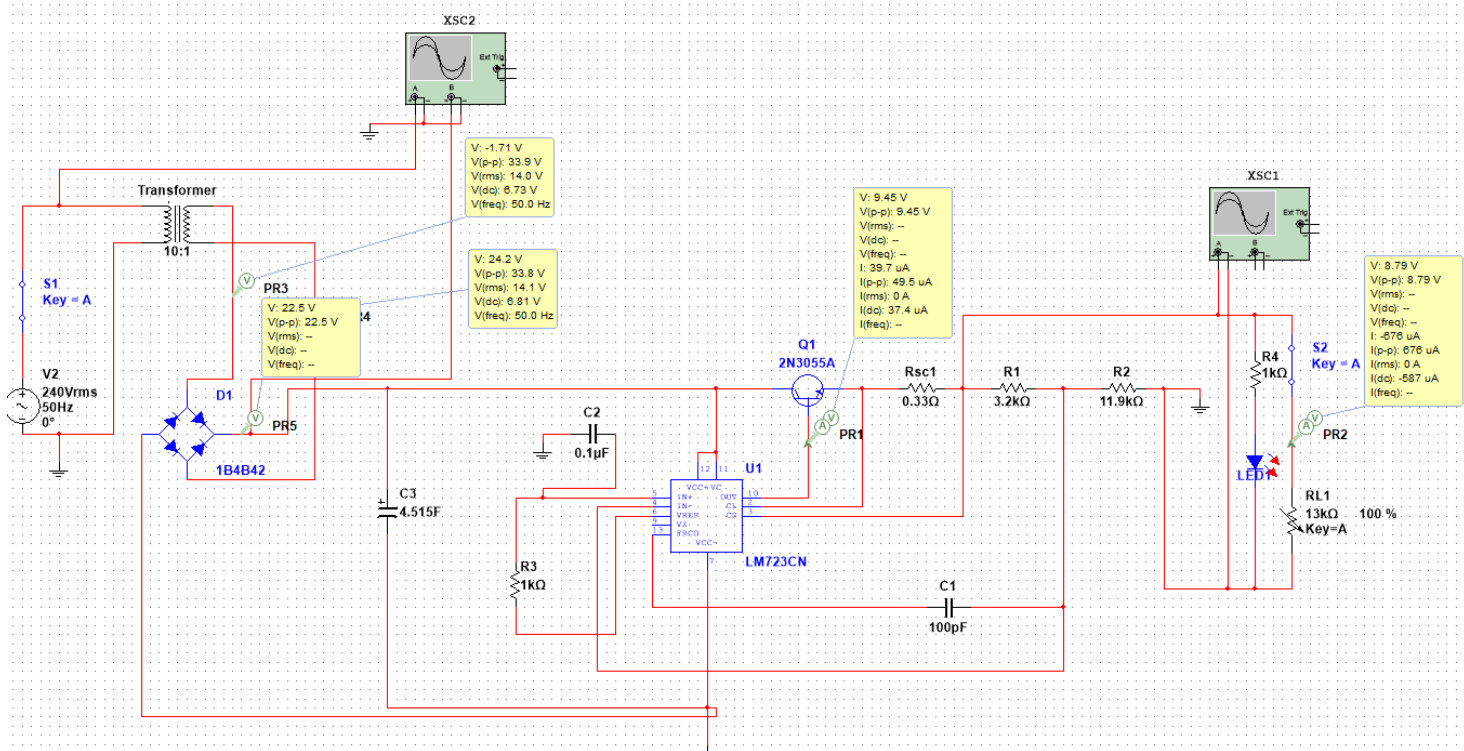


Figure 10: Regulator circuit with combined transformer circuit

Figure 14 above shows the completed regulator circuit which integrates a transformer circuit which consists of a main 240VAC supply with a transformer that has a stepdown ratio of 10:1 and a bridge rectifier on the outgoing side which in-turn supply's the rectifier circuit. Data tips have been used in the circuit to identify the Voltages and Currents at different parts of the circuits.

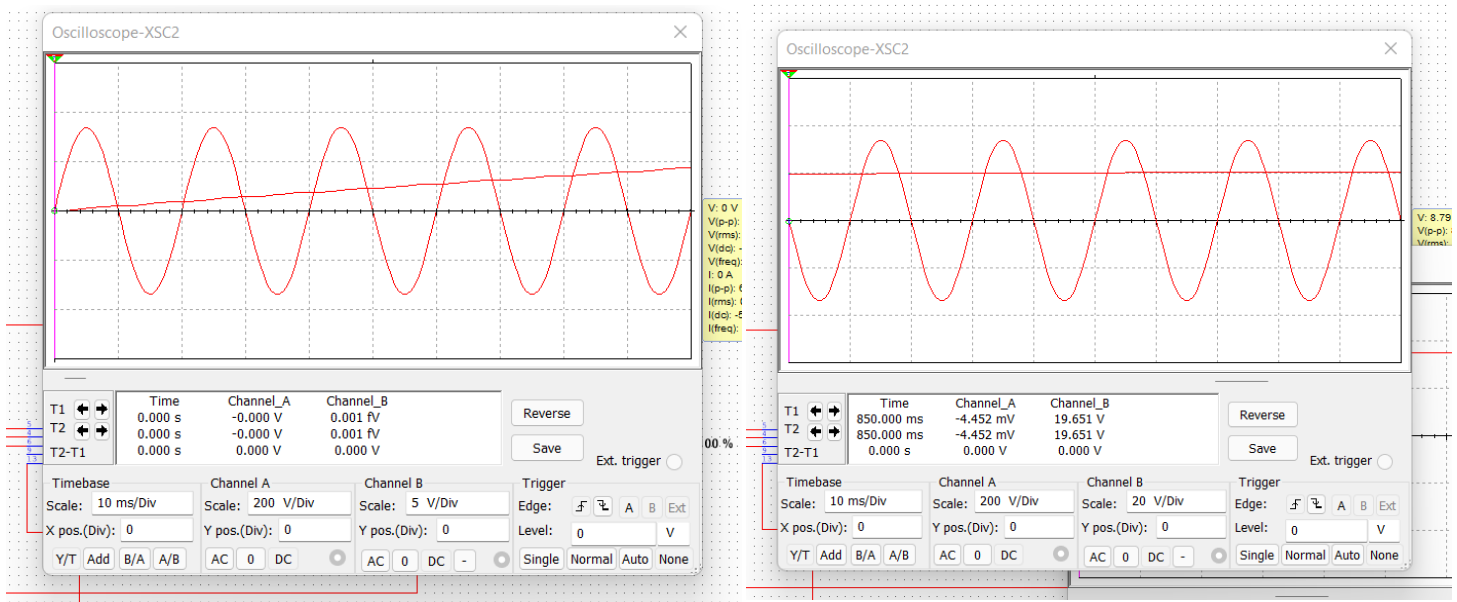


Figure 11: Oscilloscope wave readings of voltage

5. Conclusions

The complete circuit which includes the rectifier combined with the transformer circuit has been designed in-line with the specification. Throughout the designing process the values were monitored closely to ensure they were some what close to the calculated and simulated values for the circuit, there is margin for discrepancies. The Voltage regulator MC1723C was used for the process which offered a lot of datasheets and circuit diagrams as guidance. The NPN Current Boost Connection was utilised throughout construction of the circuit building process. Resistor values were quickly determined for the circuit and voltage readings were recorded to ensure accuracy.

The design has been constructed with health & safety requirements in mind. The design of the circuit includes a fuse built into the AC side, the chip on the outgoing side of the transformer has a current limiter which also regulates over voltage which could have the potential to damage components within the circuit. A bleed LED has been placed on the final compiled circuit which allows the circuit to de-energise once switched off.

To protect the micro chip a transistor has been included which sinks the full load current, it does this by bypassing the chip to protect it from high currents.

Although it is an essential step to reduce the current it also costs a lot to do in the sense that a lot of heat is generated throughout the process, thus a heatsink has been designed based off calculations to reduce and disperse the amount of heat that is given off. The heatsink chosen was chosen from RS components and has compact enough to be mounted to the board. As an improvement a more expensive heatsink could be bought as an alternative which would reduce the wear and tear on the components.

Due to the environment in which the power supply would be placed thought had to be carried out into the placement. The supply would be run from the electrical panel of the machine in which a sperate enclosure would be placed to protect the circuitry. The enclosure was selected from the environment, considerations were made into the mixture in which lots of powder heat and liquid would be given off.

A smoothing capacitor was placed into the circuit with a value of 4700 Farads, which would improve the quality of the DC signal significantly.

SOME VALID CONCLUSIONS.

YOU STILL NEED A CITATION LIST FOR YOUR SOURCES.

FINAL GRADE

GENERAL COMMENTS

Instructor

57 /100

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GRADING FORM: CSG-RUBIC

MASON MORGAN**57****RESEARCH-INFORMED LITERATURE**

There was little evidence of further reading and research and there was no reference list nor was there evidence of any in-text referencing.

1**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.

18**ANALYSIS**



Your explanation of the design process was good and the conclusions showed that you can interpret quantitative and qualitative data, although this was often descriptive. You could have evaluated the results and specified whether they concurred with theory suggesting reasons for any discrepancies. You have however demonstrated good analytical skills and your approach to the task was logical. Arguments made in the conclusions were mostly valid and demonstrated a good understanding of the topic. Further work – in your conclusion, you should relate the results to the original specification and to accepted theory.

16

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally adequate. 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 a basic circuit that functioned within the specification and achieved this by only asking for assistance when appropriate thus demonstrating some basic problem solving skills. Your results were adequate and allowed for a reasonable conclusion to be attempted.

15

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

7

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.