

1602836

by Daniel Ince

FILE	14401_DANIEL_INCE_1602836_174908_1801428297.PDF (1.65M)		
TIME SUBMITTED	06-FEB-2020 06:47PM (UTC+0000)	WORD COUNT	3870
SUBMISSION ID	119704044	CHARACTER COUNT	22572

Course: BSc Electrical & Electronic Engineering

Module: Electronic Design SGEE6000

Assignment: Regulated Power Supplies

Name: Daniel Ince

University number: 1602836

Date submitted: 06/02/2020

Word count: 3000

Table of Contents

1. Executive summary	4
2. Design specification	5
3. Design method choices and calculations	6
Regulator circuit.....	6
Regulator calculations.....	8
Input stage design.....	9
Heatsink and thermal management	13
Enclosure and physical constraints	15
4. Analysis and results.....	17
5. Conclusion.....	22
Works Cited	23
Appendix.....	25

Figure 1: LM723CN diagram (Weister, 2017).....	6
Figure 2: Regulator circuit.....	7
Figure 3: Typical NPN current boost layout (Motorola, 2020)	7
Figure 4: Schade curve RMS ripple voltage for capacitor input circuits. (ON Semiconductor, 2002)	9
Figure 5: Relationship of applied AC peak voltage to DC peak voltage for full wave rectifier. (ON Semiconductor, 2002).....	10
Figure 6: RMS and peak-to-average diode current relationship. (ON Semiconductor, 2002)	11
Figure 7: Transformer spec. (RS Components, 2020).....	12
Figure 8: 2N3055 datasheet. (ON Semiconductor, 2005)	13
Figure 9: Heatsink case table. (ON Semiconductor, 2002)	13
Figure 10: 2N3055 datasheet (ON Semiconductor, 2005)	14
Figure 11: TO-3 Heatsink (RS Components, 2020)	14
Figure 12: GUB Pepperl-fuchs Ex d IIC enclosure (Pepperl-fuchs, 2020).....	15
Figure 13: Components list	16
Figure 14: Updated regulator circuit	17
Figure 15: Voltage vs current for a given load.	18
Figure 16: Multisim full power supply design.	19
Figure 17: Front end circuit test.....	19
Figure 18: Capacitor charge up.	20
Figure 19: LED voltage bleed test.....	20
Figure 20: No bleed LED test.....	21
Figure 21: MC1723C datasheet (Motorola, 2020).....	25
Figure 22:IP reference table (RS Components, 2020)	26
Figure 23: Ex d enclosure datasheet (Pepperl-fuchs, 2020)	27
Figure 24: LED datasheet (Kingbright, 2020).....	28
Figure 25: Transformer datasheet (SolaHD, n.d.).....	29
Figure 26: Capacitor datasheet (RS Components, 2020).....	30

1. Executive summary

A power supply has been designed to match a specification provided by a customer. The design of this supply was carried out with a bottom-up approach in order to back design components to meet the specification. The supply was designed and fine-tuned to meet the criteria and suitable component parts were located for use. This included evaluating thermal management of the transistor used for current boosting and selecting an appropriate heatsink. All components were rated for correct power, voltage, current and environment. The supply was then tested in each of its constituent parts to check the performance against the spec. The optimum load was found where the supply meets the peak voltage and current and overall conclusions drawn about the design.

Brief executive summary for this level, should cover all sections and give a flavour of the entire report.

2. Design specification

A power supply will be designed to meet a desired specification, the criteria has been selected based on the product application. In this case the power supply is to be used to provide 24V supply to machinery diagnostic instruments on a compressor. The supply itself will be mounted in the field and will need to be suitable for use in a hazardous area.

V_{AC} Input	240V
Input Frequency	50Hz
V_{DC} Output	24V
I_{DC} Output	1.8A
Temperature Rating	20 to 30degC
Ingress Protection (IP) Rating	IP65
Component Cost	<£200
Environment	Hazardous area
Enclosure	Ex d

The power supply requires to take an input from a traditional 240V 50Hz AC supply, this will feed into the enclosure through a barrier gland. This supply will have to be switchable and fused for component protection. The 1.8A output will be needed to drive instrument loads that use current as a means of data transmission (4 to 20mA).

The unit will also have to meet certain additional criteria such as environmental as the power supply will be mounted outside next to a compressor and subject to outside elements such as rain. The ingress protection must be IP65 or above to prevent ingress of water as it will not be able to escape the flame path seal on the enclosure and cause corrosion and high humidity. The output is to be 24V DC and the supply will need to be able to function at 20 to 30°C due to the nature of the enclosure and heat generated by components.

Not sure on the environment, I can see "water", but the rest isn't clear.

3. Design method choices and calculations

Regulator circuit

The regulator is the back end of the system, this was designed first to meet the output criteria of the specification. To start, a suitable chip was chosen, in this case the MC1723C chip in NPN transistor boost configuration. The transistor is added to increase the current output and add a boost, the integrated circuit chip is not designed to handle high current, up to approx. 150mA is the maximum.

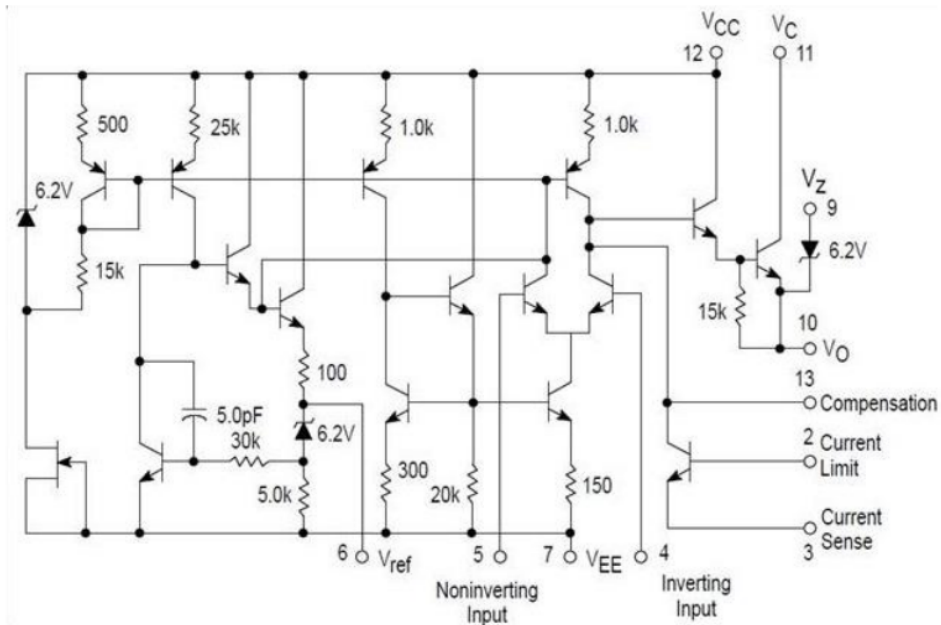


Figure 1: LM723CN diagram (Weister, 2017)

A positive regulator has been designed to produce the positive 24V output, so the VCC- terminal on the chip is grounded and VCC+ (pin 12) is connected to the 240V supply rail and common to pin 11 which supplies the power to the output transistor within the chip. Figure 1 shows a representative diagram for the chip.

The LM723NC features 0° to +70° temperature protection, the environment temperature will vary between 20° and 30°, therefore the chip is suitable.

The current limiting feature monitors the voltage drop across R_{sc} as this increases proportionally to the output current. If the drop exceeds 0.66V the transistor does not further conduct due to this matching the base-emitter on signal, holding the current at that point. This is useful to protect the instrumentation on the power supply from excess current. Adjusting the value for R_{sc} alters the current limit, the default value is 0.33Ω and reducing this value will increase the current allowed. Over voltage protection could be added through use of a Zener diode voltage clamp to protect the IC, provided the built-in protection is not sufficient.

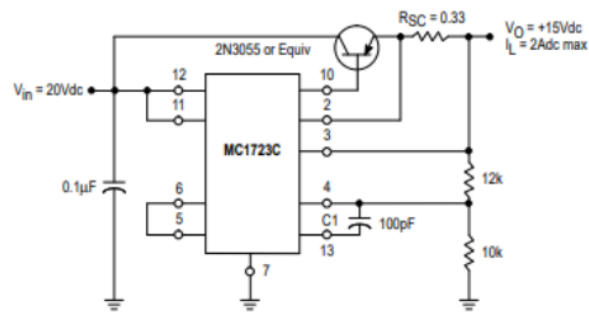


Figure 3: Typical NPN current boost layout (Motorola, 2020)

A generic layout for the MC1723C chip when in current boost format is shown in figure 2, the regulator was built in a similar configuration.

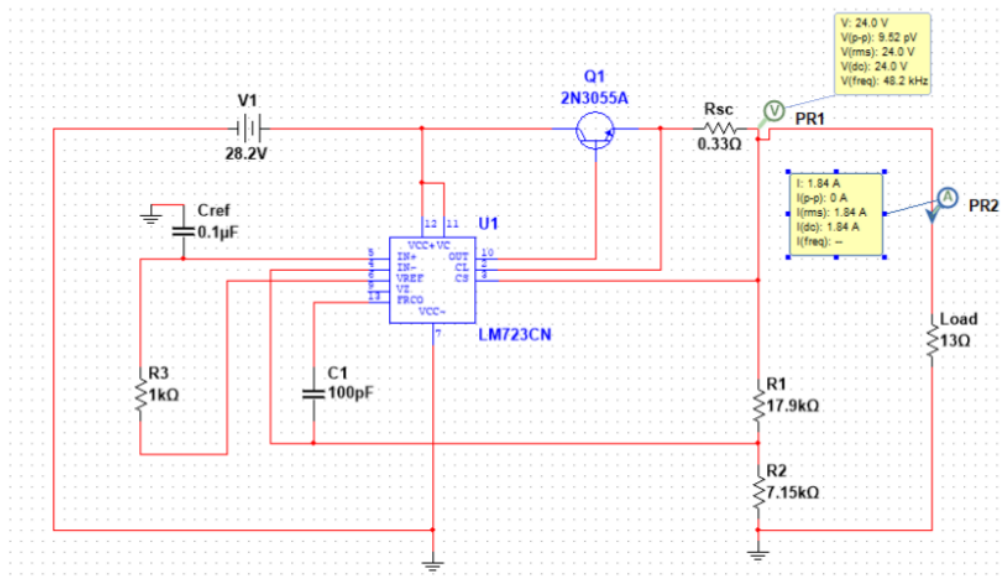


Figure 2: Regulator circuit

As this is intended to be built, more preferred values for resistors or trimmer pots would aid manufacture and set-up.

Using the datasheet configuration as a guide, the circuit in figure 3 was implemented in MultiSim and component values determined through calculations.

Regulator calculations

The component values were calculated and then fine-tuned to achieve optimum performance of the regulator.

For low noise, C_{ref} common to pins 6 and 5 was set to $0.1\mu F$.

As the output on pin 10 and 4 is determined by $R1$ and $R2$ acting as a potentiometer, these values must be balanced.

The sum of $R1 + R2$ is to be $25k\Omega$.

$$R2 = \frac{V_{ref}}{V_{out}} (R1 + R2) \rightarrow \frac{7.0}{24} (25k) \rightarrow 0.29(25k) = 7291.6\Omega$$

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

$$R1 = 25k - 7291.6 = 17.7k\Omega$$

The base-emitter junction (pins 2 and 3) voltage drop is divided by the sensing current. $R_{SC} = \frac{0.60}{1.8} = 0.33\Omega$

Calculated with these in parallel $R3 = R1 || R2 \cong 5.17k\Omega$

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

$$V_{in} \geq 24 + (2 \times 0.6) + 3 = 28.2V$$

Input stage design

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.

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

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.

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

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

$$rf = \frac{V_{\text{ripple}(p-p)}}{2\sqrt{2}V_c} \times 100 \rightarrow \frac{2.5}{2\sqrt{2} \times 28.2} = 0.0313 \times 100 = 3.134\%$$

This rf value was found on the Schade curve for RMS ripple voltage in figure 4 to obtain ωCR_L .

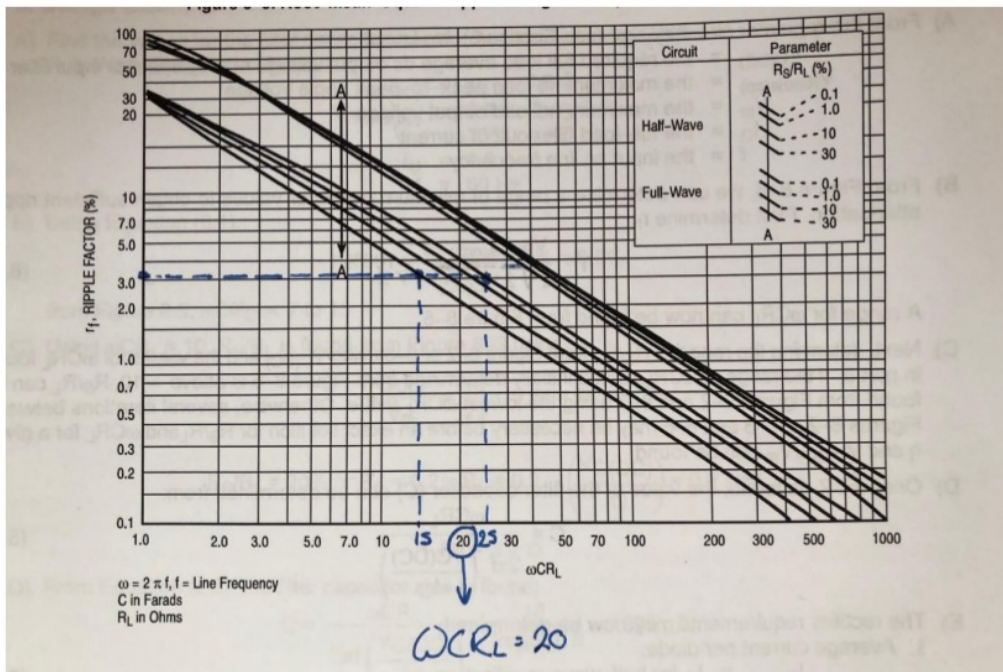


Figure 4: Schade curve RMS ripple voltage for capacitor input circuits. (ON Semiconductor, 2002)

As this is a full wave rectifier, the range between the curves is selected as 15 and 25 at approximately 3.124% ripple factor. Hence the average value of 20 is taken for ωCR_L or.

ωCR_L of 20 is then used in figure 5 schade curve to find R_s/R_L .

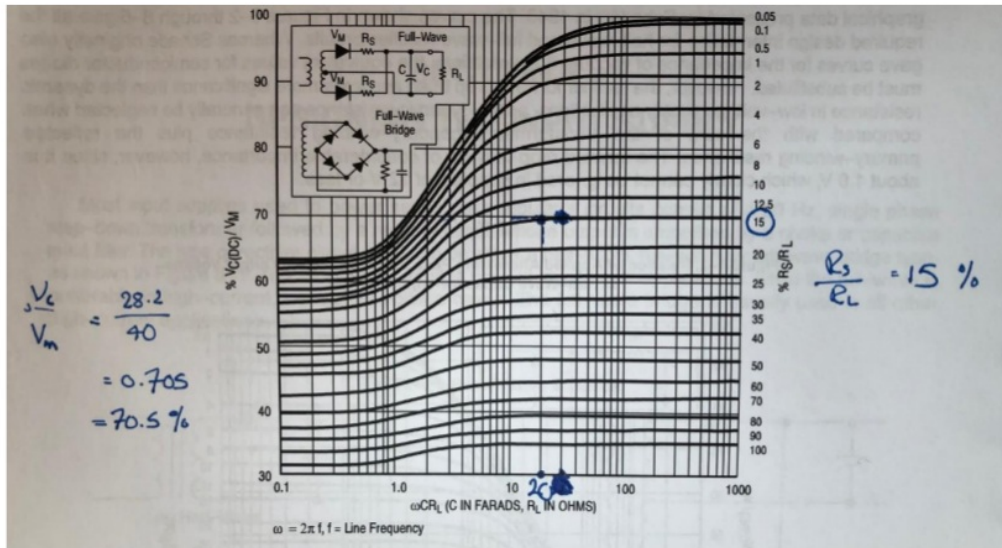


Figure 5: Relationship of applied AC peak voltage to DC peak voltage for full wave rectifier. (ON Semiconductor, 2002)

Here $\frac{V_c}{V_m} \rightarrow \frac{28.2}{40} = 0.705 \rightarrow 70.5\%$ is used to find the correct curve when matched with $20 \omega CR_L$.

R_s/R_L was found to be 15% (0.15).

Now $C = \frac{\omega CR_L}{2\pi f \left(\frac{V_c}{I_o}\right)} \rightarrow \frac{20}{2\pi \times 50 \left(\frac{28.2}{2.0}\right)} = 4.515mF$ for the filter capacitor.

$R_s = 0.15 \times R_L$ therefore $R_s = 0.15 \times \left(\frac{28.2}{2.0}\right) = 2.115\Omega$ and $R_L = 14.1\Omega$

Again, a preferred value would have reduced manufacturing costs

For the full wave rectifier, the average current I_{avg} is half the output current so 1.0A. As it is a full wave, ωCR_L is doubled. $20 \times 2 = 40$.

Figure 6 was used to determine $I_{F RMS} = 2.3$ and $I_{F Peak} = 5.3 \times I_{avg} = 5.3A$

$I_{surge} = \frac{V_m}{R_s + ESR} \rightarrow \frac{40}{2.115} = 18.9A$ In this calculation ESR is negligible and is left out.

Peak Inverse Voltage, $PIV = V_m \times 2 \rightarrow 40 \times 2 = 80$ (for safety factor)

The chosen bridge rectifier is the Comchip CDBHD2100-G, this can take a PIV of 100V and a surge current of 50A.

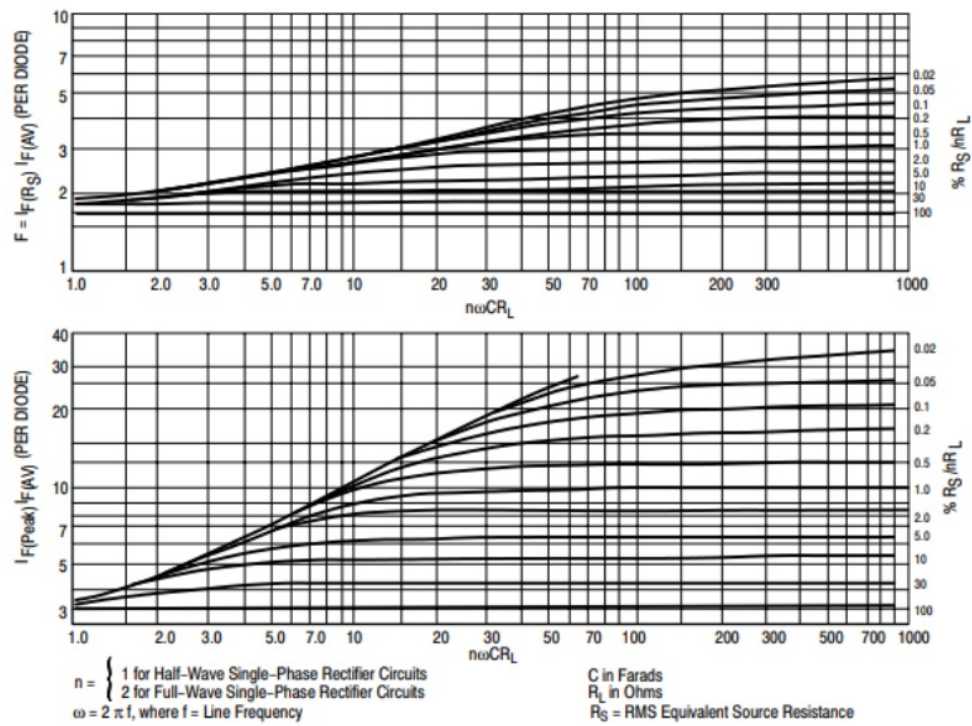


Figure 6: RMS and peak-to-average diode current relationship. (ON Semiconductor, 2002)

Values will now be calculated for the transformer.

$$V_s = \frac{V_m + 2}{\sqrt{2}} \rightarrow \frac{40 + 2}{\sqrt{2}} = 29.7 \text{ Vrms}$$

$$\text{Ratio} = \frac{V_{in}}{V_s} \rightarrow \frac{240}{29.7} = 8.08:1$$

$$\text{VA rating} = 2 \times V_s \times I_{rms} \rightarrow 2 \times 29.7 \times 2.3 = 136.62 \text{ VA}$$

A 240VAC to 24VAC DIN rail mounted transformer has been selected, supplied by RS components, the data sheet can be found in the appendix.

Attribute	Value
Primary Voltage Rating	120V ac, 240V ac
Secondary Voltage Rating	24V ac
Power Rating	200VA
Mounting Type	Panel
Dimensions	114.3 x 121.7 x 98.8mm
Maximum Operating Frequency	60Hz

Figure 7: Transformer spec. (RS Components, 2020)

The transformer is rated for 200VA which is higher than the specification of 136.62VA. As the load instrumentation will only be requiring a few milliamps, this is adequate. This transformer is encapsulated with epoxy resin and has deep moulded terminals to reduce the chance of stray wires shorting out. This also acts as a safety feature to prevent people from easily being able to touch the terminals.

Heatsink and thermal management

The performance of a heatsink depends on multiple factors. The typical equation for a heatsink is

$$\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA} \text{ where J = Junction, C = Case, S = Heatsink and A = Atmosphere.}$$

As a transistor is to be used for boosting the current, this will generate a large amount of heat and require a heatsink to effectively cool the component. The transistor chosen to be used is the 2N3055 NPN.

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction-to-Case	$R_{\theta JC}$	1.52	$^{\circ}\text{C/W}$

Figure 8: 2N3055 datasheet. (ON Semiconductor, 2005)

As taken from the datasheet shown in figure 7, the thermal resistance for JC is 1.52.

Case	θ_{CS}			
	Metal-to-Metal*		Using an Insulator*	
	Dry	With Heatsink Compound	With Heatsink Compound	Type
TO-204	0.5 $^{\circ}\text{C/W}$	0.1 $^{\circ}\text{C/W}$	0.36 $^{\circ}\text{C/W}$ 0.28 $^{\circ}\text{C/W}$	3 mil MICA Anodized Aluminum
TO-220	1.2 $^{\circ}\text{C/W}$	1.0 $^{\circ}\text{C/W}$	1.6 $^{\circ}\text{C/W}$	2 mil MICA

*Typical values; heatsink surface should be free of oxidation, paint, and anodization

Figure 9: Heatsink case table. (ON Semiconductor, 2002)

Figure 8 shows that with using heatsink compound and an insulator for a TO-204 case, $\theta_{CS} = 0.36$.

Using $T_J = T_A + P_D \theta_{JA}$ to rearrange and become $\theta_{JA} = \frac{T_J - T_A}{P_D}$, this equation can be substituted into

$$\text{the original to become } \theta_{SA} = \frac{T_J - T_A}{P_D} - \theta_{CS} - \theta_{JC}$$

T_A = Ambient temperature and P_D = Power dissipated, can be taken from the specification to determine the performance of the heatsink and how hot the sink will get.

For this application, the power will be $P_D = (24V \times 1.8A) = 43.2W$

Now, $\theta_{JA} = \frac{T_J - T_A}{P_D} \rightarrow \frac{200 - 30}{43.2} = 3.935$ and $\theta_{SA} = 3.935 - 0.28 - 1.52 = 2.135^{\circ}\text{C/W}$ So therefore a heatsink with a thermal resistance below this will be required.

A 2N3055G NPN transistor by ON Semiconductor has been chosen for use, supplied by RS Components, the package style is TO-204AA.

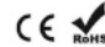
MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	60	Vdc
Collector-Emitter Voltage	V_{CER}	70	Vdc
Collector-Base Voltage	V_{CB}	100	Vdc
Emitter-Base Voltage	V_{EB}	7	Vdc
Collector Current - Continuous	I_C	15	Adc
Base Current	I_B	7	Adc
Total Power Dissipation @ $T_C = 25^\circ\text{C}$ Derate Above 25°C	P_D	115 0.657	W W/ $^\circ\text{C}$
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +200	$^\circ\text{C}$

Figure 10: 2N3055 datasheet (ON Semiconductor, 2005)

The case style is identical to that of a TO-3 package, therefore can be used with a heatsink of this style.

Datasheet Stock No: 1764162 RS Pro Heatsink TO-3



Type: Board Level, Vertical
Package Cooled: TO-3
Attachment: Bolt On
Shape: Rectangular, Fins
Length: 47.2mm
Width: 47.2mm
Height of Fins: 33.3mm
Power Dissipation @ Temperature Rise: 7.5W @ 44°C
Thermal Resistance Forced Air Flow: 2.0°C/W @ 400LFM
Thermal Resistance Natural: 2.0°C/W
Material: Aluminium
Finish: Black Anodise



Figure 11: TO-3 Heatsink (RS Components, 2020)

The selected heatsink shown in figure 11 costs £1.084 in a pack of five and the cost reduces for larger pack purchases, making this suitable for large volume applications. The heatsink features a thermal resistance of 2.0°C/W without forced air flow, less than the required 2.135°C/W when fixed with an insulator and heatsink compound. The power supply will be situated inside an enclosure where there will be limited air flow.

This means that with this heatsink, the junction temperature will reach $43.2 \times (2.0 + 0.28 + 1.52) = 164.16^\circ\text{C}$ above ambient, Therefore at maximum 30°C ambient temperature, it will reach 194.16°C , which is below the datasheet value.

Enclosure and physical constraints

The power supply designed is to be mounted within a hazardous area next to a compressor. The input to this supply is 240V and does not feature an energy limiting barrier. The enclosure will therefore need to be an 'Ex d' Explosion proof ATEX certificated enclosure. Stated on the website *Enclosures (Ex d)*, "The explosion protection types **Ex d and Ex tb** allow the use of instrumentation not designed for dangerous environments in gas or dust explosion hazardous areas as well as in harsh or corrosive atmospheres." (Pepperl-fuchs, 2020)

Control Panels (Ex d IIC) in Aluminum		GUB*
Technical Data		
Electrical specifications		
Operating voltage	1000 V DC / 1500 V AC max.	
Operating current	recommended: 1600 A max.	
Mechanical specifications		
Dimensions	see data tables values might differ slightly due to casting and manufacturing tolerances	
Thread type	metric ISO pitch 1.5 mm or NPT ANSI ASME B1.20.1	
Enclosure cover	threaded round cover	
Cover fixing	flamepath thread	
Cover seal	none, O-ring for IP66/67	
Degree of protection	IP66 (IP66/67 with O-ring)	

Figure 12: GUB Pepperl-fuchs Ex d IIC enclosure (Pepperl-fuchs, 2020)

The Pepperl-fuchs GUB enclosure has been chosen to house the power supply. The specification input/output is well below the maximum rated voltage and current. As the material is aluminium it is lighter than an equivalent steel enclosure and so better for mounting on a compressor. This enclosure is rated Ex d and can be used in gas group IIC environments, giving it the highest gas group rating. The ingress protection rating of the enclosure is IP66, meaning it will protect against ingress of dust and strong water jetting in all direction, (see IP reference table in appendix). This is suitably protected against agitated dust and rain when being mounted on a high vibration compressor outside in a hazardous area.

Whilst also providing indication the LED connected across the output acts as a voltage bleed when the supply is switched off with no load. The LED selected is an L-53HD, with a maximum volt drop of 2.5V and forward current of 20mA taken from the datasheet in the appendix. This is connected across the output in series with a resistor bring the current to the rated level. In this case $Resistor = \frac{V_S - V_{LED}}{I_{LED}} \rightarrow \frac{24 - 2.5}{0.02} = 1075\Omega$, so a 1k Ω . This LED will allow the large capacitor to discharge if the load is disconnected, acting as component protection and safety.

Resistors were chosen from RS components to make up the correct resistance for the circuit, through hole types were chosen for fixing to the circuit board.

The table below in figure 13 displays all components selected.

Component	Supplier	Product code	Details	Manufacturer	Cost
NPN chip	Rich Electronics	OM0020A	MC1723C	Motorola	£5.45
Capacitor	RS	711-1526	4700uF	RS Pro	£3.66 (pack of 2)
Transformer	RS	890-8848	200VA 10:1 Encapsulated	SolaHD	£120.61
Bridge rectifier	RS	906-6712	CDBHD2100-G 2A 100V 4-pin	Comchip Technology	£0.84
Transistor	RS	545-2210	2N3055	ON Semiconductor	£4.54
Heatsink	RS	176-4162	TO-3 2°C/W	RS Pro	£5.42 (pack of 5)
LED	RS	228-5988	L-53HD Red 2.5V	Kingbright	£1.89 (pack of 5)
Resistor1	RS	168-0156	RCH50 series 15k Ω	Vishay	£5.795 (pack of 25)
	RS	845-9949	RCH50 series 3k Ω	Vishay	£3.69
Resistor2	RS	175-4132	Aluminium housed 6.8k Ω 50W	RS Pro	£3.034 (pack of 5)
	RS	162-1010	H550 Series aluminium 360 Ω 50W	ArcoI	£2.254 (pack of 20)
Resistor 3	RS	175-4119	Aluminium housed 1k Ω 50W	Rs Pro	£3.034(pack of 5)
Sensing current resistor	RS	175-4124	Aluminium housed 330m Ω 50W	RS Pro	£3.034 (pack of 5)
Enclosure	Pepperl+fuchs	GUB1	IP66 Ex d IIC enclosure	Pepperl+fuchs	POA
				Total:	£163.25

Figure 13: Components list

You have shown preferred values in the shopping list, but the circuit was tested with ideal values. Would the change have an impact on your results?

4. Analysis and results

The rectifier circuit was first built and tested to analyse the performance of the back end of the power supply, the revised version shown in figure 15.

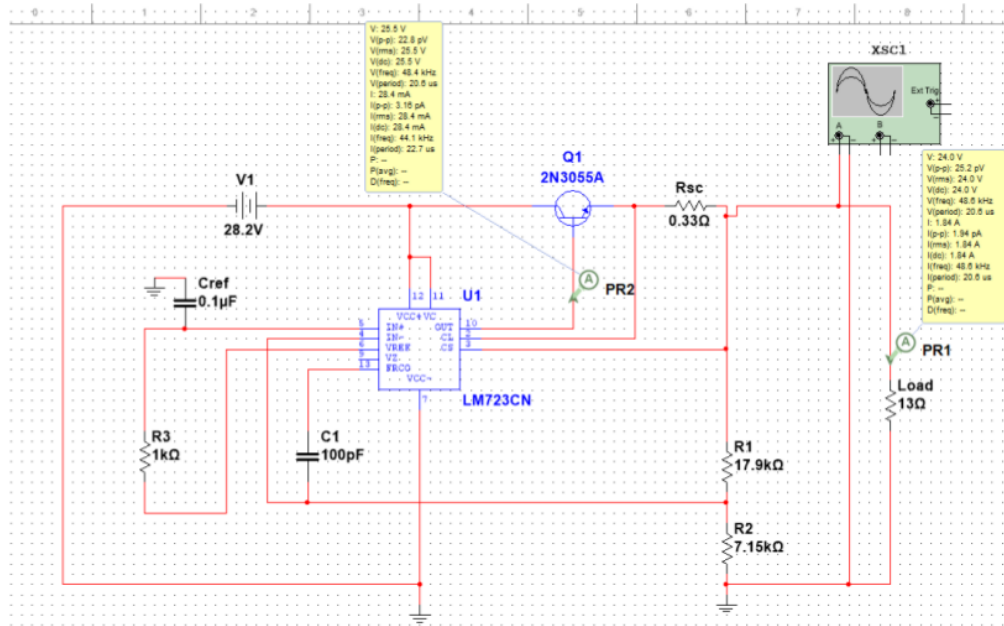


Figure 14: Updated regulator circuit

Initially, building the circuit with the calculated resistor values provided an output of 23.8V, these values were fine-tuned to result with 17.9kΩ and 7.15kΩ and an output of 24V and 1.84A, as shown in the figure. A 28.2V DC voltage source was added to simulate the

Following the design of the voltage regulator circuit on MultiSim, the load resistance was varied to provide a view of the circuit performance across a range of loads. The output voltage and current were compared against the load in figure 15.

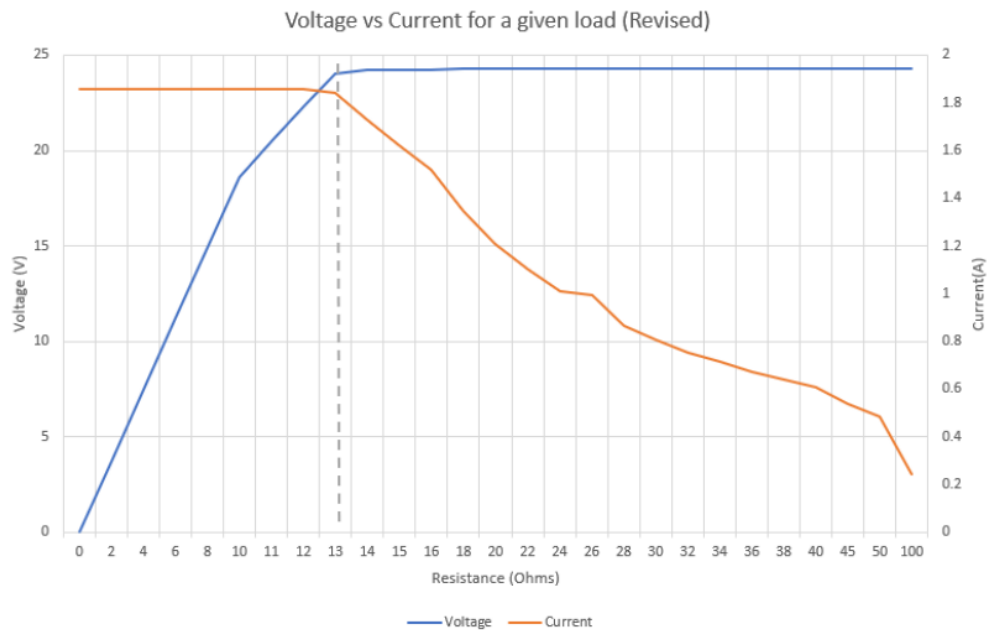


Figure 15: Voltage vs current for a given load.

Looking at the graph, the voltage steadily climbs as the load increases from zero, whereas the current is already at maximum 1.8A until a load of 13.4Ω. It is at this point where 24V output is met and the current remains at 1.8A, this is the point of ideal load and optimum power supply performance. From this point on as the load increases in the logarithmic scale, the current drops off following Ohm's law as the resistance increases and voltage stays constant. This output successfully meets the specification as it outputs enough to consistently drive instrumentation with up to 20mA of current.

The full circuit was designed with all components and compiled on multisim, shown in figure 16. With the simulation it was possible to test the front end of the circuit, such as the transformer, capacitor and rectifier, shown in figure 17. This figure shows how the 240VAC input has been stepped down to a smaller AC signal before being rectified to 31.5V DC. The scope displays how the waveform changes from the AC input to DC.

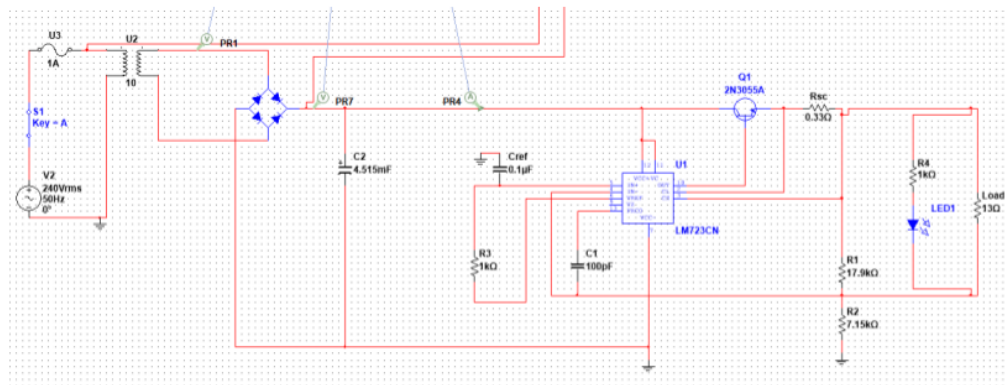


Figure 16: Multisim full power supply design.

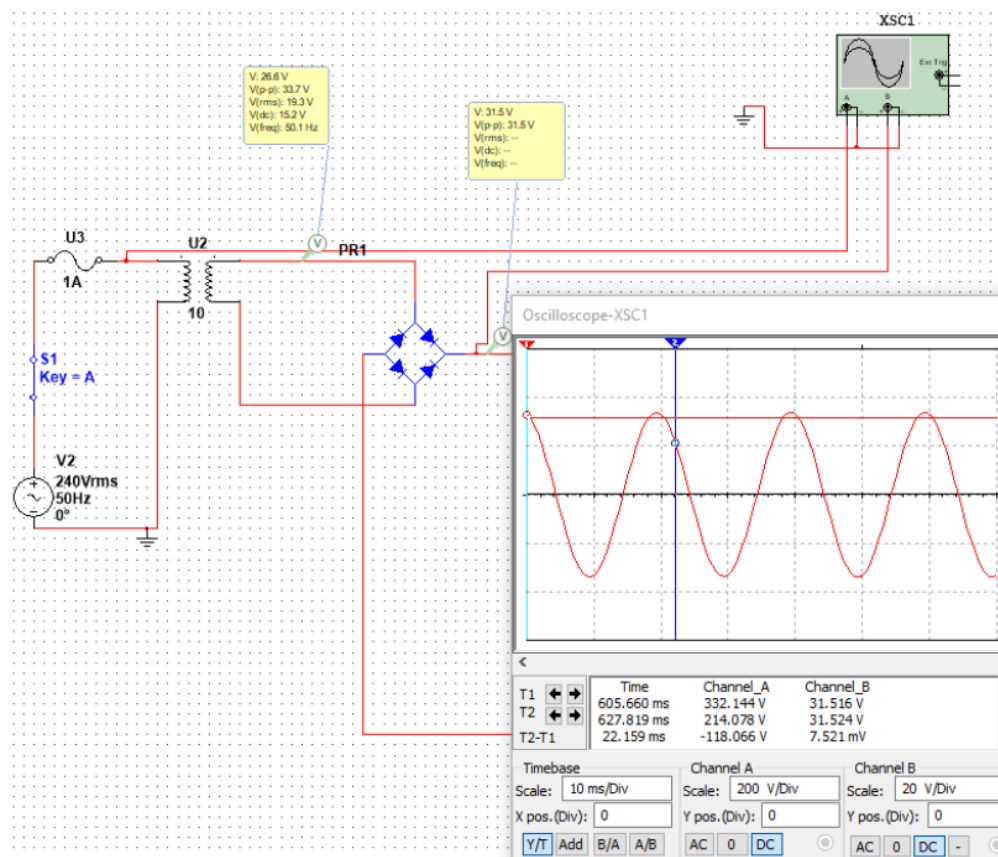


Figure 17: Front end circuit test

Upon initial start of the power supply, the capacitor must charge up, as seen in figure 18.

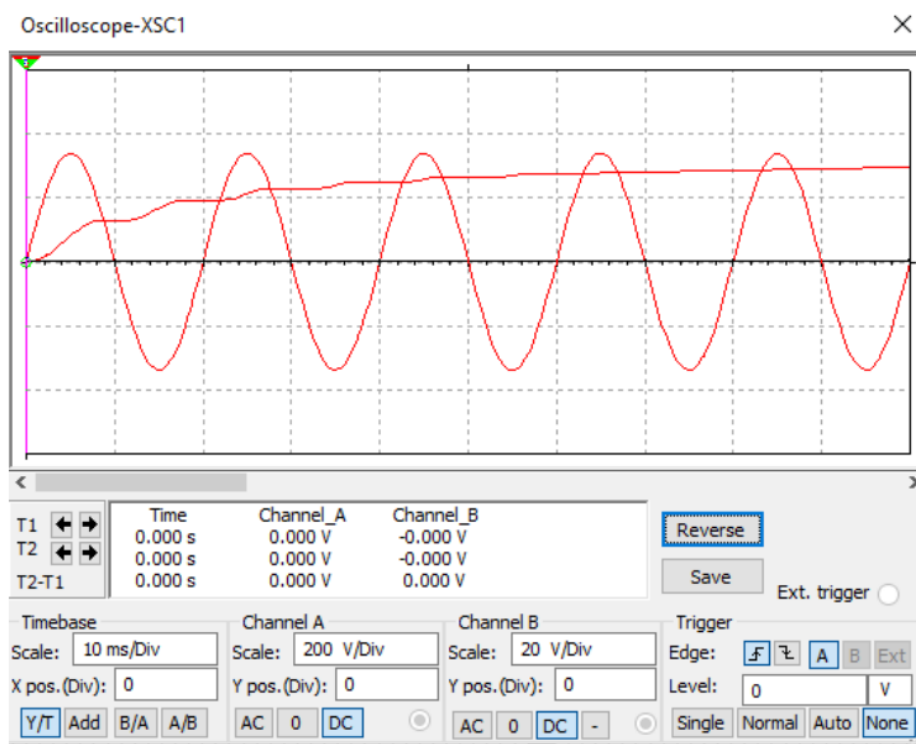


Figure 18: Capacitor charge up.

The ripples can be seen prominent from the bridge rectifier before the capacitor is fully charged and can be seen to decrease and the output stabilise as the charge increases. This is due to the size of the capacitor, if multiple smaller capacitors were used, these ripples would be less prominent and the capacitor would charge faster, providing a more stable supply on initial start-up.

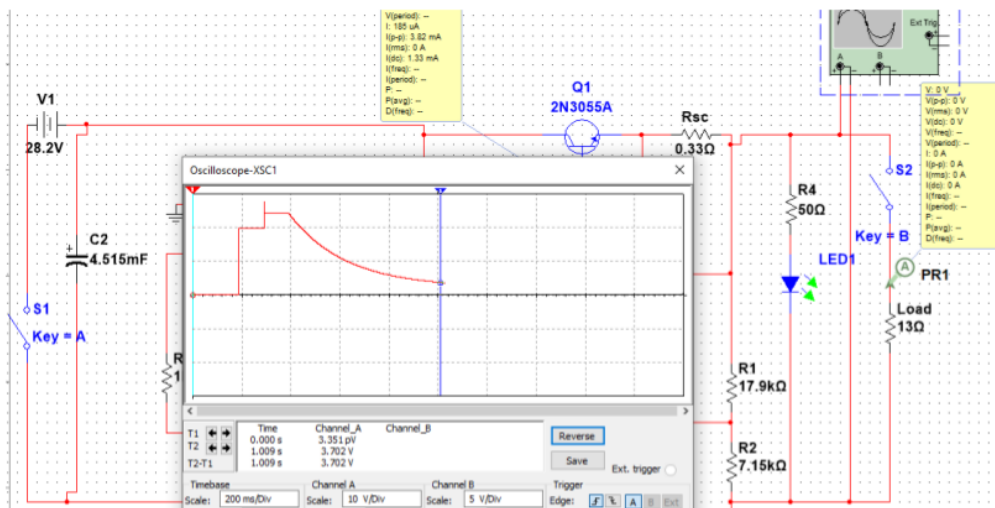


Figure 19: LED voltage bleed test

Figures 19 and 20 display results of a test to check the effectiveness of the bleed LED when the supply was switched off and output disconnected. For the purposes of the simulation, the LED resistor was reduced by a 20-fold decrease to 50Ω , this is to increase the discharge time. As shown, the load removal (indicated by the small peak) and then supply power off triggers the capacitor discharge through the LED. A reference test was performed in figure 20, without the LED, proving that the safety system functioned as intended to prevent charge from being held in the supply.

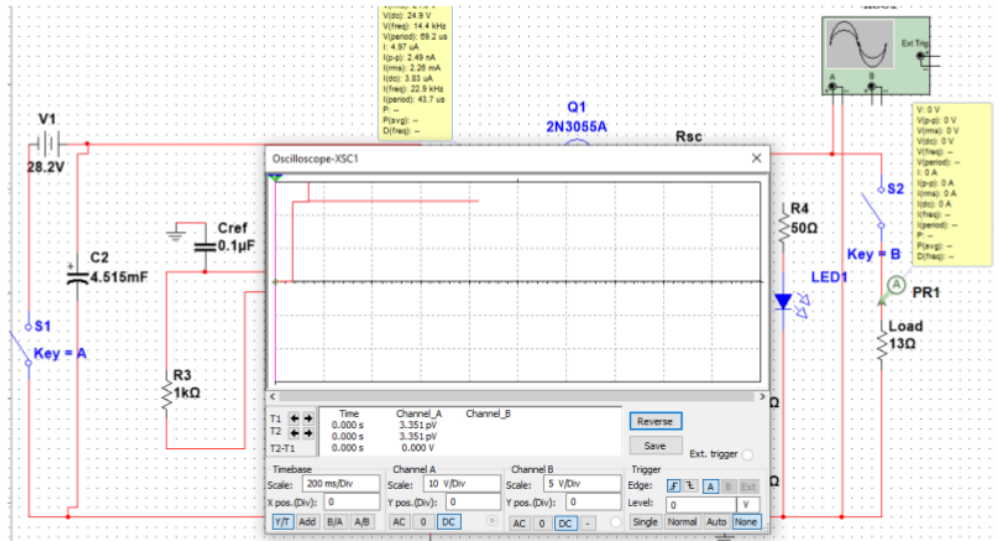


Figure 20: No bleed LED test

Due to issues with the simulation, the whole supply could not be tested at once, however evaluating the test of the input and output ends individually, the supply successfully meets the specification. The IC holds the output at a stable 24V and switches the NPN transistor to output the correct current of 1.8A. This is provided the load across the power supply output is held at 13Ω for optimum performance, higher resistance loads will gradually drop the current but maintain 24V, below the 13Ω threshold the voltage will struggle.

5. Conclusion

The power supply was designed in accordance with the specification, the chosen method was the bottom up approach. Using this method allowed the final output of the supply to be chosen to match the specification, and intermediate values to be calculated based on the output. These are back calculated working through the design back to front until the input values are met. While this allowed a full design to be calculated with the correct output to the specification, it was not fully accurate and required adjustment. This method is a more effective method than top down as it bases the whole design off the output.

The total cost of the supply components is £163.25, not including the enclosure. The main bulk of the cost comes from the transformer, so savings made here will have the greatest effect and smaller components can be bought in bulk to reduce the price. The design has safety and protection features built in on the AC side such as a fuse, whereas the chip itself has current limiting. The bleed LED also allows the supply to de-energise when switched off with no load. Certain components are designed to prevent unwanted contact such as the encapsulated transformer.

The design of the power supply uses a transistor that sinks the full load current and bypasses the chip to protect it from currents greater than 150mA. Whilst this method is good for achieving higher current outputs, it means there is a lot of heat generation from the transistor and the specified heatsink does not provide a large degree of tolerance at the maximum junction temperature. To avoid one component getting too hot, another transistor could be used to share the load, this would mean the power for each semiconductor would be halved, preventing them from getting as hot. To improve reliability and component life, a more expensive heatsink could also be used to reduce operating junction temperatures to a more acceptable level.

The smoothing capacitor is one large 4700uF component, to improve the quality of the DC signal, multiple smaller capacitors could be used, taking up less space. Very small capacitors (e.g. 100nF) could also be added to remove high frequency spikes in the DC signal.

To summarise, the power supply successfully met the specification, the bottom-up approach brought the results within range of the specification and then fine adjustment was needed by analysing the performance of the simulation.

Works Cited

Kingbright, 2020. *Bright red LED datasheet*. [Online]

Available at: <https://docs.rs-online.com/824c/0900766b8151e40a.pdf>

[Accessed 20 January 2020].

Motorola, 2020. *MC1723C Voltage Regulator Datasheet*. [Online]

Available at: <https://datasheet.datasheetarchive.com/originals/distributors/Datasheets-21/DSA-410152.pdf>

[Accessed 05 January 2020].

ON Semiconductor, 2002. *Linear & Switching Voltage Regulator Handbook*. s.l.:s.n.

ON Semiconductor, 2005. *Complementary Silicon Power Transistors 2N3055*. [Online]

Available at: <https://www.onsemi.com/pub/Collateral/2N3055-D.PDF>

[Accessed 05 January 2020].

Pepperl-fuchs, 2020. *Control Panels (Ex d IIC) in Aluminum*. [Online]

Available at: https://files.pepperl-fuchs.com/webcat/navi/productInfo/edb/tmdoc6069e_eng.pdf?v=20190828144755

[Accessed 15 January 2020].

Pepperl-fuchs, 2020. *Enclosures (Ex d)*. [Online]

Available at: https://www.pepperl-fuchs.com/great_britain/en/classid_3074.htm

[Accessed 15 January 2020].

RS Components, 2020. *4700uF 50V Capacitor Datasheet*. [Online]

Available at: <https://docs.rs-online.com/6c99/0900766b81581713.pdf>

[Accessed 20 January 2020].

RS Components, 2020. *IP - Ingress protection explained*. [Online]

Available at: https://sg.rs-online.com/web/generalDisplay.html?id=centre/mro_techref_iprating

[Accessed 20 January 2020].

RS Components, 2020. *RS Pro Heatsink TO-3*. [Online]

Available at: <https://docs.rs-online.com/2952/0900766b81704cb2.pdf>

[Accessed 10 January 2020].

RS Components, 2020. *SolaHD 200VA DIN Rail & Panel Mount Transformer, 120V ac, 240V ac Primary, 24V ac Secondary*. [Online]

Available at: <https://uk.rs-online.com/web/p/din-rail-panel-mount-transformers/8908848/>

[Accessed 20 January 2020].

SolaHD, n.d. *The SBE - Encapsulated Series*. [Online]

Available at: <https://docs.rs-online.com/b575/0900766b814a6ae0.pdf>

[Accessed 20 January 2020].

Texas Instruments, 2013. *LM723/LM723C Voltage Regulator*. [Online]

Available at: <http://www.ti.com/lit/ds/symlink/lm723.pdf>

[Accessed 24 January 2020].

Weister, R. M., 2017. *LM723 Regulator Operation in Astron Linear Power Supplies*. [Online]
Available at: <http://www.repeater-builder.com/astron/astron-repair/regulator-operation.html>
[Accessed 24 January 2020].

Appendix

MC1723C

MAXIMUM RATINGS ($T_A = +25^\circ\text{C}$, unless otherwise noted.)

Rating	Symbol	Value	Unit
Pulse Voltage from V_{CC} to V_{EE} (50 ms)	$V_{I(p)}$	50	V_{pk}
Continuous Voltage from V_{CC} to V_{EE}	V_I	40	Vdc
Input-Output Voltage Differential	$V_I - V_O$	40	Vdc
Maximum Output Current	I_L	150	mA
Current from V_{ref}	I_{ref}	15	mA
Current from V_Z	I_Z	25	mA
Voltage Between Noninverting Input and V_{EE}	V_{IE}	8.0	Vdc
Differential Input Voltage	V_{ID}	± 5.0	Vdc
Power Dissipation and Thermal Characteristics $T_A = +25^\circ\text{C}$ Derate above $T_A = +25^\circ\text{C}$ Thermal Resistance, Junction-to-Air	P_D $1/\theta_{JA}$ θ_{JA}	1.25 10 100	W mW/°C °C/W
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +175	°C
Operating Ambient Temperature Range	T_A	0 to +70	°C

ELECTRICAL CHARACTERISTICS ($T_A = +25^\circ\text{C}$, $V_{IN} = 12\text{ Vdc}$, $V_O = 5.0\text{ Vdc}$, $I_L = 1.0\text{ mA}$, $R_{SC} = 0$, $C_1 = 100\text{ pF}$, $C_{ref} = 0$ and divider impedance as seen by the error amplifier $\leq 10\text{ k}\Omega$ connected as shown in Figure 2, unless otherwise noted.)

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 ($I_L = 0$, $V_{IN} = 30\text{ V}$)	I_{IB}	—	2.3	4.0	mA
Output Noise Voltage ($f = 100\text{ Hz to }10\text{ kHz}$) $C_{ref} = 0$ $C_{ref} = 5.0\text{ }\mu\text{F}$	V_n	— —	20 2.5	— —	$\mu\text{V(RMS)}$
Average Temperature Coefficient of Output Voltage ($T_{low} < T_A < T_{high}$)	TCV_O	—	0.003	0.015	%/°C
Line Regulation $(T_A = +25^\circ\text{C}) \begin{cases} 12\text{ V} < V_{IN} < 15\text{ V} \\ 12\text{ V} < V_{IN} < 40\text{ V} \end{cases}$ $(T_{low} < T_A < T_{high})$ $12\text{ V} < V_{IN} < 15\text{ V}$	Regline	— — —	0.01 0.1 —	0.1 0.5 0.3	% V_O
Load Regulation ($1.0\text{ mA} < I_L < 50\text{ mA}$) $T_A = +25^\circ\text{C}$ $T_{low} < T_A < T_{high}$	Regload	— —	0.03 —	0.2 0.6	% V_O
Ripple Rejection ($f = 50\text{ Hz to }10\text{ kHz}$) $C_{ref} = 0$ $C_{ref} = 5.0\text{ }\mu\text{F}$	RR	— —	74 86	— —	dB
Short Circuit Current Limit ($R_{SC} = 10\text{ }\Omega$, $V_O = 0$)	I_{SC}	—	65	—	mA
Long Term Stability	$\Delta V_O/\Delta t$	—	0.1	—	%/1000 Hr.

NOTE: T_{low} to $T_{high} = 0^\circ$ to $+70^\circ\text{C}$

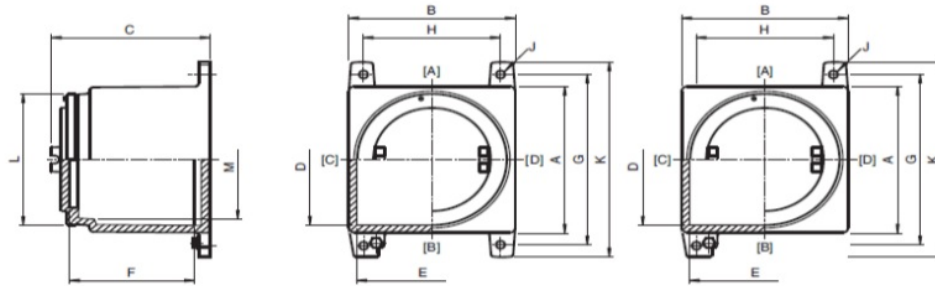
Figure 21: MC1723C datasheet (Motorola, 2020)

Handy reference table for I.P. ratings

First characteristic numeral				Second characteristic numeral			
Protection against solid foreign objects			Degree of protection for people against access to hazardous parts with:	Protection against harmful ingress of water			Degree of protection from water
I.P.	Example	TESTS		I.P.	Example	TESTS	
0		No protection	Non-protected	0		No protection	Non-protected
1		Full penetration of 50mm diameter of sphere not allowed. Contact with hazardous parts not permitted.	Back of hand	1		Protected against vertically falling drops of water	Vertically dripping
2		Full penetration of 12.5mm diameter of sphere not allowed. The jointed test finger shall have adequate clearance from hazardous parts.	Finger	2		Protected against vertically falling drops of water with enclosure tilted 15° from the vertical.	Dripping up to 15° from the vertical
3		The access probe of 2.5mm diameter shall not penetrate.	Tool	3		Protected against sprays to 60° from the vertical.	Limited spraying
4		The access probe of 1mm diameter shall not penetrate.	Wire	4		Protected against water splashed from all directions – limited ingress permitted	Splashing from all directions
5		Limited ingress of dust permitted (no harmful deposit).	Dust protected	5		Protected against low pressure jets of water from all directions – limited ingress permitted	Hosing jets from all directions
6		No ingress of dust.	Dust tight	6		Protected against strong jets of water eg for use on ship decks – limited ingress permitted	Strong hosing jets from all directions
			W I R E	7		Protected against the effects of immersion between 150mm and 1m	Temporary immersion
				8		Protected against continuous submersion at a specified depth.	Continuous immersion

Figure 22: IP reference table (RS Components, 2020)

GUB* Dimensions



Legend	
A	Height
B	Width
C	Depth
D	Internal height
E	Internal width
F	Internal depth to surface mounting plate
G	Mounting holes distance, vertical
H	Mounting holes distance, horizontal
J	Mounting holes diameter

Legend	
K	Maximum external dimension with mounting bracket
L	Diameter cover
M	Diameter mounting aperture
[A] ... [D]	Cable entry faces

Dimension values see data table.
Real values might differ slightly due to casting and manufacturing tolerances.
Image and drawing are generic for this enclosure type and may deviate from the specific variant.

Dimensions and Enclosure Details															
Type	External dimensions [mm]				Internal dimensions [mm]			Mounting [mm]			Diameter [mm]		Mounting brackets quantity	Mass [kg]	Max. power dissipation at T ₄ /+40 °C [W]
	A	B	C	K	D	E	F	G	H	J	L	M			
GUB00*	119	119	137	170	92	92	98	145	95	8	112	97	2	2	48
GUB0*	150	150	145	205	125	125	117	178	125	8	136	114	2	3.5	78
GUB0H*	150	150	185	205	125	125	150	178	125	8	136	114	2	4.5	91
GUB1*	200	200	160	255	170	170	110	228	178	10	189	163	2	6.4	122
GUB1H*	200	200	200	255	170	170	150	228	178	10	189	163	2	7.6	143

Figure 23: Ex d enclosure datasheet (Pepperl-fuchs, 2020)

Kingbright

Selection Guide

Part No.	Dice	Lens Type	Iv (mcd) @ 10mA		Viewing Angle
			Min.	Typ.	2θ1/2
L-53HD	BRIGHT RED(GaP)	RED DIFFUSED	1.8	5	60°

Note:

1. θ1/2 is the angle from optical centerline where the luminous intensity is 1/2 the optical centerline value.

Electrical / Optical Characteristics at T_A=25°C

Symbol	Parameter	Device	Typ.	Max.	Units	Test Conditions
λ _{peak}	Peak Wavelength	Bright Red	700		nm	I _F =20mA
λ _D	Dominate Wavelength	Bright Red	660		nm	I _F =20mA
Δλ _{1/2}	Spectral Line Half-width	Bright Red	45		nm	I _F =20mA
C	Capacitance	Bright Red	40		pF	V _F =0V; f=1MHz
V _F	Forward Voltage	Bright Red	2.25	2.5	V	I _F =20mA
I _R	Reverse Current	Bright Red		10	uA	V _R = 5V

Absolute Maximum Ratings at T_A=25°C

Parameter	Bright Red	Units
Power dissipation	120	mW
DC Forward Current	25	mA
Peak Forward Current [1]	130	mA
Reverse Voltage	5	V
Operating/Storage Temperature	-40°C To +85°C	
Lead Solder Temperature [2]	260°C For 5 Seconds	

Notes:

- 1/10 Duty Cycle, 0.1ms Pulse Width.
- 2mm below package base.

Figure 24: LED datasheet (Kingbright, 2020)

The SBE - Encapsulated Series

The SBE Encapsulated industrial control transformers are epoxy encapsulated to seal the transformer windings against moisture, dirt and industrial contaminants. Extra deep, molded terminal barriers reduce the chance of electrical failure as the result of arcing or frayed lead wires. The rugged construction and proven reliability of the SBE design is uniquely suited for all industrial environments.

Features

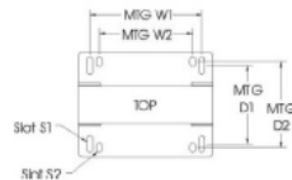
- 50 - 1000 VA, 50/60 Hz – suitable for worldwide applications.
- Interleaved copper windings reduce I²R losses and maximize efficiency.
- 55°C Rise, 105°C insulation system to minimize heat
- Epoxy encapsulated to protect cores and coils against moisture, dirt, and other contaminants.
- Meets or Exceeds NEMA Standard ST 1 and ANSI C89.1 for load inrush capability.
- Integrally molded, flame retardant (IEC 707/ISO Class 1210) Terminal Blocks provide greater terminal contact area and improved conductivity.
- Heavy gauge steel mounting plate
- Mounting dimensions are compatible with similar control transformers.
- **Secondary fuse holders (FB2X) included for 13/32 x 1½ cartridges (fuses not included).**
- **Factory-installed fuse holders are available (See W, WA & WB options).**
- 10 year warranty



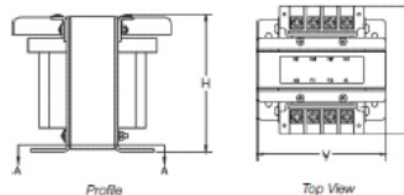
Related Products

- Linear Power Supplies
- DIN Rail DC Power Supplies
- Constant Voltage Transformers
- Line Reactors

SBE Mounting Profiles



Mounting Dimensions



Accessories

Catalog Number	Description
FBP	Primary "OC" Rejection Type Fuse Holder (Finger Safe covers not available)
FB2	Secondary Fuse Holder only (Glass or Ceramic, ¼" x 1¼" fuse)
FB2X	Secondary Fuse Holder only included where applicable. Not sold separately. (Midget Cartridge Type, 13/32" x 1½" fuse)
FBPC1	Primary "OC" Rejection Type Fuse Holder and Finger Safe Cover Kit
IP20	IEC Touchproof Cover Kit
SBEDIN	IEC Fuse Holder Adaptor Kit
W	Factory installed Primary Fuse Holder with Midget Type (no covers)
WA	Factory installed Fuse Holder with Glass/Ceramic Type and Covers
WB	Factory installed Fuse Holder with Midget Type and Covers

Figure 25: Transformer datasheet (SolaHD, n.d.)

Datasheet

ENGL

4700µF 50 V dc, Through Hole Aluminium Electrolytic Capacitor

RS Stock number [711-1526](#)



Specifications:

Item	Performance Characteristics															
Operating Temperature Range	-40 to +105□										-25 to +105□					
Rated Voltage Range	6.3 to 100 VDC										160 to 450 VDC					
Capacitance Tolerance	±20%(120Hz, +20□)															
Leakage Current (+20□)	10V ~100V DC										IL: 0.01CV+3(μA)					
	160V~450V DC										IL: 0.03CV+3(μA)					
	I: Leakage current(μA) C: Rated Capacitance(μF) V: Working Voltage[V] After 1minute whichever is greater measured with rated working voltage applied.															
Dissipation Factor [120Hz, 20 °C]	W.V	6.3	10	16	25	35	50	63	100	160	200	250	350	400	450	
	Tanδ	0.23	0.20	0.16	0.14	0.12	0.10	0.10	0.10	0.15	0.15	0.16	0.20	0.20	0.20	
For capacitance exceeding 1000uF, add 0.02 per increment of 1000uF																
Temperature Characteristics [Tanδ]	W.V.		6.3	10	16	25	35	50	63	100	160	200	250	350	400	450
	Impedance	-25°C/+20°C	4	3	2	2	2	2	2	2	3	3	3	5	6	15
		-40°C/+20°C	8	6	4	3	3	3	3	3	-	-	-	-	-	-
Impedance ratio of 120Hz																
Load Test	Test conditions Duration time : 50~6000Hrs 80~250 2000Hrs Ambient temperature:+105□ Applied voltage: Rated DC working voltage After test requirements:at+20□ After test requirements:□±20% of the initial measured value Dissipation Factor: □200% of the initial specified value Leakage current: □The initial specified value															
Shelf Test	Test conditions Duration time :500Hrs Ambient temperature:+105□ Applied voltage: None After test requirements at +20□: Some limits as Load life. Pre-treatment for measurements shall be conducted after application of DC working voltage for 30 minutes.															

Figure 26: Capacitor datasheet (RS Components, 2020)

1602836

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

82/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

Text Comment. Brief executive summary for this level, should cover all sections and give a flavour of the entire report.

PAGE 5

Text Comment. Not sure on the environment, I can see "water", but the rest isn't clear.

PAGE 6

Text Comment. A block diagram and plan to design the entire system was needed here. Then go into the design of each block

PAGE 7

Text Comment. As this is intended to be built, more preferred values for resistors or trimmer pots would aid manufacture and set-up.

PAGE 8

PAGE 9

PAGE 10

Text Comment. Again, a preferred value would have reduced manufacturing costs

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

Text Comment. You have shown preferred values in the shopping list, but the circuit was tested with ideal values. Would the change have an impact on your results?

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

PAGE 28

PAGE 29

PAGE 30

GRADING FORM: CSG-RUBIC

RESEARCH-INFORMED LITERATURE



There was evidence of extensive further reading and research from credible and reliable sources. Your interpretation and understanding of the additional research was very good and demonstrated a deep underlying appreciation of the subject. Your references were consistently applied and appropriate to the task and your reference list was of an appropriate length for this assignment.

8

KNOWLEDGE AND UNDERSTANDING



The knowledge and understanding of the subject demonstrated by this assignment was generally excellent. There were very 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 highly competent critical understanding of the main concepts and expanded your knowledge well beyond that contained in the course notes.

25

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.

23

PRACTICAL APPLICATION AND DEP.



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

18

SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was written in a professional and confident style, however you still need to be more efficient with your word count. The report was very well presented, with excellent diagrams in

8

appropriate places, good sentence/paragraph
structure and clear calculations