

1809799

by Thomas Grennan

Submission date: 28-Feb-2022 10:46PM (UTC+0000)

Submission ID: 172340813

File name: 11301_Thomas_Grennan_1809799_179513_1440224741.pdf (3.6M)

Word count: 10463

Character count: 63260

85-90

Course: BSc (Hons) Electrical and Electronic Engineering

Module: SGEE6005 Electronic Design

Assignment: Regulated Power Supply Design

Name: Thomas Grennan

University number: 1809799

Date submitted: 28/02/2022

Word count: 4694 words

OVER LIMIT. - 5

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1. Executive Summary

This report outlines the process of the research, design and implementation of a power supply in order to meet the specification of a company within the clear vision sector of automotive industry, primarily used for clearing pollutant that comes into contact with headlight, windshield and camera systems on automotive vehicles.

The customer's specification was received and reviewed to ensure that it could be met within budget whilst meeting all relevant standards. Research was undertaken into the system as a whole, consequently resulting in further research into the 4 main sub-sections that are integrated together to produce this circuit, providing an underpinning knowledge of the requirements of each sub-circuit.

Research was ventured into the differing power supply technologies, primarily the 'Linear' and 'Shunt' regulators. It was found that the application in question would benefit largely from the use of the linear regulator configuration due to its low cost, low development time and simplicity in the aspect of required components. The design of a switch-mode power supply (SMPS) is far more complex, increasing costs and extending development times, and the requirements of this application does not require the benefits of the SMPS such as low heat generation and smaller stature.

The first design element saw the requirement to choose a suitable voltage regulator, research into voltage regulators found that the Motorola's MC1732C offered suitable characteristics required for the design. Established design methods, equations and analysis of 'Schade Curve' graphs were implemented in conjunction with the bottom-up approach, designing from the linear regulator sub-circuit through to the transformer sub-circuit. This design choice was implemented as it is less complex to start at the regulator and work backwards, than to start at the power supply and work forwards. This is largely due to the stringent requirements of the regulator compared to the other circuits. It was found that it would be easier to find components to complement the regulator circuit than vice versa. Suitable components were chosen from reputable suppliers after each design stage.

The final design element undertaken was performed in the thermal analysis area, this was performed to determine whether a heatsink was required, and if so, what heatsink suits this application. Through research into the characteristics of the series-pass transistor and trusted calculations it was determined that a heatsink is required, a suitable heatsink was chosen.

The simulation aspect was found to be highly useful. Testing started with the Linear Regulator sub-circuit. It was found that the circuit with components based directly upon the design calculations worked well, however, a small error was seen on both output voltage and current. Slight adjustments to resistor R2 enabled the customer's specification to be met with no errors. Further testing into the sub-circuits Line and Load regulation proved that the circuit was operating as designed.

Further successful testing was undertaken into the 'front-end' sub-circuits, all performing as intended with the exception of simulation errors that occurred during the addition of the smoothing capacitor.

The final testing element saw the integration of both the Linear Regulator circuit and the front-end circuit to create overall power supply circuit. The stringent testing performed on each sub-circuit enabled the circuit to successfully operate to customer specifications first time. The error produced by the capacitor was seen again, causing the input voltage to the regulator to rise to 33Vdc compared to the desired 24Vdc. However, figures obtained from the 'Line Regulation' test proved the voltage regulators high tolerance to input voltage, ensuring no adverse effects would occur due to the simulation error. The final test saw the measurement of remaining AC component in the regulated DC output, this was found to be $578.5\mu V^{p-p}$, meeting the maximum requirement of 1mV output ripple stated in the specification.

It was concluded that the design and implementation were successful, the research undertaken into the circuit principles and components was found to be extensively useful, providing key underpinning knowledge into the operation of key components and the overall system. The approach to the bottom-up design method was found to be highly efficient, enabling the design and testing to be successfully completed within a short time period, this quick design and analysis was achieved through tried and tested equations coupled with detailed analysis within Multisim enabling efficient and accurate foundations to fully analyse the systems performance. The success of the report was further proven, tabulated evidence displayed the comparison between the design and specification showing strong correlation, further confirming the success of the design.

Recommendations were made to further develop knowledge and improve the circuit's performance. The addition of 'Voltage Clamping' was found to be an efficient method of 'clamping' the output voltage at a safe level under fault conditions. Further recommendations explored the potential of the design and implementation of a shunt regulator power supply and switch mode power supply, enabling analysis to be undertaken comparing the operation, complexity and performance off the differing power supply designs.

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INCLUDE THE IMPORTANT DETAILS.

2. Requirements and Specification

A customer within the clear vision sector of the automotive industry has the requirement for a power supply to be designed to be incorporated into their control systems for the testing of automotive water pumps. The power supply is required to deliver 12Vdc to the pump during its functional test before full assembly of the pump and reservoir unit, with the overall unit controlling the washer fluid delivered to the vehicle's windscreen. The pump has a winding with a resistance of 6Ω , therefore the power supply must deliver 2A of current.

The power supply will be incorporated in a key functional test during the manufacturing process. This test confirms that the pump is operating correctly, this is established through measuring a 'healthy' current draw. A precision 'Shunt' resistor is connected in series between the power supply and the pump, generating a low-resistance path for the current. The voltage drop across the resistor is measured by an 'ISOCON-6' signal converter. This signal is scaled and converted into a 4-20mA signal sent to a PLC, the PLC logic then determines if the pumps current draw is sufficient to pass or fail.

Due to the nature of the system, the power supply is housed within a Rittal control panel cabinet with climate control ensuring that the minimum temperature is 0°C , with the maximum being 25°C . The power supply must be din rail mountable, with the exception of direct mounting to the back plate with suitable fixings. The functional design specification of the power supply states further requirements for the system. In order to prevent a floating voltage on the output, the transformers secondary 0V must be connected to ground. Both the primary and secondary of the power supply must be appropriately fused, however, this is only a requirement during implementation into the control system.

All requirements for the power supply are outlined in table 1.

Power Supply Requirements	
Parameter	Requirement
Supply Voltage (Transformer Primary)	240VAC -6/+10%
Supply Frequency	50Hz
Output Voltage (V_o)	12Vdc $\pm 0.1V$
Output Current (I_o)	2Adc $\pm 0.1A$
Ambient Temperature Rating	0°C to 25°C
Output Ripple	$\leq 1\text{mV}^{P-P}$
Load Regulation	$\leq 1\%$
Dimensions	150mm x 150mm x 130mm
Weight	Not applicable (Not part of a portable system)
IP Rating	Mounted in IP65 control panel
Cost	$\leq \text{£}160$

Table 1 – Power Supply Requirements

You could lose some words here as the numbers are in the table below.

THE PRODUCT WILL COMPLY WITH THE STANDARDS
IN THE TABLE TO ENSURE COMPLIANCE WITH CE/UKCA

All good design procedures will be considered and followed throughout the design; guidance will be received from the various British, International and European standards seen in table 2. Following good working practices and relevant standards enables the component to be CE/UKCA marked to ensure that the product affirms with relevant EU and UK legislation (GOV.UK, 2020).

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The control panel that will house the power supply is designed to 'BS EN 60204-1:2018 Safety of machinery. Electrical equipment of machines. General requirements' and 'BS EN ISO 13849-1:2015 Safety of machinery. Safety-related parts of control systems. General principles for design' allowing for CE/UKCA marking of the entire system (engineering, 2021).

Relevant Standards applicable to Power Supply Design	
Standard No.	Standard
BS IEC 60748-1:2002	Semiconductor devices and Integrated Circuits - General
BS EN 62132-1:2016	Integrated circuits – Measurement of electromagnetic immunity
BS EN 60940:2015	Integrated circuits. Measurement of electromagnetic immunity - General conditions and definitions
BS EN 60204-1:2018	Safety of machinery – Electrical equipment of machines
BS EN IEC 60384-21:2019	Fixed capacitors for use in electronic equipment - Sectional specification. Fixed surface mount multilayer capacitors of ceramic dielectric, Class
BS IEC 60748-4-3:2006	Semiconductor devices. Integrated circuits - Interface integrated circuits. Dynamic criteria for analogue-digital converters (ADC)

Table 2 – Relevant Standards applicable to Power Supply Design

3. Design method, choices and calculations

The premise of this report is based upon mathematical calculations implemented to calculate the ideal values of the systems components. Circuit modelling and analysis is executed through NI Multisim, each sub-circuit seen in figure 1 will be individually functionally tested, with the integration of all sub-circuits together to produce the overall power supply circuit for final testing and analysis. This is based upon the 'Bottom-up' methodology where by the primitive operations such as design and calculations of the individual components are implemented first known as the 'base elements'. These elements are merged together to create the overall system.

There are four key elements to the design of a power supply as seen in figure 1.

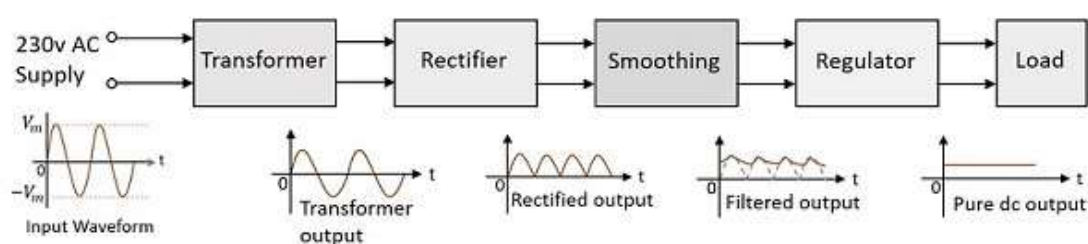


Figure 1 - Power Supply Block Diagram

The first element is the transformer, this component is required to reduce the incoming voltage to a lower voltage that the rectifier can deal with. In this application, an input supply voltage of 240VAC at 50Hz is connected to the transformers primary winding, the transformer will reduce or "step-down" the voltage to a suitable level for the rectifier on its secondary winding, therefore a 'step-down' transformer is required (Daware, 2020).

The output from the transformers secondary winding will supply a 'full-bridge rectifier', this is a bridge of four diodes connected in a closed loop bridge configuration. The diode arrangement converts the AC input into a rippled DC output. 2 of the 4 diodes will conduct the supply current through the positive half-cycle, whilst the remaining two conduct through the negative half cycle, allowing the full input sine wave to be utilised on the output (DERF, 2018).

The rippled output from the bridge rectifier is not ideal, the third element is the smoothing capacitor stage. This stage is a means of smoothing the rippled DC. An electrolytic capacitor is connected in parallel with the rectified output, smoothing it. On the positive half cycle the capacitor charges, on the negative half cycle it discharges delivering a filtered DC output, removing large amounts of undesired AC component (DERF, 2018).

The final element is the regulator. This is required as the smoothing capacitor cannot provide total voltage stability. This circuit will create and maintain the fixed output voltage, disregarding changes to its input voltage or load conditions, ensuring that the power supply is operating within a range that is compatible with its load (monolithicpower, 2019).

3.1 Linear Regulator

The first design element is the regulator, more specifically a linear regulator, this element is the power management device for the circuit. Linear regulators are best suited to ground-based power supplies where the generation of heat is not a major concern and a voltage of less than 40VDC is required. Benefits of linear regulators include their low cost, low development time and zero radiofrequency interference. (Brown, 2001).

There are two common variations of the linear regulator, the shunt regulator and the series-pass regulator. The shunt regulator is placed in parallel with the load and an unregulated current source is connected to a higher voltage source. The shunt regulator draws output current to maintain a regulated voltage across the load given a variable input voltage and load current, this is the principle of the Zener diode regulator (Brown, 2001).

A more efficient configuration is the series-pass regulator, this uses an active semiconductor like a BJT as a series-pass component between the input and the load. This configuration operates in linear mode, in this mode it operates as “partially on” instead of on or off. Therefore, it is reliant on the variable conductivity of its active component to deliver a regulated output voltage by acting like a variable resistance. This BJT then “drops” the unwanted voltage ($V_{IN} - V_{OUT}$) across itself, this is known as the “headroom”. A negative aspect of the linear regulator is that it dissipates power as heat, this is so it can regulate the output voltage. This can often be a significant amount of power to dissipate therefore heatsinks are often a requirement. A method of limiting the dissipation of heat can be employed in the circuit design, the input voltage can be limited to around 3V greater than its output, limiting the power dissipated whilst improving the efficiency.

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A negative feedback loop determines the conductivity degree the transistor needs to perform at to maintain an accurate output voltage. This negative feedback is possible by a ‘voltage error amplifier’. This is an operational amplifier with high-gain which compares the difference between a stable reference point and the output voltage, if an error is found between the reference point and the output, a correction is made to the series-pass components conductivity to increase or decrease as necessary. As the load increases, the output voltage will fall, in turn increasing the amplifiers output providing more current to the load. Opposingly, as the load decreases, the output voltage will rise causing the error amplifier to decrease the loads pass unit current.

Research was undertaken into a suitable voltage regulator for this application, it was found that the Motorola MC1723C is suitable for this application, it is capable of delivering an output current of 150mA, between an output voltage range of 2Vdc to 37Vdc. The current output can be increased through the use of external pass transistors in the NPN current boost configuration as seen in figure 2.

The MC1723C operates with a line regulation of 0.01% and a load regulation of 0.03%. Therefore, at 12VDC, changes to its input voltage and changes in its load within its permissible load range will only affect its output voltage by millivolts (ibex, 2018).

The MC1723C is operational in conditions between 0° to +70°C, with a short circuit current limit of 65mA_{dc} (Motorola, 2001).

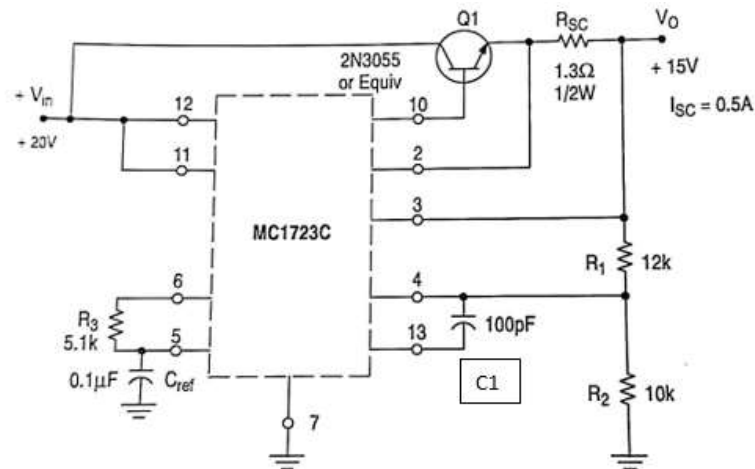


Figure 2 - MC1723C in NPN Current Boost Configuration

As the voltage regulator has been chosen, a value for capacitor C_{REF} is chosen, from the datasheet seen in appendix 8.3.1 it states that 0.1μF is an ideal value for low noise operation, therefore:

$$C_{ref} = 0.1\mu F$$

The value for $R_1 + R_2$ is then determined, the datasheet seen in appendix 8.3.1 specifies that this value should be within the range of 10KΩ and 100KΩ, a value of 20KΩ is chosen:

$$R_1 + R_2 = 20K\Omega$$

R_2 is calculated using the equation below, with V_o being the desired output voltage:

$$R_2 = \frac{V_{ref}}{V_o} \times (R_1 \times R_2)$$

From the datasheet seen in appendix 8.3.1 it is found that V_{ref} is 7Vdc, therefore:

$$R_2 = \frac{7V}{12V} \times (20 \times 10^3) = 11.667K\Omega$$

As 11.667KΩ is not a standard resistor value, R_2 is increased to 12KΩ. R_2 should have leeway for adjustment to accurately set up the output characteristics.

R_1 is found using the equation below:

$$R_1 = 20K\Omega - R_2 = 20K\Omega - 12K\Omega = 8K\Omega$$

8KΩ is not a standard value resistor, referring to the standard resistor table seen in appendix 8.1:

$$R_1 = 8.2K\Omega$$

R_3 is then calculated using the equation below:

$$R_3 = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{8.2K\Omega \times 12K\Omega}{8.2K\Omega + 12K\Omega} = 4.87 K\Omega$$

Referring to the standard resistor value table in appendix 8.1, 4.87KΩ is not a standard resistor value, therefore R_3 is chosen below:

$$R_3 = 5.1 K\Omega$$

The maximum current is determined by the current sense resistor (R_{SC}). These resistors inherently have a low Ohmic value and a high-power value in order to limit power consumption. The purpose of this resistor is to gauge the flow of current, the calibrated resistance senses the current flow and therefore determines the voltage drop across it. If the voltage-drop across R_{SC} exceeds V_{BE} (0.66V), the series-pass transistor will stop further conduction holding the current at that point. This is a simple and economical method of current flow measurement, mitigating the effect of overloads and short-circuits (Electronics, 2019).

As seen in the MC1323C datasheet seen in appendix 8.3.1, R_{SC} is connected across pins 2 & 3 which is the base-emitter junction of the transistor, this produces an inherent volt-drop V_{BE} of around 0.6V, this is taken into account within the calculation. The chip utilises this as short-circuit current protection, when the volt drop is greater than 0.6V it determines that current drawn is greater than the the circuit is designed for, in-turn reducing the voltage and current to prevent damage.

R_{SC} is calculated below, where I_{SC} the required output current:

$$R_{SC} = \frac{0.6V}{I_{SC}} = \frac{0.6V}{2A} = 0.3\Omega$$

The power rating for R_{SC} is calculated below:

$$P = I^2 \times R = 2^2 \times 0.3\Omega = 1.2W$$

Therefore R_{SC} is chosen as 0.3Ω, 1.2W

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The input voltage (V_{IN}) is then determined using the equation below, where ϕ is equal to the 0.6V voltage drop across the transistors base-emitter junction (V_{BE}):

$$V_{in} \geq V_{out} + 2\phi + 3V$$

$$V_{in} \geq 12 + 1.2 + 3V$$

$$V_{in} \geq 16.2V$$

V_{IN} has been calculated at a minimum of 16.2Vdc, therefore, in order for the regulator to function it requires a minimum supply voltage of 16.2Vdc. Linear regulators have a high tolerance to its incoming voltage; therefore, it is safer to marginally increase the input voltage to ensure full operation. For this design, V_{IN} is increased to 20Vdc, this allows for adequate voltage to be supplied to the linear regulator, whilst also allowing for ease of sourcing components as 20Vac transformers are widely available.

Table 3 displays the circuit component values calculated for the regulator circuit.

Linear Regulator – Calculated Components	
Component	Calculated Value
R_1	8.2K Ω
R_2	12K Ω
R_3	5.1K Ω
R_{SC}	0.3 Ω , 1.2W
C_{REF}	0.1 μF
V_I	20V
V_O	12V

Table 3 – Linear Regulator: Calculated Components

NOT COMPONENTS.

3.2 Series Pass Element

As seen in the data sheet in appendix 8.3.1, Motorola recommend the use of an NPN transistor in series between the supply voltage and load. In this configuration the IC regulator provides a current to the transistor base (I_B). This allows the series-pass element to act like a current amplifier increasing the output current (I_O) potential.

The Series-Pass element is researched and chosen, the requirements for this component are seen in table 4.

Linear Regulator – Series Pass Element Requirements
$V_{CEO} \geq V_{IN(MAX)}$
$I_{C(MAX)} \geq I_{SC}$
$h_{fe} \geq \frac{I_{SC}}{I_O} @ V_{CE} = V_{IN} - V_O - \varphi, \text{ where } \varphi = V_{BE ON} \approx 0.6V$
$P_{D(MAX)} \geq V_{IN} \times I_{SC}$
θ_{JC} to allow for practical heatsinking
Safe Operating Area (SOA) to withstand $V_{CE} = V_{IN} @ I_C = I_{SC}$

Table 4 – Linear Regulator: Series Pass Element Requirements

Firstly, the minimum h_{fe} is calculated:

$$h_{fe} \geq \frac{I_{SC}}{I_O} @ V_{CE} = V_{IN} - V_O - \varphi, \text{ where } \varphi = V_{BE ON} \approx 0.6V$$

When:

$$I_{SC} = 2A, I_O = 100mA, V_{IN} = 20Vdc, V_O = 12Vdc$$

h_{fe} :

$$h_{fe} \geq \frac{2A}{100mA} @ V_{CE} = 20Vdc - 12Vdc - 0.6Vdc$$

$$h_{fe} \geq 20 @ V_{CE} = 7.4Vdc @ I_C = 2Adc$$

The calculation for h_{fe} has determined that the transistors current gain must be ≥ 20 when a load of 2Adc is drawn. The SOA (Safe Operating Area) of the transistor is the area where the transistor operates with high reliability (Manias, 2017), therefore:

$$SOA = 2A @ 20Vdc$$

Therefore,

$$P_{D(MAX)} = V_{IN} \times I_{SC}$$

$$P_{D(MAX)} = 2A \times 20Vdc = 40W$$

A transistor suited to this application is the 'onsemi 2N3055G NPN Transistor', 15 A, 60 V, 2-Pin TO-204AA (RS No. 103-2964) (Components, 2016). Table 5 compares the component requirements to the actual component's parameters.

As seen in table 5, the 2N3055G exceeds the device requirements, it is housed in a TO-204AA casing which allows for integration with a heatsink if required. Calculations will be undertaken in the thermal management analysis section to determine if its Thermal Resistance Junction-to-Case of $1.52^{\circ}C/W$ is satisfactory. This component is also supported in Multisims parts database.

Series Pass Element – Comparison of Requirement and Chosen Component		
Parameter	Required Value	2N3055G
$V_{CE(MAX)}$	$\geq 20Vdc$	$60Vdc$
$I_{C(MAX)}$	$\geq 2A$	$15Adc$
$I_{O(MAX)}$	$\geq 100mA$	$2Adc$
h_{fe}	$\geq 20 @ V_{CE} = 7.4Vdc @ I_C = 2Adc$	$20-70Vdc @ I_C = 4Adc$
$P_{D(MAX)}$	$\geq 40W$	$115W$
ϕ_{JC}	<i>Determined under thermal management analysis</i>	$1.52^{\circ}C/W$
SOA	$SOA = 2A @ 20Vdc$	$SOA = 15A @ 60Vdc$

Table 5 – Series Pass Element: Comparison of Requirement and Chosen Component

3.3 Input Stage

Table 6 displays the key base values calculated from the regulator design circuit; these values are vital in the design of the front end.

Regulator Design – Base Values	
V_c	20 V
V_{Ripple}	3V
V_m	30V
I_o	2A
f	50Hz

Table 6 – Regulator Design: Base Values

The second design element is for the input stage of the circuit, this stage will supply the input voltage to the regulator circuit. This consists of three main elements: A transformer to step down the input voltage, a full-bridge rectifier to convert the AC input into a rippled DC output and a smoothing capacitor to smooth the DC output from the full bridge rectifier.

As per specification, the power supply will operate of a standard UK mains voltage of 240VAC at 50Hz, this will supply the primary side of the step-down transformer. This is an essential stage before the regulator as this provides dielectric isolation from the AC power supply.

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The first characteristic to be determined for the input stage is the ripple factor(r_f):

$$r_f = \frac{V_{Ripple\ p-p}}{2\sqrt{2} \times V_c} \times 100$$

$$r_f = \frac{3V}{2\sqrt{2} \times 20} \times 100 = 5.303\%$$

Using the value calculated for r_f , the value of ωCR_L is determined using the Schade Curve graph for the RMS Ripple Voltage for Capacitor-Input circuits as seen in figure 3, as the input stage will utilise a full-wave rectifier the top 4 lines on the graph are ignored. It is seen that at a ripple factor of 5.303% there is a minimum ωCR_L of 9 and a maximum ωCR_L value of 18, a value of 14 is chosen for ωCR_L as this is around the mid-point of the range.

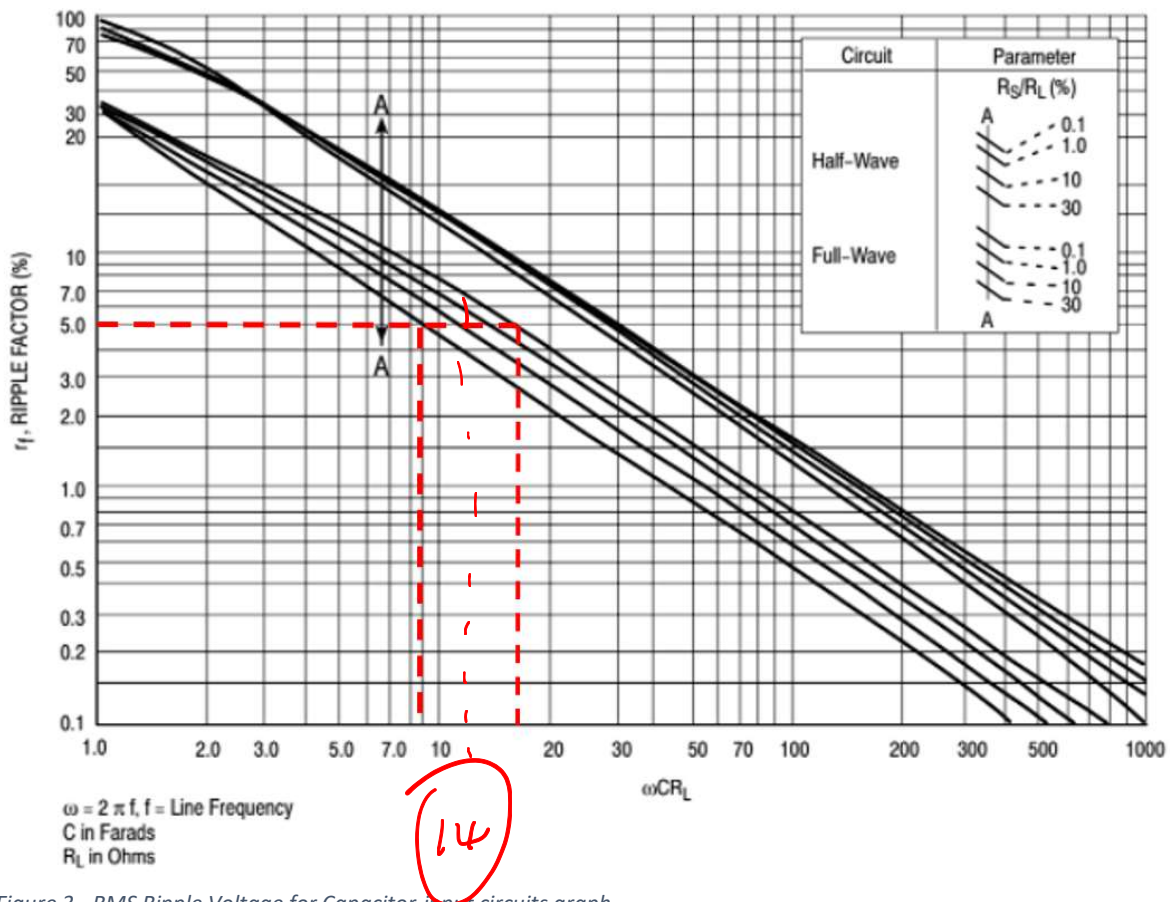


Figure 3 - RMS Ripple Voltage for Capacitor-Input circuits graph

The ratio of the parameter R_S/R_L is calculated as a percentage using the equation below:

$$\frac{V_C}{V_M} = \frac{20}{30} = 66.667\%$$

The value of V_C/V_M is used to choose the ratio of R_S/R_L on the Schade Curve graph for the relation of Applied Alternating Peak Voltage to Direct Output Voltage in Full-Wave Capacitor-Input Circuits, as seen in figure 4.

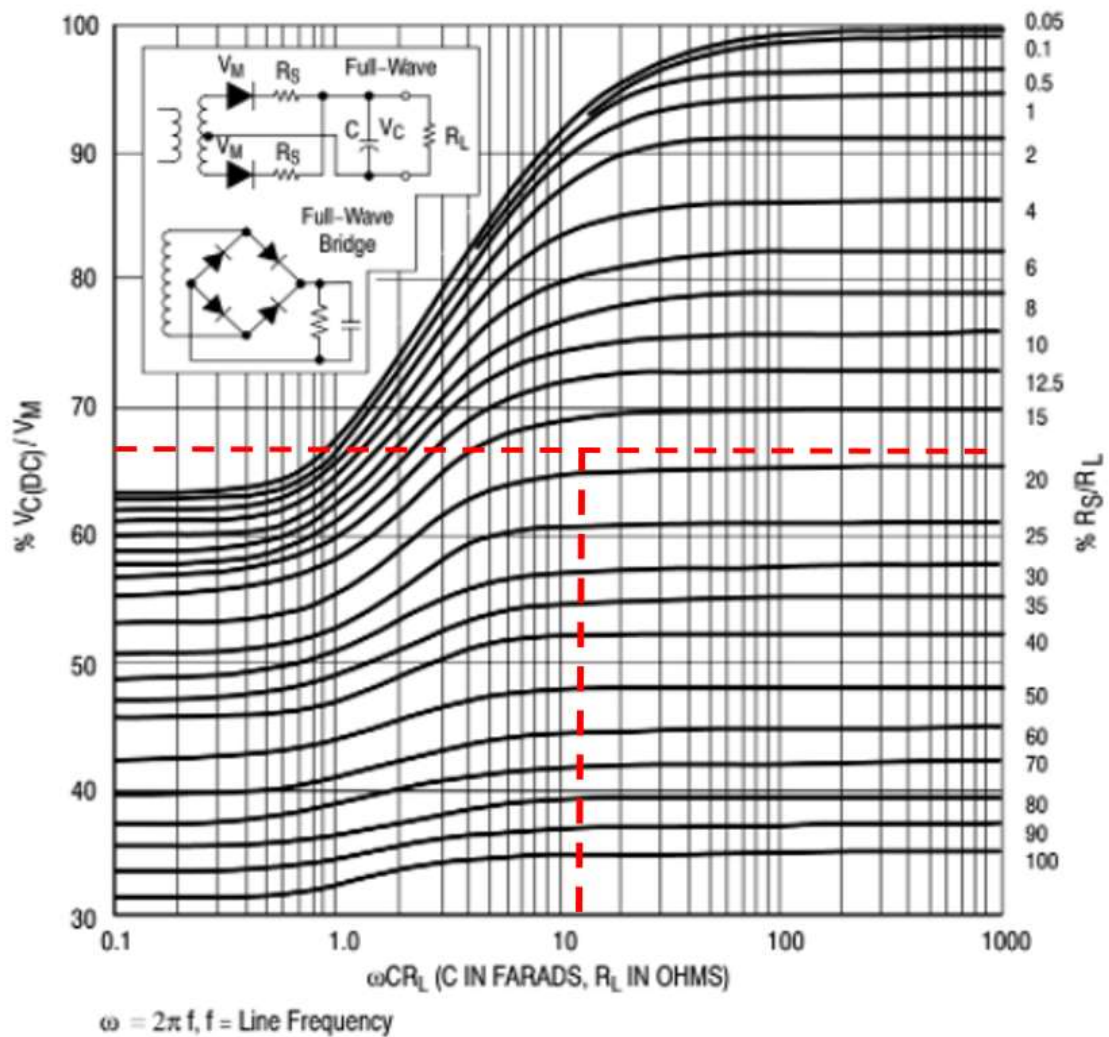


Figure 4 - Applied Alternating Peak Voltage to Direct Output Voltage in Full-Wave CI Circuits graph

As seen in figure 4, the nearest Schade curve to the plotted horizontal line is at an R_S/R_L value of 20%, this is the percentage ratio of R_S/R_L . Using this obtained value of R_S/R_L and the below equation, a value of R_L and R_S can be calculated:

$$R_S/R_L = 20\%$$

$$R_L = \frac{V_C}{I_O} = \frac{20}{2} = 10\Omega$$

$$R_S = 0.2 \times \frac{V_C}{I_O} = 0.2 \times \frac{20}{2} = 2\Omega$$

3.4 Capacitor Stage

The output from the rectifier is not pure DC, therefore it will possess some undesired AC component. The AC component can be removed by a parallel capacitor across the rectifiers output. Using the equation below, the minimum required capacitance for the smoothing capacitor is determined:

$$C = \frac{\omega CR_L}{2\pi \times f \times \frac{V_C}{I_O}} = \frac{14}{2\pi \times 50 \times \frac{20}{2}} = 4.456338mF$$

From the equation above, it is calculated that the minimum required rating for the smoothing capacitor is 4.456mF (4456μF), the nearest common rated capacitor to this is the 4700μF (4.7 mF) capacitor. This capacitor will operate at a top voltage (V_M) of 30V. Therefore, as a general guideline the capacitor should be rated to double the working voltage, in this case at 60V. The operating of typical electrolytic capacitors is -30°C to +125°C which is well within the specified operating temperatures of the power supply (Subramanyam, 2014).

The capacitor chosen is a KEMET 4700μF (RS No. 172-6838) with solder lugs to allow for tri rated cable to be soldered, table 7 displays the calculated requirements compared to the KEMET 4700uF (KEMET, 2020).

Smoothing Capacitor – Comparison of Requirement and Chosen Component		
Parameter	Requirement	KEMET 4700uF
Capacitance	4700uF	4700uF
Top Voltage (V_M)	60Vdc	63Vdc
Temperature Range	0°C - 25°C	-40°C - 85°C

Table 7 - Capacitor: Comparison between Calculated value and Chosen Component (KEMET, 2020)

3.5 Rectifier Stage

The next design element is the full-wave bridge rectifier. ~~In this topology 4 diodes are arranged in a bridge formation connected diametrically to the transformers secondary winding at nodes A & C with the load connected at nodes B & D as displayed in figure 5 (circuitstoday, 2012).~~

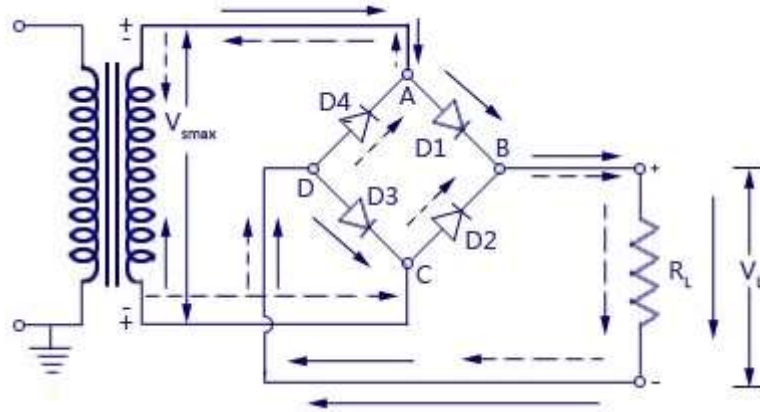


Figure 5 - Full-Bridge Rectifier Circuit (circuitstoday, 2012)

In the full-bridge arrangement, the average current per diode is half of the output current (I_o). This is calculated below as $I_{F(AVG)}$:

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

The peak RMS current is then calculated:

$$I_{F(PK)} = 5.2 \times I_{F(AVG)} = 5.2 \times 1 = 5.2A$$

The required surge current requirements for the Using the Schade Curve graph for the relation between RMS and Peak-to-Average Diode Current in capacitor-input circuits as seen in figure 6.

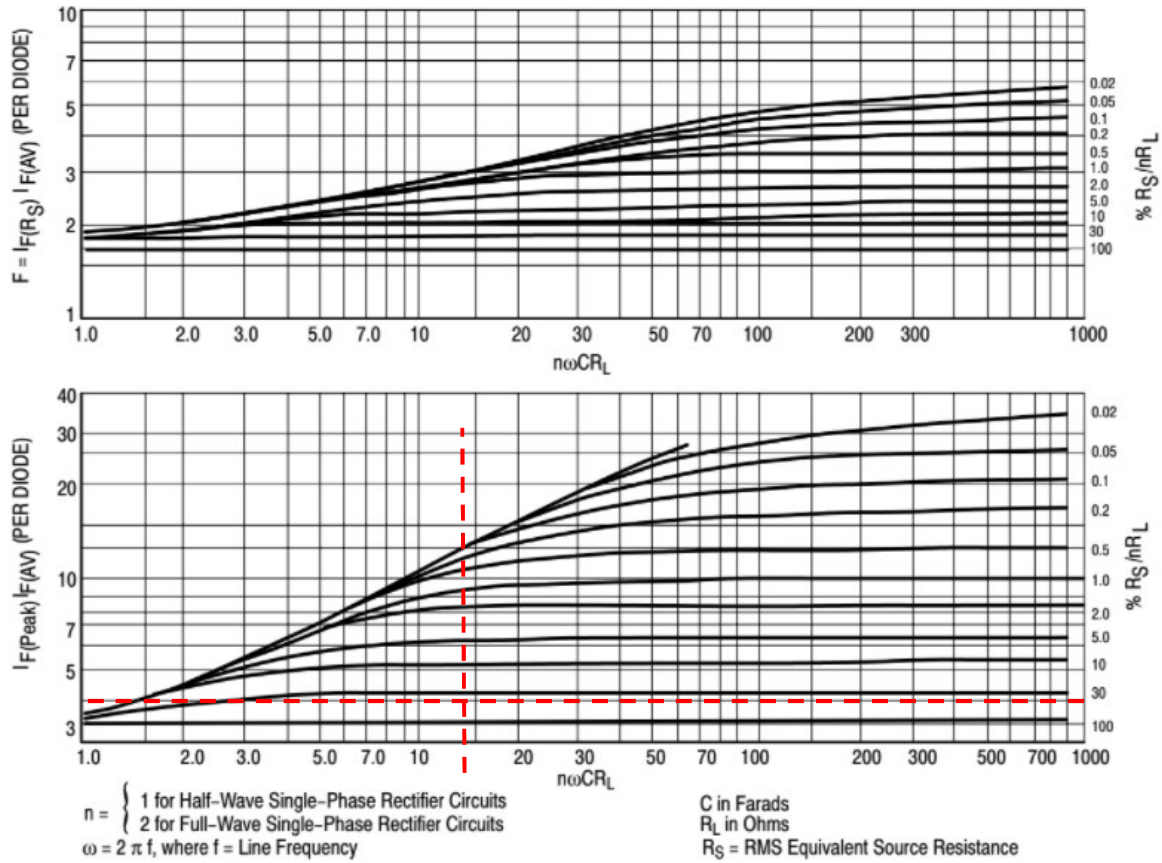


Figure 6 - Relation between RMS and Peak-to-Average Diode Current in capacitor-input circuits graph

The PIV is equal to V_M , in this case $V_M = 30\text{Vdc}$ as determined in section 3.4, and due to the guideline of doubling the working voltage in order to allow for potential surges on the mains lines, this in turn prevents any strain being placed on the rectifier.

The minimum required surge current is calculated below, where ESR in ranges of $< 0.1\Omega$ are negated:

$$I_{\text{Surge}} = \frac{V_M}{R_S + \text{ESR}} = \frac{30V}{2\Omega} = 15\text{A}dc$$

It is vital that the rectifier is able to withstand a surge current of $15\text{A}dc$ during its initial power on to allow for the capacitor to charge, $4700\mu\text{F}$ capacitors typically have an ESR value of 0.025 , allowing for the ESR to be negated in this calculation.

Table 8 displays the calculated requirements for the rectifier compared to the Vishay GBU6G rectifier (RS No. 145-1679) that has been selected, as seen when comparing the required value to the selected component, the GBU6G will perform well within the required values. It is also an available component in Multisims parts database (Components, 2019). The datasheet for GBU6G does not state its $I_{F(PK)}$ value, however, as its $I_{F(AVG)}$ value is 6Adc, it is determined that its peak current rating is far greater than the 5.1Adc required.

<i>Full Bridge Rectifier – Comparison of Requirement and Chosen Component</i>		
Parameter	Required Value	Vishay GBU6G
$I_{F(AVG)}$	1Adc	6Adc
$I_{F(PK)}$	5.2Adc	-
V_{in}	$\geq 20V$	280V (Maximum)
I_{Surge}	15A	175A

Table 8 - Full Bridge Rectifier: Comparison of Requirement and Chosen Component (Components, 2019)

3.6 Transformer Specification

The transformer element of the design is calculated. Using the equation below, the transformers secondary voltage is calculated, where $n = 2$ for full-wave bridge rectifiers:

$$V_S = \frac{(V_M + n(1.0))}{\sqrt{2}} = \frac{(30 + 2(1.0))}{\sqrt{2}} = 22.627V$$

As 22.627V is an obscure voltage, this is rounded up to 24V. 240VAC to 24VAC is one of the most widely used transformers in control systems engineering, enabling the components to be sourced easily. The transformers ratio is calculated below:

$$Ratio = \frac{V_{Primary}}{V_{Secondary}} = \frac{240V}{24V} = 10:1 \text{ Ratio}$$

The secondary current rating is then calculated:

$$I_S = \sqrt{2} \times I_{RMS} = \sqrt{2} \times 2 = 2.828A$$

The secondary power rating is then calculated:

$$Power = V_S \times I_{RMS} \times \sqrt{2} = 24 \times 2 \times \sqrt{2} = 67.9VA$$

The chosen component for the transformer is the RS Pro 100VA Panel Mount Transformer (Rs No. 880-2602) (Components, 2018). ~~This exceeds the specification offering a higher power rating than required. Table 9 displays the transformer requirements compared to the chosen model, this model operates at 230VAC +/- 10%, therefore the proposed 240VAC supply voltage can be used.~~

Transformer – Comparison of Requirement and Chosen Component		
Parameter	Required Value	RS PRO (880-2602)
Primary Voltage	240VAC	230VAC +/- 10%
Secondary Voltage	24VAC	24VAC
Power Rating	69.7VA	100VA
Operating Frequency	50Hz	50Hz
Mounting Type	Panel Mount	Panel Mount

Table 9 - Transformer : Comparison of Requirement and Chosen Component (Components, 2018)

3.7 Heatsink Design for thermal management

Semiconductors under operation produce heat which originates at its junction and travels outwards. The semiconductor's reliability and longevity are inversely proportional to the square of the change in junction temperature. For example, if the temperature change of the junction is halved, the life-expectancy of the component is quadrupled. Therefore, calculations are performed in order to ensure that the semiconductor can reliably operate within the power supply, if not a heatsink is required (Yong, 2012).

The primary heat source is the junction, the heat is transferred from the junction to the case during operation. If a heatsink is required, the transistor is mounted on the heatsink (case to heatsink) as seen in figure 7.

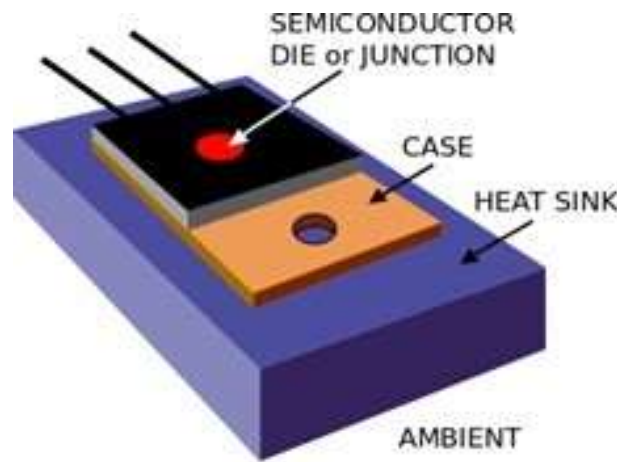


Figure 7 - Thermal boundaries of a Transistor (Yong, 2012)

The equation below is used to calculate the operating junction temperature:

$$T_J = T_A + P_D \times \phi_{JA}$$

Where:

$$T_J = \text{Junction Temperature } (^{\circ}\text{C})$$

$$T_A = \text{Ambient Air Temperature } (^{\circ}\text{C})$$

$$P_D = \text{Power Dissipated (W)}$$

$$\phi_{JA} = \text{Thermal Resistance from junction to ambient air } (^{\circ}\text{C/W})$$

The thermal resistance from junction-to-ambient air is calculated using the equation below:

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

Where:

ϕ_{JC} = Thermal Resistance of Junction to case ($^{\circ}\text{C}/\text{W}$)

ϕ_{CS} = Thermal Resistance of Case to Heatsink ($^{\circ}\text{C}/\text{W}$)

ϕ_{SA} = Thermal Resistance of Heatsink to Ambient Air ($^{\circ}\text{C}/\text{W}$)

From the datasheet seen in appendix 8.3.2, the chosen transistor (2N3055G) has a thermal resistance from junction-to-case (ϕ_{JC}) of $1.52^{\circ}\text{C}/\text{W}$. ~~It is also found in the 2N3055G datasheet that is implemented with a TO-204AA metallic case which has an ϕ_{cs} value of $0.5^{\circ}\text{C}/\text{W}$.~~

AND A

To calculate ϕ_{SA} , the power dissipated must be calculated:

$$P_D = V_O \times I_O$$

$$P_D = 12\text{V} \times 2\text{A} = 24\text{W}$$

The maximum transistor operating temperature without a heatsink is then calculated:

$$T_J = T_A + P_D \times \phi_{JA}$$

Re-arranged:

$$T_A = T_J - P_D \times \phi_{JA}$$

Where $T_J = 200$ and $\phi_{JA} = 1.52^{\circ}\text{C}/\text{W}$

$$T_A = 200 - (24 \times 1.52) = 163.52^{\circ}\text{C}/\text{W}$$

The equation $T_J = T_A + P_D \times \phi_{JA}$ is rearranged:

$$\phi_{JA} = \frac{T_J - T_A}{P_D}$$

This equation is substituted into the original equation to find θ_{SA} , Where, T_A = Ambient Temperature and P_D = Power Dissipated. For this calculation T_A is chosen at its worst-case scenario temperature of 25°C:

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

$$\theta_{SA} = \frac{200 - 25}{24} - 0.5 - 1.52 = 5.272^\circ\text{C/W}$$

θ_{JA} is calculated below:

$$\theta_{JA} = 1.52 + 0.5 + 5.272 = 7.292^\circ\text{C/W}$$

*NOT
NEEDED.*

It is determined that the transistor will need a heatsink, due to its maximum junction-to-case temperature of 1.52°C/W. A heatsink is chosen from Mouser (576403B00000G). This offers a thermal resistance 5.1°C/W through convection and is small enough to be mounted on a panel back plate (Farnell, 2018). The maximum junction temperature including ambient temperature is calculated as:

$$24 \times (5.272 + 0.5 + 1.52) + 25 = 199.6^\circ\text{C}$$

This is 0.4°C less than the transistors maximum junction temperature therefore it is permissible. As the panel is climate controlled to a maximum of 25°C it is not possible for the ambient temperature to increase to have a negative impact on the junction temperature.

4. Testing, results and analysis

All sub-circuits are functionally tested individually, this enables each circuit to be tested and refined if required to produce the correct output. Also, individual functional testing reduces the complexity of fault finding if faults occur, when all sub-circuits are tested, they are integrated to produce the final circuit.

4.1. Linear Regulator Testing

Figure 8 displays the Multisim design of the regulator circuit; ~~the regulator is designed from the calculated values from sections 3.1 & 3.2. Multisim does not include the Motorola MC1723C in its parts database, an alternative to this in the 'LM723CN' is used, this alternative is also characteristically suited to this application.~~ A value of 24Vdc is applied for V_{IN} as this imitates the supply from the rectifier.

Figure 8 shows that the circuit is operating under a 6Ω load which replicates the pump winding. The circuit operates close to the specification, a 3.2% error is seen on I_{OUT} compared to the desired 2A and a 3.29% error on V_{OUT} compared to the specifications 12Vdc requirement. ~~Alterations to passive components can be made to improve this.~~

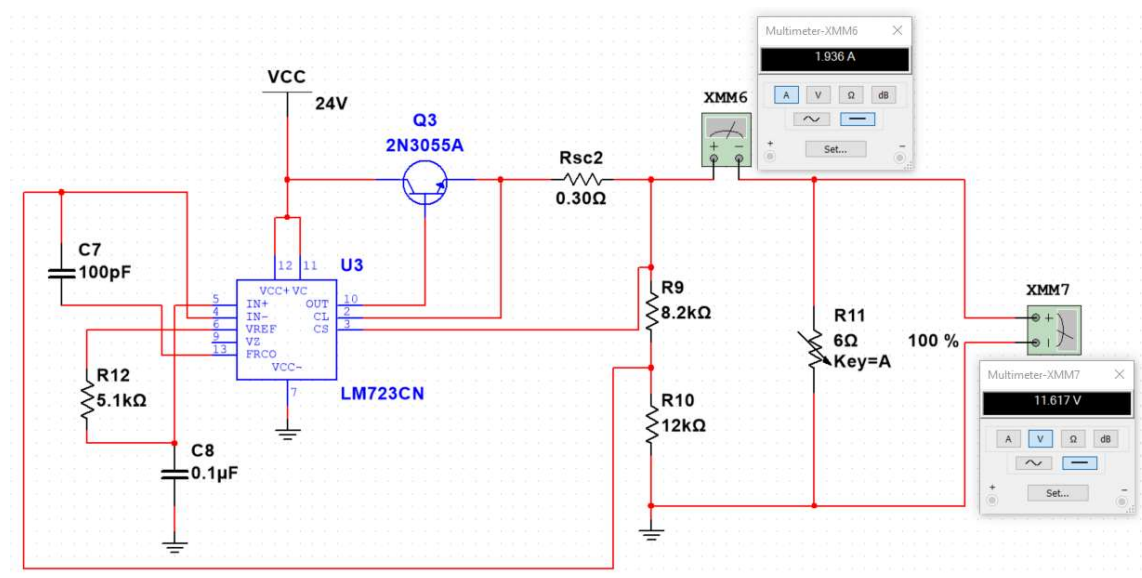


Figure 8 - Linear Regulator Testing: Original Component Values

To improve the accuracy of V_{OUT} and I_{OUT} , the value of R2 is altered. A Standard resistor value of is 11KΩ chosen. As seen in figure 9, these values vastly improve the values of V_{OUT} and I_{OUT} to 12Vdc at 2A respectively, meeting the exact specification and reducing the errors for V_{OUT} and I_{OUT} to 0%.

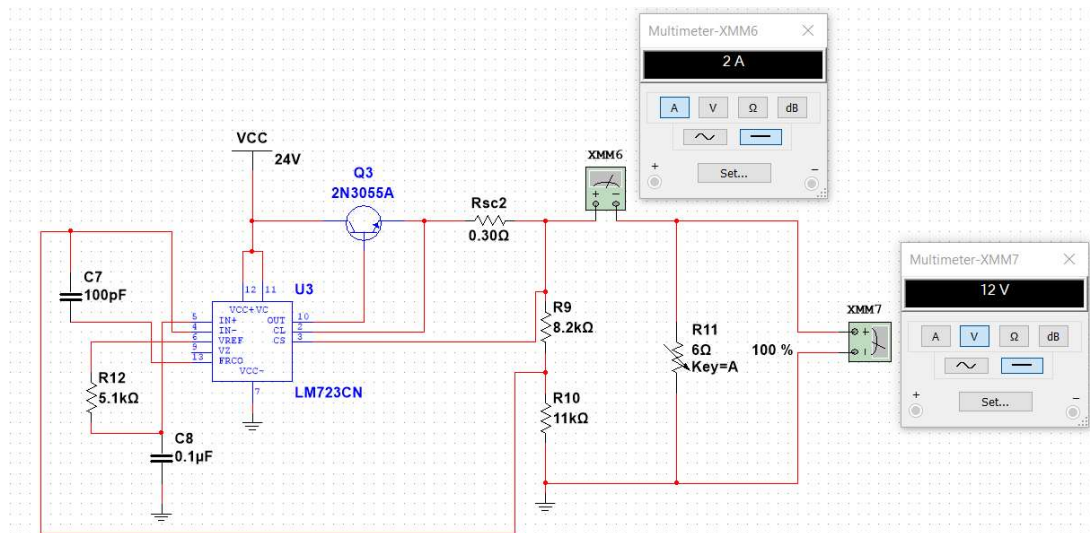


Figure 9 - Linear Regulator Testing: R2 adjusted to 11kΩ

Under full-load, the voltage across the series-pass transistor is measured, this allows for the power dissipated across it to be measured. As seen in figure 10, the collector-emitter voltage is 11.4V under full load, therefore the power dissipated across it:

$$P_D \text{ Full Load} = V_{CE} \times I_O$$

$$P_D \text{ Full Load} = 11.4V \times 2A = 22.8W$$

The datasheet in appendix 8.3.2 states that the 2N3055A transistor has a maximum power dissipation of 115W at 25°C, therefore the dissipated power at full load is 92.2W lower than the permitted value.

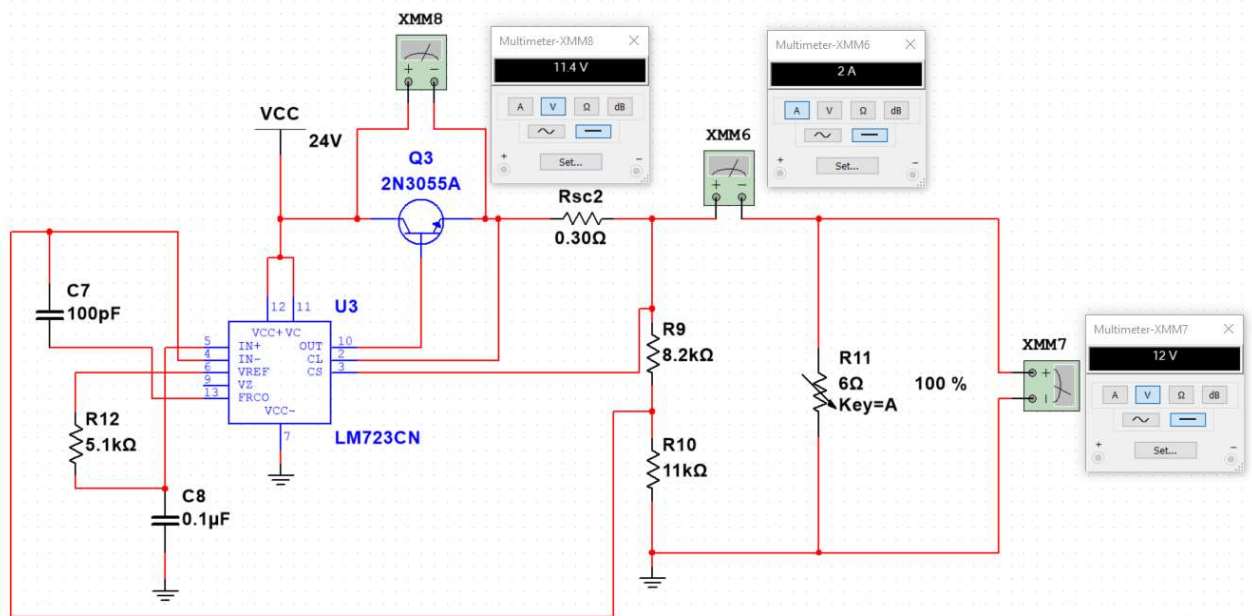


Figure 10 - Linear Regulator Testing: Power Dissipated across series-pass transistor under full-load

4.1.1 Short Circuit test of Linear Regulator

The short-circuit aspect of the design is also tested to ensure that the current-sense resistor is designed correctly, ensuring that it limits the current drawn under a 'short-circuit condition' (SCC) as designed, the load is set at 0Ω to imitate an SCC.

Figure 11 displays the linear regulator circuit under short-circuit conditions. As expected, V_{OUT} is measured at 2.049mV as there is no potential difference across the load. In turn drawing 49mA more than the specifications rated current at 2A, the rise in current under these conditions is minimal. This protects the series-pass transistor from thermal damage, restricting excessive power dissipation across it associated with short-circuit conditions.

The total power dissipation across the series-pass element is calculated below as 47.91W, this is well within the 2N3055A's rating of 115W at 25°C.

$$P_D \text{ Short Circuit} = 23.383 \times 2.049 = 47.91W$$

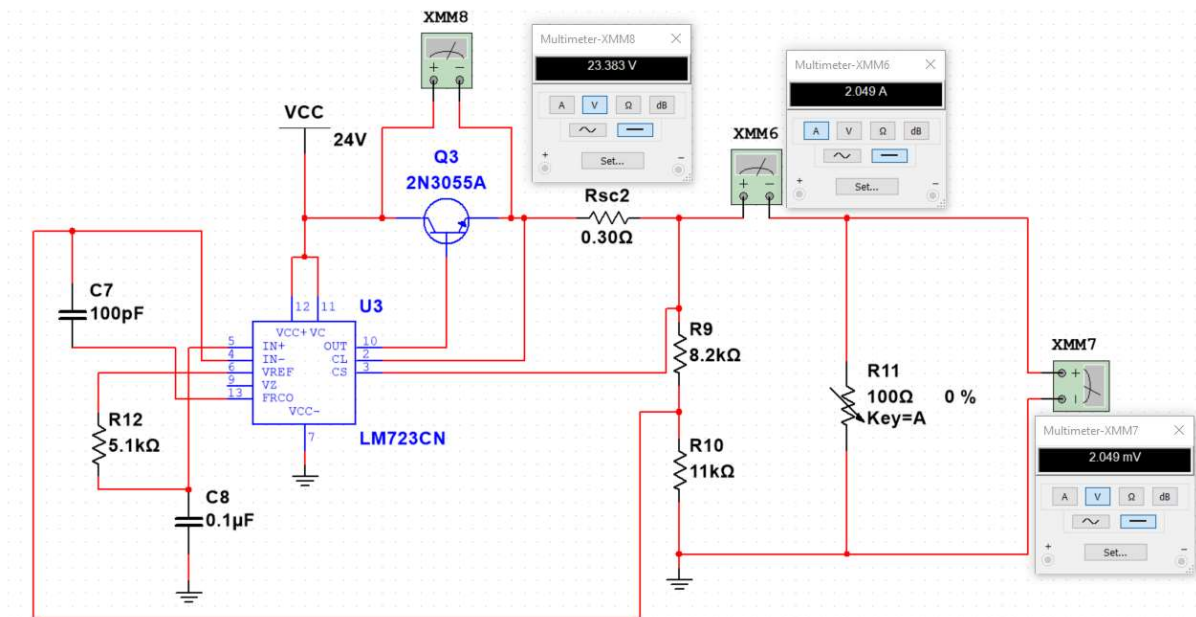


Figure 11 - Linear Regulator Testing: Power Dissipated across series-pass transistor under short-circuit

4.1.2 Line Regulation Test

Figure 12 shows the effect that varying the linear regulators input voltage (V_{IN}) has on the output voltage, the voltage was increased from 0Vdc to the regulators maximum rated input voltage of 40Vdc. As seen below, at approximately 16Vdc the desired output voltage of 12Vdc enters steady state, displaying the desired flat response, this is highly accurate to the calculation seen in section 3.1 where the minimum required value for ' V_{IN} ' was calculated at 16.2Vdc.

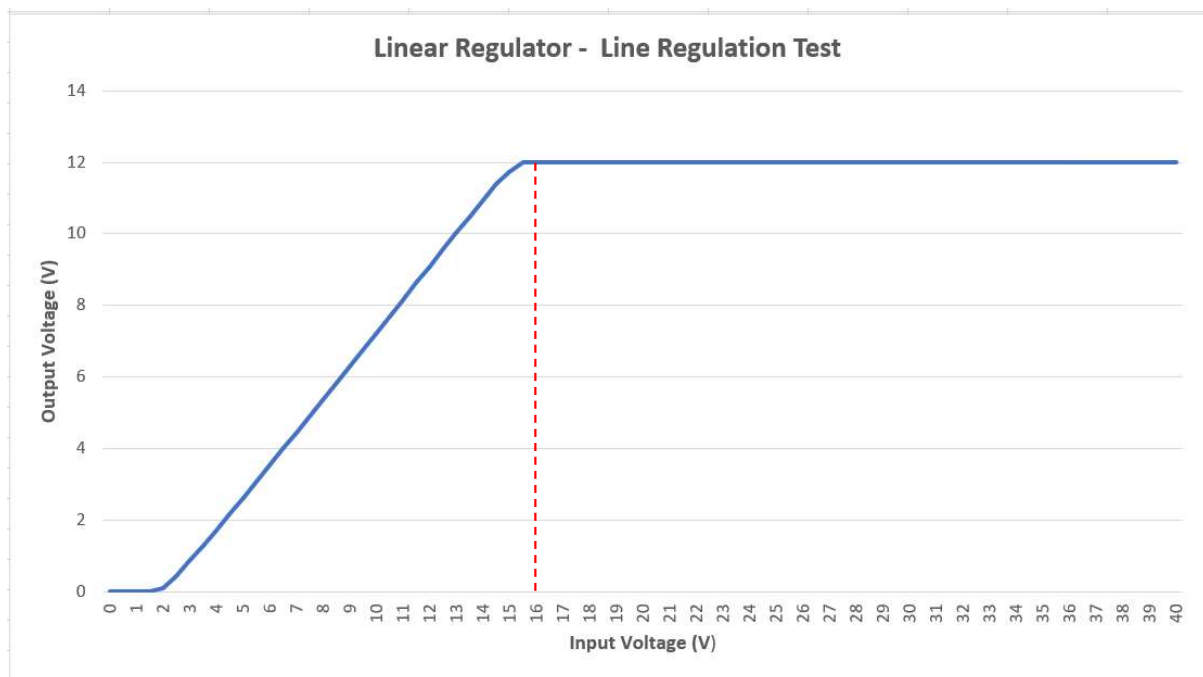


Figure 12 - Linear Regulator: Line Regulation Test Results

4.1.3 Load Regulation Test

The 'Load Regulation' test is performed to determine the power supply's ability to maintain its constant desired output voltage despite variability in the resistance of its load. Figure 13 shows the results from varying the load resistance between 0Ω and 20Ω, the values of load voltage (V_L) and load current (I_L) are plotted against each other to determine the effect that various loads have on these circuit parameters.

The test is started at 0Ω; therefore, the maximum possible current of 2.049A is drawn as this is under short-circuit conditions, at this load the output voltage is at its minimum of 2.049mV as there is no potential difference across the load. As the load is increased in 0.5Ω increments, the output voltage increases by roughly 1Vdc per increment, with miniscule current fall. At 6Ω optimum performance of the power supply is seen, delivering the specification requirement 12Vdc at 2A. As the load increased from 6.5Ω to 20Ω, the current fell steadily by around 110mA per increment. As expected, the load voltage was stable, marginally increasing by 85mV to 12.085V under a 20Ω load.

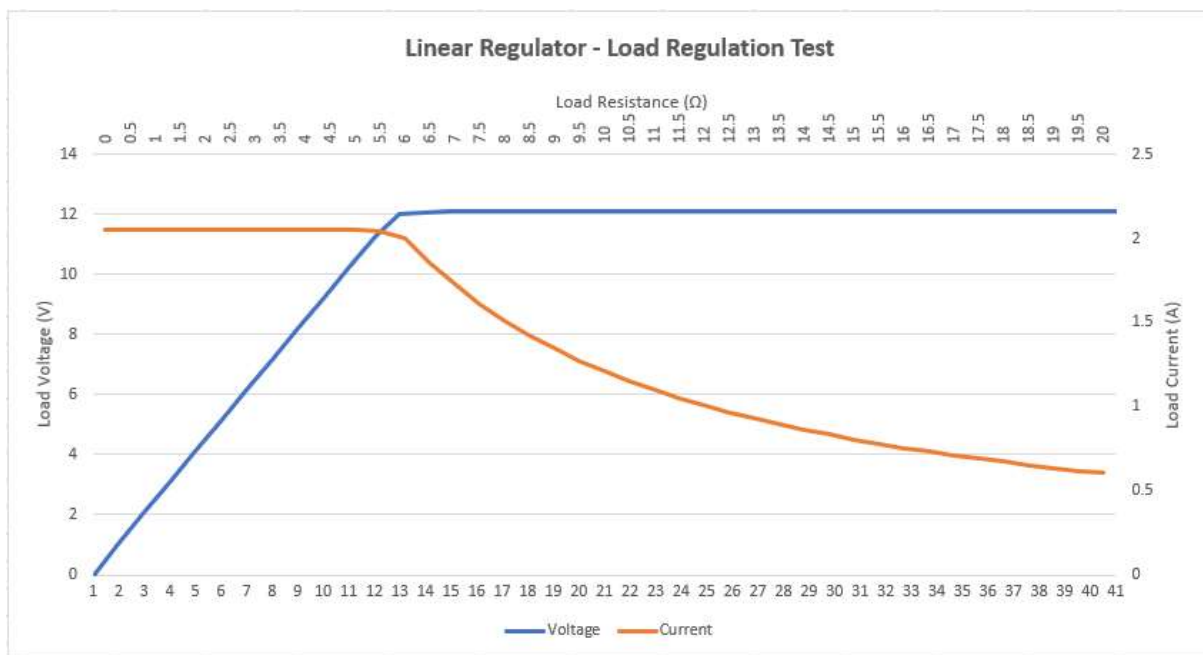


Figure 13 - Linear Regulator: Load Regulation Test Results

Figures 38 and 39 in appendix 8.4 display the circuit under full-load and no-load. Voltage under full-load measured at 12Vdc and Voltage under no-load measured at 12.087, therefore the voltage regulation percentage is calculated using the equation below, the specification requirement is $\leq 1\%$:

$$\% \text{ Voltage Regulation} = \frac{V_{NO-LOAD} - V_{FULL-LOAD}}{V_{NO-LOAD}} \times 100$$

$$\% \text{ Voltage Regulation} = \frac{12.087 - 12}{12.087} \times 100 = 0.72\%$$

4.2 Front End Testing

The second stage of testing is the testing of the individual front-end circuit elements, ~~these being the Transformer, Rectifier and Capacitor. Although the transformer was the last circuit element to be designed (other than the heatsink), it is more logical to test this first as it supplies the rectifier and capacitor elements~~

4.2.1 Transformer Testing

Figure 14 displays the simulated power supply circuit. The primary winding of the 10:1 isolating transformer is supplied with 240VAC, the 10:1 winding reduces this by a factor of 10 to 24VAC. 24VAC is a more manageable input voltage for the rectifier, offering dielectric isolation from the voltage supply.

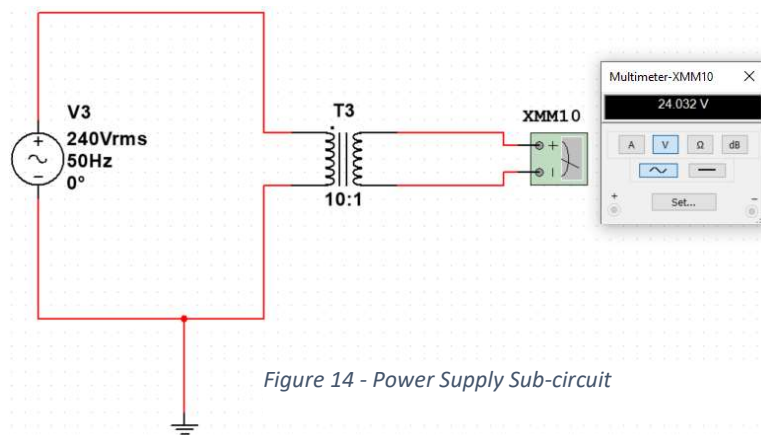


Figure 14 - Power Supply Sub-circuit

~~The transformer circuit is connected to an oscilloscope in order to display the process of the primary voltage being stepped down to 24VAC.~~ Figure 15 shows the simulation results of the oscilloscope, as the average RMS voltage is difficult to determine on Multisim, the maximum voltage (V_{MAX}) is found at 339.282VAC for the primary and 33.928VAC for the secondary.

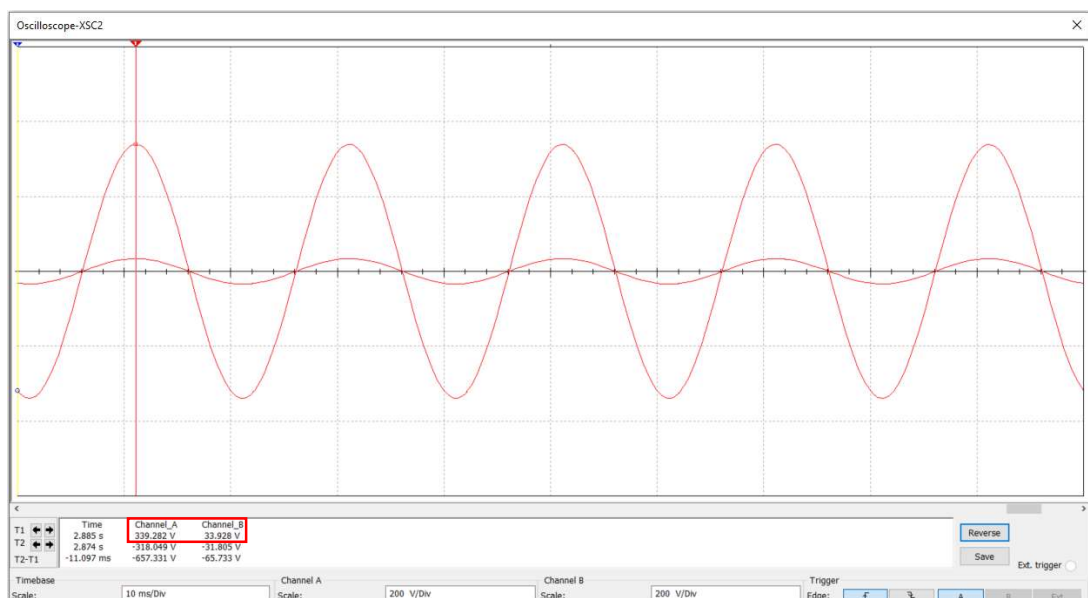


Figure 15 - Power Supply Sub-circuit: Oscilloscope results under test

Using the equation below the RMS voltage is calculated:

$$RMS = V_{peak} \div \sqrt{2}$$

Therefore:

$$Primary = 339.282 \div \sqrt{2} = 239.9VAC$$

$$Secondary = 33.928 \div \sqrt{2} = 23.99VAC$$

The waveforms seen in figure 14 and equations prove that the front-end of the power supply is operating to the specification.

4.2.2 Rectifier Testing

The next stage of the front end is the rectifier, figure 16 shows the GBU6G-E3/45 bridge rectifier connected to the output of the isolating transformer. The multimeter connected to the output of the bridge rectifier displays 24.927Vdc, measuring 927mV greater than expected. This error is likely caused during rectification as Multisim cannot determine if the output is DC or RMS. This error is further explained in section 4.3.

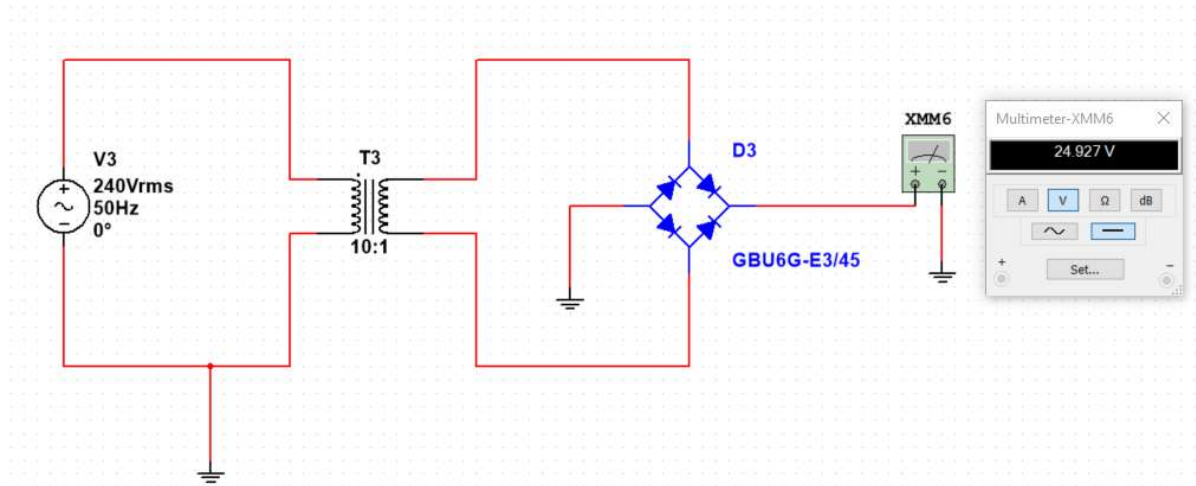


Figure 16 - Rectifier Sub-circuit

Figure 17 shows the waveform obtained from the oscilloscope, this shows the rippled DC voltage output from the bridge rectifier at around 24.927V, proving the circuits operation is correct including the 0.9V error. The waveform is proven to be rippled DC as it is constantly in the positive half of the oscilloscope graph with the inclusion of some AC component seen by the oscillations.

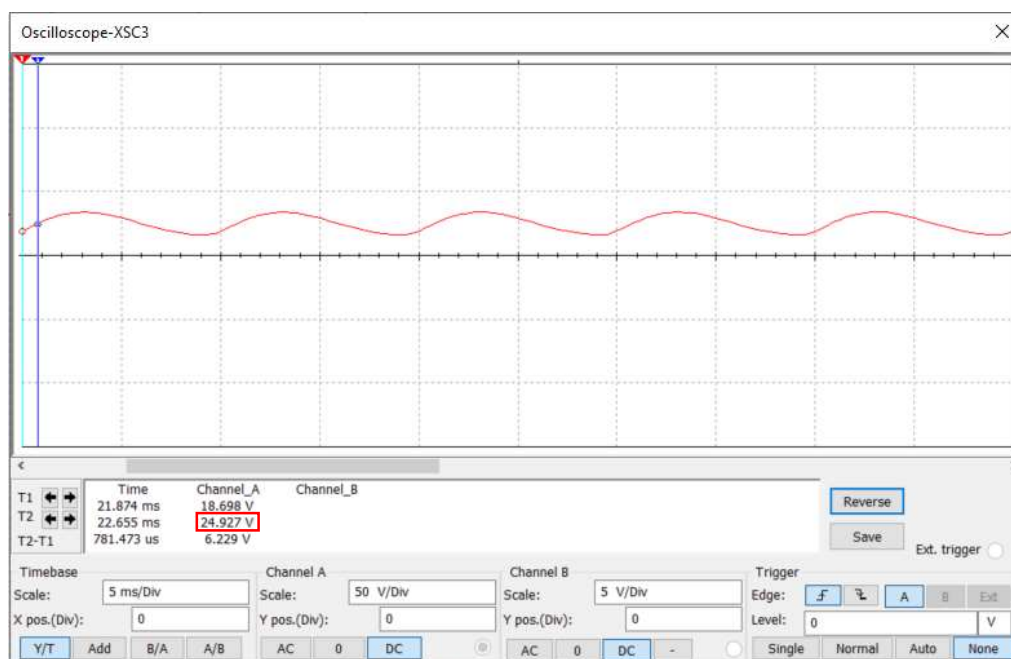


Figure 17 - Rectifier Sub-circuit: Oscilloscope result under test

4.2.3 Capacitor Testing

Figure 18 shows the addition of the smoothing capacitor to the rectifier output, this will smooth the output from a rippled DC waveform to a pure DC output. However, the addition of the capacitor has caused the voltage to increase to 33.18V, this is due to Multisim not being able to interpret the voltage as rectified DC, as the output of the rectifier is not pure DC nor a Sinewave, Multisim cannot determine it as DC or RMS. The regulator has a high tolerance to the incoming voltage rating as demonstrated in the line regulation test, therefore an input of 33.18Vdc will have no negative effect on the circuit performance.

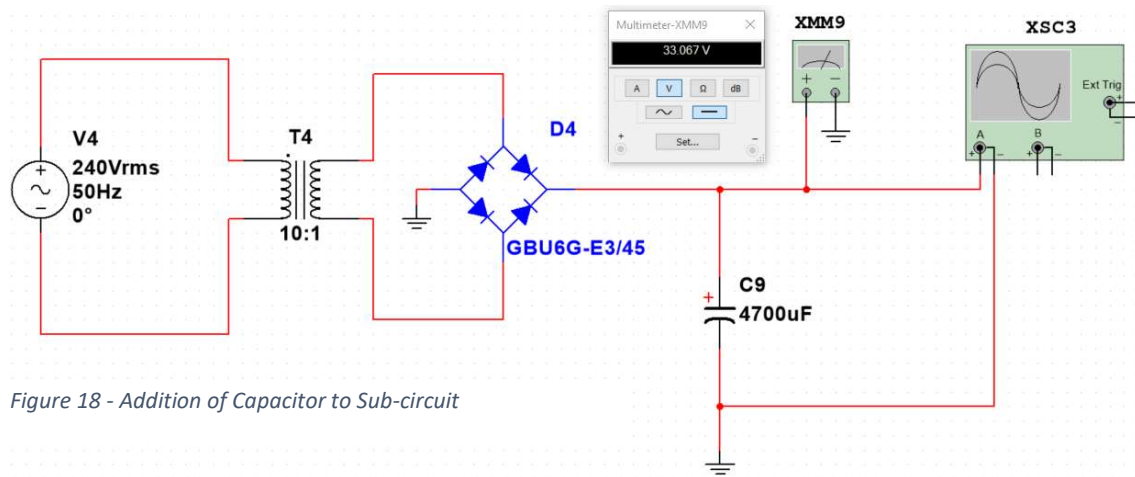


Figure 18 - Addition of Capacitor to Sub-circuit

Figure 19 shows the oscilloscope graph of the front-end circuit with the capacitor, it shows that during the initial power on period the capacitor charges, after it has charged it enters steady-state DC.

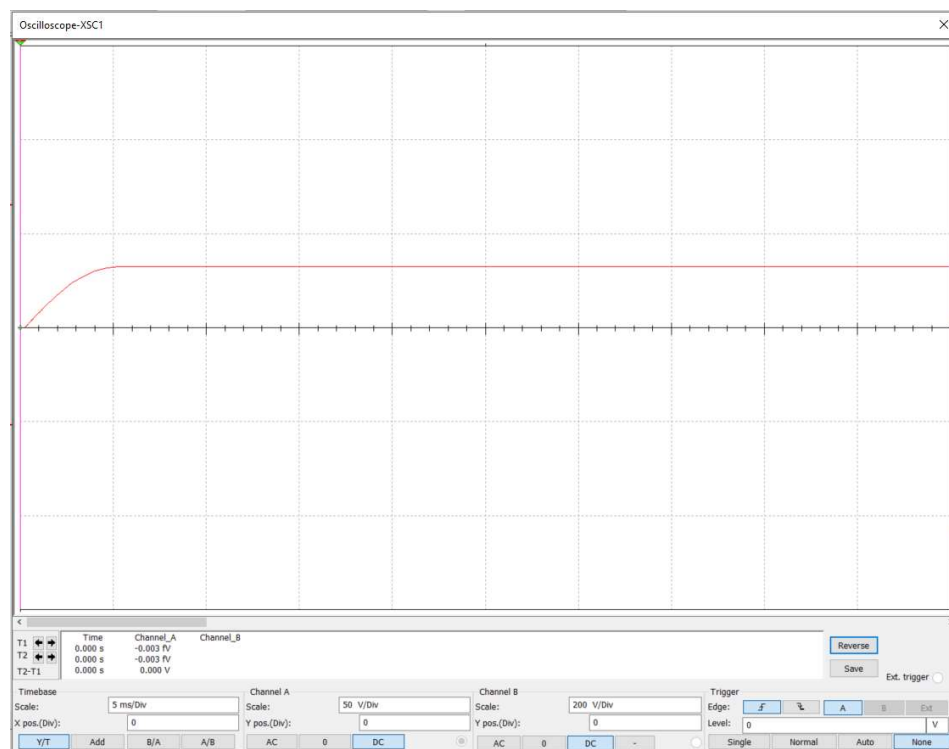


Figure 19 - Addition of capacitor to sub-circuit – Capacitor charge test

4.3 Testing Full Circuit Integration

Figure 20 shows the final circuit. The sub-circuits that create the ‘front-end’ circuit is integrated with the linear regulator circuit to produce the full power supply circuit. Figure 20 shows that under the load that imitates the pump winding (6Ω), the power supply successfully delivers exactly 2A at 12Vdc, successfully meeting the customer specification. The current-sense resistor (R_{sc}) operates well in conjunction with the linear voltage regulator to deliver a constant current of 2A.

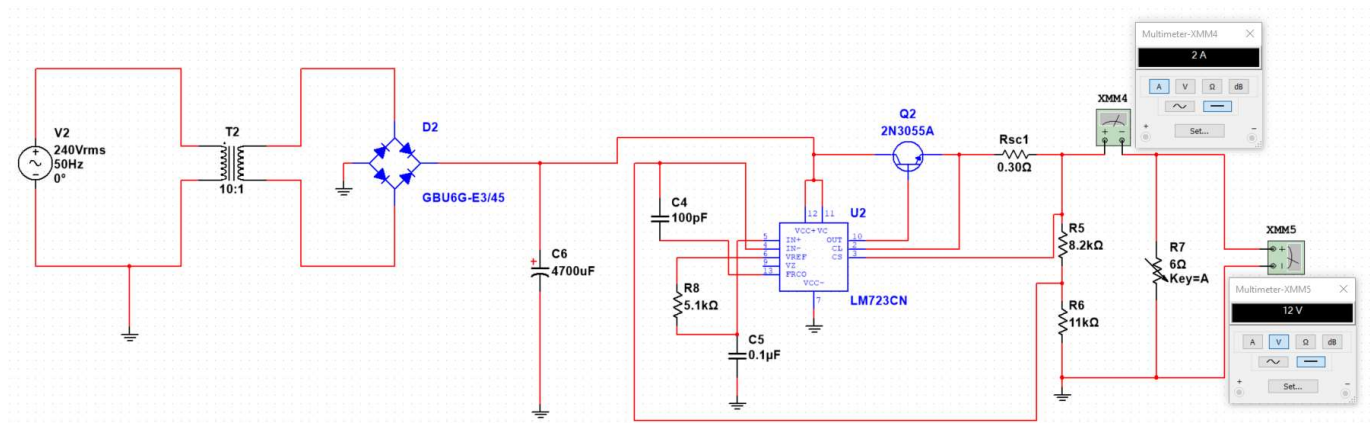


Figure 20 - Power Supply Circuit: Integration of Sub-circuits

A four-channel oscilloscope is added to the circuit seen in appendix 8.5. Figure 21 visually shows the full process of the power supply from the 240VAC input to the rectified and regulated 12VDC output. The red trace displays the 240VAC input waveform, the blue trace displays the 10:1 step-down ratio of the supply to 24VAC, the green trace displays the rectification and smoothing of the AC signal to produce a rippled DC waveform, the purple waveform shows the regulated 12VDC output from the linear regulator. These waveforms prove the full functionality of the power supply.

The discrepancy outlined in sections 4.2.2 and 4.2.3 is displayed on ‘Channel C’. The rectified and smoothed ‘DC’ output from the capacitor is measuring a voltage of 32.122Vdc. This discrepancy is not a design error, but due to Multisims inability to interpret a rectified AC voltage as DC, as it is neither a pure sinewave nor pure DC it cannot accurately determine its magnitude. This has no effect on the overall circuit due to the high input voltage tolerance of the regulator, as both the MC1723C chosen for the design requirements and the LM723CN used in the simulation both allow input voltages up to and including 40Vdc.

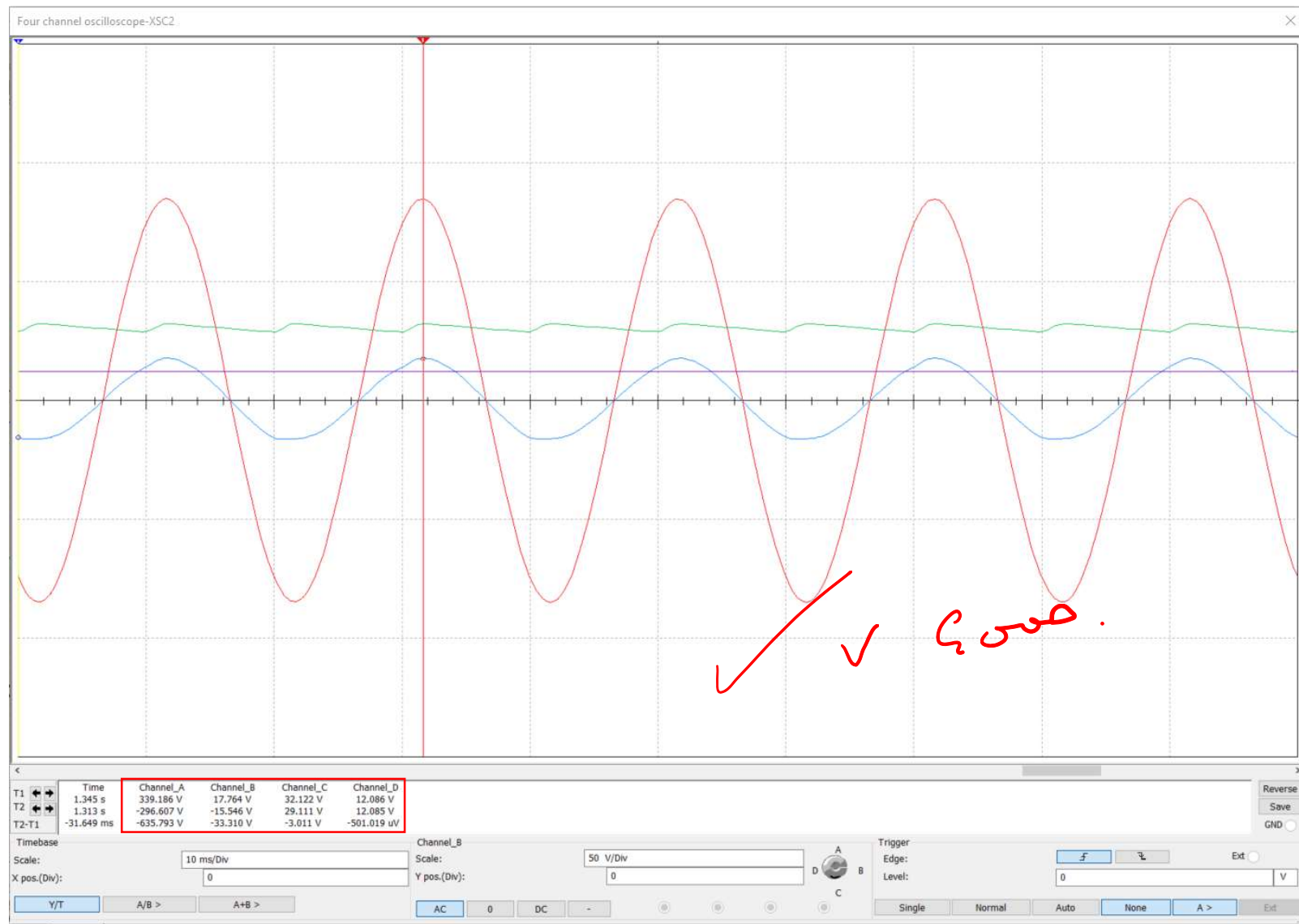


Figure 21 - Power Supply Circuit: 4 channel Oscilloscope results

An oscilloscope is connected across the load as seen in figure 22. The oscilloscope is connected in order to measure the AC component in the regulated DC output, known as ripple voltage.

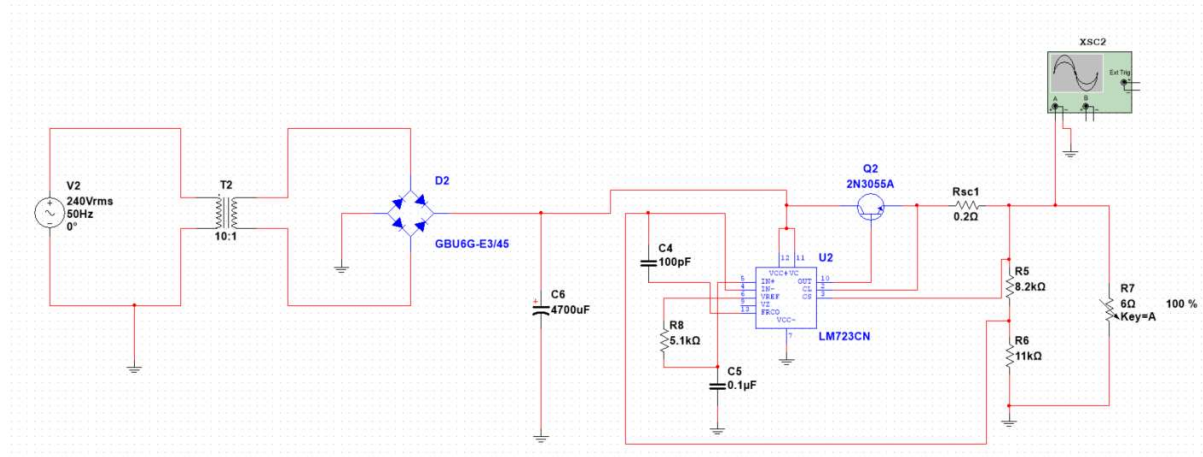


Figure 22 - Power Supply Circuit: Oscilloscope across load to measure ripple voltage

Figure 23 displays the measure ripple voltage at $578.5\mu V^{p-p}$, this is marginal ripple and is within the specifications permitted value of $1mV^{p-p}$. This value is so miniscule that the oscilloscope is set to $500\mu V/Div$ in order to view it.

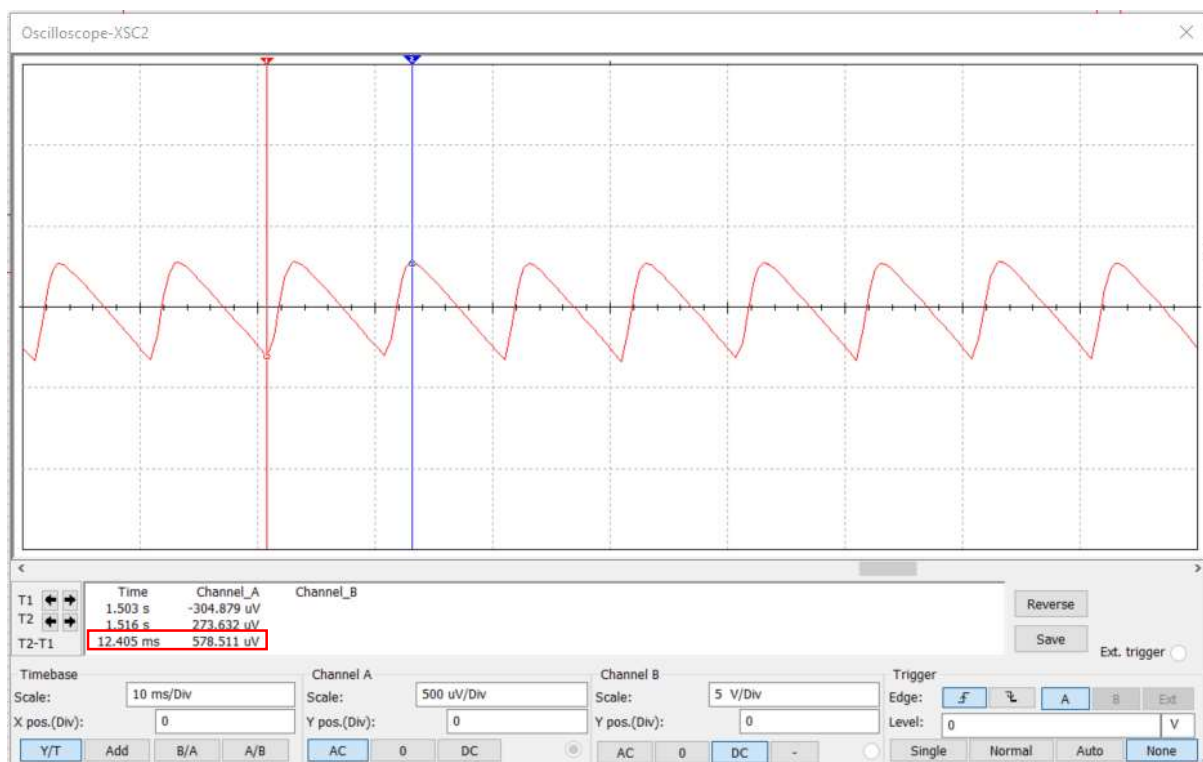


Figure 23 - Power Supply Circuit: Output Ripple

5. Component List

Table 10 displays the list of components required for the power supply construction, including suppliers, part numbers, manufacturers, quantities and costs per unit.

SGEE6005 - Power Supply Design Parts List						
Component	Component Description	Supplier	Part Number	Manufacturer	Qty	Cost per Unit
Regulator	MC1723C Voltage Regulator	Finedon Electronics	MC1723C	Motorola	1	3.34
NPN Transistor	2N3055 Series Pass Transistor	RS Components	545-2210	onsemi	1	5.56
Smoothing Capacitor	KEMET 4700uF Electrolytic Capacitor	RS Components	381-9756	KEMET	1	3.165
Bridge Rectifier *1	GBU66-E3/45 6A 400V, 4-Pin GBU	RS Components	812-2338	Vishay	5	1.59
Transformer	Panel mount - 100VA, 230VAC-24VAC	RS Components	880-2602	RS PRO	1	58.46
Heatsink	Square Basket, Heat Sink, TO3, Horizontal, 5.1C/W, 31.75mm	Farnell	576403B00000G	AAVID	1	£1.72
R1	8.2kΩ 25W Wire Wound Chassis Mount Resistor ±5%	RS Components	615-0448	ARCOL	1	2.85
R2	11kΩ 100W Aluminium Chassis Mount Resistor ±1%	RS Components	162-3563	ARCOL	1	9.88
R3	5kΩ 25W Wire Wound Chassis Mount Resistor ±1%	RS Components	845-9848	Vishay	1	3.06
Rsc	200mΩ 50W Aluminium Chassis Mount Resistor ±1%	RS Components	162-3451	ARCOL	1	4.604
C1 *2	Single Layer Ceramic Capacitor 100pF 6kV dc ±10%	RS Components	180-5121	RS PRO	100	0.058
C2 *3	100nF Multilayer Ceramic Capacitor MLCC 50V dc ±20%	RS Components	538-1203	KEMET	5	0.338
Total Cost (£)		£107.99				

Table 10 – Power Supply Parts List

*1 - 812-2338 is only available in quantities of 5

*2 – 280-5121 is only available in quantities of 1000

*3 - 538-1203 is only available in quantities of 5

6. Conclusion and Recommendations

The design, implementation and testing of the power supply has proved highly successful, meeting the customers specification and producing a stable power supply system. The specification outlined by the customer provided valid requirements for the power supply to be designed upon. ~~Research undertaken into the individual sub-elements that are implemented together to create the power supply circuit provided the underpinning knowledge and understanding required to design the system.~~ Research into Regulated power supply's outlined the differences between the two main variants, the 'Series Regulator' and the 'Shunt Regulator'. It was found that the series is efficient under higher loads whilst providing excellent voltage regulation, therefore this configuration was chosen.

Further research was undertaken into a suitable regulator for this application, it was found that Motorola's MC1723 is suited to this application, allowing for the integration of a series-pass transistor in the NPN boost configuration to deliver the required 2A current. ~~The datasheets for these components were found to be extensively useful. The implementation of tried and tested calculations was effective, enabling efficient design of the power supply in smaller sub-circuits for the regulator, series-pass transistor, and the 'front end' circuit.~~ The use of 'Schade Curve' graphs were found to be essential in accurately calculating parameters for the input stage and rectifier.

Essential calculations on the thermal analysis of the system found that the series-pass transistor will be operating in temperatures far greater than its specification, the implementation of these calculations is essential in providing safety measures in terms of over-temperature, these calculations determined that a heatsink is a requirement for this design. ~~Components were chosen after every design stage from reputable electronic suppliers, allowing for all components to be successfully chosen, either meeting or exceeding the design requirements.~~

Testing was initially undertaken on each individual sub-circuit; ~~this is a quicker method of diagnosing faults compared to the final circuit, drastically reducing the complexity. Throughout the design stage a clear understanding was developed on the expected operation of each sub-circuit, therefore testing the sub-circuits ensured that the final overall integrated circuit will work~~

The testing and analysis performed was highly successful, results obtained correlated with the expectations outlined in the specification and design stages. The initial testing of the linear regulator was partially successful, it proved that the regulator could deliver and maintain a steady voltage and current at the desired load, however, these values were close but did not meet the specification with errors of 3% for both V_o and I_o . The value of resistor 'R2' was lowered from 12k Ω to the next 'standard resistor value' of 11k Ω , this enabled the regulator to

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meet the exact specification requirement of 12Vdc at 2A under a 6Ω load, ~~reducing the errors of V_O and I_O to 0%, proving that the linear regulator is performing as required.~~

Further tests were performed on the linear regulator sub-circuit to ensure that the power dissipated across the series-pass transistor under full-load and short-circuit meets the transistor requirements of not exceeding 115W at 25°C. Calculations found that 22.8W is dissipated under full-load, increasing to 47.9W under short-circuit conditions, proving that the series-pass transistor is correctly suited for this application. Also proving that the current-sense resistor is working correctly in conjunction with the voltage regulator, limiting excessive current flow under short-circuit conditions to only 49mA above rated current.

Both 'Line Regulation' and 'Load Regulation' tests were performed on the regulator. The line regulation test displayed the high tolerance that the regulator has on its incoming voltage. Varying the input voltage from 0Vdc to 40Vdc found that the output voltage reached the desired 12Vdc output at an input voltage of 16Vdc, correlating with the calculations seen in section 3.1, the desired output was successfully delivered between input voltages of 16Vdc-40Vdc, correlating with the manufacturer's documentation. The load regulation test displayed that the regulator successfully maintained an output voltage of 12Vdc as the load was increased passed 6Ω, also providing visual indication that the power supply can deliver 12Vdc at 2A.

Tests were then undertaken on the front-end sub-circuit. ~~The transformer, rectifier and capacitor were all tested.~~ Both the transformer and rectifier performed well, however, the output from the capacitor increased 9.067Vdc above the ideal V_{IN} value of 24Vdc, the reasoning behind this is explained below.

The implementation of the two sub-circuits was highly successful. The final power supply circuit was tested under the 6Ω load, prosperously delivering the specification requirements of 12Vdc at 2A with no error. The addition of a four-channel oscilloscope connected at the transformer, rectifier, capacitor and regulator output was particularly useful in displaying the full process of producing regulated 12Vdc from a 240VAC input.

The only issues that arose during testing were due to Multisims inability to define the output from the front-end circuit as DC. As the output from this circuit is neither AC RMS nor pure DC, Multisim cannot determine it as DC, in turn producing an incorrect output of 33.067Vdc. Thus, causing greater power dissipation across the transistor's collector-emitter junction. As this is a simulation error, and not a design error, these errors are negated with the most credible results from section 4.1 being taken as the true results.

The final test was performed to measure the remaining 'AC component' in the regulated DC voltage, this was measured at a minuscule value of $578.5\mu V^{p-p}$, far less than the required minimum value of $1mV^{p-p}$.

Table 11 portrays the success of the system design and implementation, comparing the specification requirements to the outcome of the design. As seen in this table, the simulated circuit met or exceeded the requirements outlined in the specification proving that the report is successful as a whole.

The choice of physical components in the design section enables a proven circuit to be constructed using tried and tested components under the customer's budget.

The 'bottom-up' approach was proven to be a successful design method, choosing the first component to be the voltage regulator allowed for proven calculations to be implemented to calculate the required active and passive components to suit the voltage regulator. The circuit design would have been far more laborious starting from the transformer sub-circuit, due to the stringent component requirements to complement the regulator.

As a recommendation, over voltage protection could have been implemented in the circuit, methods such as 'Voltage Clamping' where a Zener diode is connected across the regulators output terminal. This Zener diode will be rated slightly greater than the maximum output voltage, therefore under normal operating conditions the diode will not conduct. If the output voltage was to rise above the Zener diodes rated voltage, the diode will conduct clamping the voltage at just above rated voltage. More complex solutions could also be implemented such as the 'SCR Crowbar' method. However, for this circuit under the test conditions the voltage did not fluctuate to a dangerous level. Further stress testing could have been performed to analyse the linear regulators response to excessive voltage.

An additional recommendation is the design of the power supply implementing a 'Shunt Regulator' to replace the linear regulator allowing for both power supply's to be compared technically in terms of operation, performance and cost.

Further recommendations include the design of a 'Switch Mode Power Supply' to compare the design complexity, operation and efficiency to that of the Linear Regulated Power Supply.

*THIS ISN'T A PRACTICAL
OPTION. SMPS ARE VERY
HARD TO DESIGN.*

Power Supply Specification Requirements compared to End Design		
Parameter	Requirement	End Design
<i>Supply Voltage (Transformer Primary)</i>	<i>240VAC -6/+10%</i>	<i>240VAC</i>
<i>Supply Frequency</i>	<i>50Hz</i>	<i>50Hz</i>
<i>Output Voltage (Vdc)</i>	<i>12Vdc $\pm$ 0.1V</i>	<i>12V</i>
<i>Output Current (Idc)</i>	<i>2Adc $\pm$ 0.5A</i>	<i>2A</i>
<i>Temperature Rating</i>	<i>0°C to 25°C</i>	<i>Will operate comfortably between 0°C to 25°C</i>
<i>Output Ripple</i>	<i>$\leq 1\text{mV}_{P-P}$</i>	<i>578.511 μV_{P-P}</i>
<i>Load Regulation</i>	<i>$\leq 0.1\%$</i>	<i>0.72%</i>
<i>Dimensions</i>	<i>200mm x 200mm x 130mm</i>	<i>150mm x 140mm x 107mm</i>
<i>Weight</i>	<i>Not applicable (Not part of a portable system)</i>	<i>-</i>
<i>IP Rating</i>	<i>Mounted in IP65 control panel</i>	<i>To be mounted in an IP65 control panel</i>
<i>Cost</i>	<i>$\leq$ £160</i>	<i>£107.99</i>

Table 11 – Power Supply Specification Requirements compared to End Design

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8. Appendix for diagrams, data sheets, results tables

8.1 Standard Resistor Values

Standard Resistor Values ($\pm 5\%$)						
1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M

Figure 24 - Table of Standard Resistor Values (ch00ftech, 2012)

8.2 Standard Capacitor Values

These are the most commonly available capacitor values. Tolerances are highly dependent on dielectric and package type.										
pF	pF	pF	pF	μF	μF	μF	μF	μF	μF	μF
1.0	10	100	1000	0.01	0.1	1.0	10	100	1000	10,000
1.1	11	110	1100							
1.2	12	120	1200							
1.3	13	130	1300							
1.5	15	150	1500	0.015	0.15	1.5	15	150	1500	
1.6	16	160	1600							
1.8	18	180	1800							
2.0	20	200	2000							
2.2	22	220	2200	0.022	0.22	2.2	22	220	2200	
2.4	24	240	2400							
2.7	27	270	2700							
3.0	30	300	3000							
3.3	33	330	3300	0.033	0.33	3.3	33	330	3300	
3.6	36	360	3600							
3.9	39	390	3900							
4.3	43	430	4300							
4.7	47	470	4700	0.047	0.47	4.7	47	470	4700	
5.1	51	510	5100							
5.6	56	560	5600							
6.2	62	620	6200							
6.8	68	680	6800	0.068	0.68	6.8	68	680	6800	
7.5	75	750	7500							
8.2	82	820	8200							
9.1	91	910	9100							

Common Capacitor Working Voltages (DC), by Capacitor Type				
Ceramic	Electrolytic	Tantalum	Mylar (Polyester)	Mylar (Metal Film)
	10V	10V		
16V	16V	16V		
		20V		
25V	25V	25V		
	35V	35V		
50V	50V	50V	50V	
	63V			
100V	100V		100V	
	160V			
			200V	
	250V			250V
	350V			
			400V	400V
	450V			
600V				
				630V
1000V				

Figure 25 - Table of Standard Capacitor Values (rtcafe, 2011)

8.3 Component Datasheets

8.3.1 MC1723C Voltage Regulator Datasheet



MOTOROLA

Order this document by MC1723C/D

MC1723C

Voltage Regulator

The MC1723C is a positive or negative voltage regulator designed to deliver load current to 150 mAdc. Output current capability can be increased to several amperes through use of one or more external pass transistors. MC1723C is specified for operation over the commercial temperature range (0° to +70°C).

- Output Voltage Adjustable from 2.0 Vdc to 37 Vdc
- Output Current to 150 mAdc Without External Pass Transistors
- 0.01% Line and 0.03% Load Regulation
- Adjustable Short Circuit Protection

VOLTAGE REGULATOR

SEMICONDUCTOR
TECHNICAL DATA

Figure 26 - Motorola MC1723C Datasheet (Motorola, 2001)

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	mAdc
Current from V_{ref}	I_{ref}	15	mAdc
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

Figure 27 - Motorola MC1723C Datasheet: Maximum Ratings (Motorola, 2001)

ELECTRICAL CHARACTERISTICS ($T_A = +25^\circ\text{C}$, $V_{in} = 12\text{ Vdc}$, $V_O = 5.0\text{ Vdc}$, $I_L = 1.0\text{ mAdc}$, $R_{SC} = 0$, $C_1 = 100\text{ pF}$, $C_{ref} = 0$ 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	mAdc
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	%/ $^\circ\text{C}$
Line Regulation ($T_A = 25^\circ\text{C}$) $\begin{cases} 12\text{ V} < V_{in} < 15\text{ V} \\ 12\text{ V} < V_{in} < 40\text{ V} \end{cases}$ ($T_{low} < T_A < T_{high}$) $12\text{ V} < V_{in} < 15\text{ V}$	Reg_{line}	– – –	0.01 0.1 –	0.1 0.5 0.3	% V_O
Load Regulation ($1.0\text{ mA} < I_L < 50\text{ mA}$) $T_A = 25^\circ\text{C}$ $T_{low} < T_A < T_{high}$	Reg_{load}	– –	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	–	mAdc
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 28 - Motorola MC1723C Datasheet: Electrical Characteristics (Motorola, 2001)

8.3.2 2N3055 NPN Transistor Datasheet

2N3055(NPN), MJ2955(PNP)

Preferred Device

Complementary Silicon Power Transistors

Complementary silicon power transistors are designed for general-purpose switching and amplifier applications.

Features

- DC Current Gain – $h_{FE} = 20-70$ @ $I_C = 4 \text{ A dc}$
- Collector-Emitter Saturation Voltage –
 $V_{CE(sat)} = 1.1 \text{ V dc (Max) @ } I_C = 4 \text{ A dc}$
- Excellent Safe Operating Area
- Pb-Free Packages are Available*

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	A dc
Base Current	I_B	7	A dc
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	$^\circ\text{C}$

Maximum ratings are those values beyond which device damage can occur. Maximum ratings applied to the device are individual stress limit values (not normal operating conditions) and are not valid simultaneously. If these limits are exceeded, device functional operation is not implied, damage may occur and reliability may be affected.



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**15 AMPERE
POWER TRANSISTORS
COMPLEMENTARY SILICON
60 VOLTS, 115 WATTS**



TO-204AA (TO-3)
CASE 1-07
STYLE 1

MARKING DIAGRAM



Figure 29 - 2N3055 Datasheet: Maximum Ratings (onsemi, 2000)

2N3055(NPN), MJ2955(PNP)

THERMAL CHARACTERISTICS

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

ELECTRICAL CHARACTERISTICS ($T_C = 25^{\circ}\text{C}$ unless otherwise noted)

Characteristic	Symbol	Min	Max	Unit
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OFF CHARACTERISTICS*

Collector-Emitter Sustaining Voltage (Note 1) ($I_C = 200\text{ mAdc}$, $I_B = 0$)	$V_{CEO(sus)}$	60	–	Vdc
Collector-Emitter Sustaining Voltage (Note 1) ($I_C = 200\text{ mAdc}$, $R_{BE} = 100\ \Omega$)	$V_{CER(sus)}$	70	–	Vdc
Collector Cutoff Current ($V_{CE} = 30\text{ Vdc}$, $I_B = 0$)	I_{CEO}	–	0.7	mAdc
Collector Cutoff Current ($V_{CE} = 100\text{ Vdc}$, $V_{BE(off)} = 1.5\text{ Vdc}$) ($V_{CE} = 100\text{ Vdc}$, $V_{BE(off)} = 1.5\text{ Vdc}$, $T_C = 150^{\circ}\text{C}$)	I_{CEX}	–	1.0 5.0	mAdc
Emitter Cutoff Current ($V_{BE} = 7.0\text{ Vdc}$, $I_C = 0$)	I_{EBO}	–	5.0	mAdc

ON CHARACTERISTICS* (Note 1)

DC Current Gain ($I_C = 4.0\text{ Adc}$, $V_{CE} = 4.0\text{ Vdc}$) ($I_C = 10\text{ Adc}$, $V_{CE} = 4.0\text{ Vdc}$)	h_{FE}	20 5.0	70 –	–
Collector-Emitter Saturation Voltage ($I_C = 4.0\text{ Adc}$, $I_B = 400\text{ mAdc}$) ($I_C = 10\text{ Adc}$, $I_B = 3.3\text{ Adc}$)	$V_{CE(sat)}$	–	1.1 3.0	Vdc
Base-Emitter On Voltage ($I_C = 4.0\text{ Adc}$, $V_{CE} = 4.0\text{ Vdc}$)	$V_{BE(on)}$	–	1.5	Vdc

SECOND BREAKDOWN

Second Breakdown Collector Current with Base Forward Biased ($V_{CE} = 40\text{ Vdc}$, $t = 1.0\text{ s}$, Nonrepetitive)	$I_{s/b}$	2.87	–	Adc
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DYNAMIC CHARACTERISTICS

Current Gain – Bandwidth Product ($I_C = 0.5\text{ Adc}$, $V_{CE} = 10\text{ Vdc}$, $f = 1.0\text{ MHz}$)	f_T	2.5	–	MHz
*Small-Signal Current Gain ($I_C = 1.0\text{ Adc}$, $V_{CE} = 4.0\text{ Vdc}$, $f = 1.0\text{ kHz}$)	h_{fe}	15	120	–
*Small-Signal Current Gain Cutoff Frequency ($V_{CE} = 4.0\text{ Vdc}$, $I_C = 1.0\text{ Adc}$, $f = 1.0\text{ kHz}$)	f_{hfe}	10	–	kHz

*Indicates Within JEDEC Registration. (2N3055)

1. Pulse Test: Pulse Width $\leq 300\ \mu\text{s}$, Duty Cycle $\leq 2.0\%$.

Figure 30 - 2N3055 Datasheet: Characteristics (onsemi, 2000)

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

Figure 31 - TO-204 (TO-203) θ_{CS} values

8.3.3 KEMET 4700μF Electrolytic Capacitor 63V dc

Performance Characteristics

Item	Performance Characteristics	
Capacitance Range	22 – 150,000 μF	
Rated Voltage	40 – 450 VDC	
Operating Temperature	-40 to +85°C	
Storage Temperature Range	-55 to +85°C	
Capacitance Tolerance	±20% at 100 Hz/+20°C	
Operational Lifetime	D (mm)	Rated Voltage and Ripple Current at +85°C (hours)
	25	12,000
	30	15,000
	35	18,000
	40	26,000
End of Life Requirement	Δ C/C < ±10%	
Shelf Life	2,000 hours at +85°C or 30,000 hours at +40°C 0 VDC	
Leakage Current	I = 0.006 CV or 6,000 μA (whichever is smaller)	
	C = rated capacitance (μF), V = rated voltage (VDC). Voltage applied for 5 minutes at +20°C.	
Standards	IEC 60384-4	

Surge Voltage

Condition	Voltage (VDC)				
	40	63	100	200	385
≤ 30 second surge, 1,000 cycles at +85°C	46	72.5	115	230	423.5

Figure 32 - KEMET 4700μF Electrolytic Capacitor 63V dc Datasheet (KEMET, 2020)

8.3.4 GBU6G Single Phase Bridge Rectifier Datasheet



GBU6A, GBU6B, GBU6D, GBU6G, GBU6J, GBU6K, GBU6M

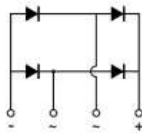
www.vishay.com

Vishay General Semiconductor

Glass Passivated Single-Phase Bridge Rectifier



Case Style GBU



Case Style GBU

FEATURES

- UL recognition file number E54214
- Ideal for printed circuit boards
- High surge current capability
- High case dielectric strength of 1500 V_{RMS}
- Solder dip 275 °C max, 10 s, per JESD 22-B106
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912



RoHS
COMPLIANT

TYPICAL APPLICATIONS

General purpose use in AC/DC bridge full wave rectification for monitor, TV, printer, switching mode power supply, adapter, audio equipment, and home appliances applications.

MECHANICAL DATA

Case: GBU

Molding compound meets UL 94 V-0 flammability rating
Base P/N-E3 - RoHS-compliant, commercial grade

Terminals: Matte tin plated leads, solderable per J-STD-002 and JESD 22-B102

E3 suffix meets JESD 201 class 1A whisker test

Polarity: As marked on body

Mounting Torque: 10 cm·kg (8.8 inches·lbs) max.

Recommended Torque: 5.7 cm·kg (5 inches·lbs)

PRIMARY CHARACTERISTICS	
Package	GBU
$I_{F(AV)}$	6.0 A
V_{RRM}	50 V, 100 V, 200 V, 400 V, 600 V, 800 V, 1000 V
I_{FSM}	175 A
I_R	5 μ A
V_F at $I_F = 6.0$ A	1.0 V
T_J max.	150 °C
Diode variations	In-Line

MAXIMUM RATINGS (T _A = 25 °C unless otherwise noted)									
PARAMETER	SYMBOL	GBU6A	GBU6B	GBU6D	GBU6G	GBU6J	GBU6K	GBU6M	UNIT
Maximum repetitive peak reverse voltage	V _{RRM}	50	100	200	400	600	800	1000	V
Maximum RMS voltage	V _{RMS}	35	70	140	280	420	560	700	V
Maximum DC blocking voltage	V _{DC}	50	100	200	400	600	800	1000	V
Maximum average forward rectified output current at (fig. 1)	I _{F(AV)}	T _C = 90 °C ⁽¹⁾							A
		T _A = 40 °C ⁽²⁾							
Peak forward surge current single sine-wave superimposed on rated load	I _{FSM}	175							A
Rating for fusing (t < 8.3 ms)	I ² t	127							A ² s
Operating junction and storage temperature range	T _J , T _{STG}	- 55 to + 150							°C

Figure 33 - Vishay GBU6G Datasheet (Vishay, 2015)



GBU6A, GBU6B, GBU6D, GBU6G, GBU6J, GBU6K, GBU6M

www.vishay.com

Vishay General Semiconductor

ELECTRICAL CHARACTERISTICS (T _A = 25 °C unless otherwise noted)										
PARAMETER	TEST CONDITIONS	SYMBOL	GBU6A	GBU6B	GBU6D	GBU6G	GBU6J	GBU6K	GBU6M	UNIT
Maximum instantaneous forward voltage drop per diode	6.0 A	V _F	1.0							V
Maximum DC reverse current at rated DC blocking voltage per diode	T _A = 25 °C	I _R	5.0							μA
	T _A = 125 °C		500							
Typical junction capacitance per diode	4 V, 1 MHz	C _J	211				94			pF

THERMAL CHARACTERISTICS (T _A = 25 °C unless otherwise noted)									
PARAMETER	SYMBOL	GBU6A	GBU6B	GBU6D	GBU6G	GBU6J	GBU6K	GBU6M	UNIT
Typical thermal resistance	R _{θJA} ⁽²⁾	20							°C/W
	R _{θJC} ⁽¹⁾⁽³⁾	2.5							

Figure 34 - Vishay GBU6G Datasheet: Electrical and Thermal Characteristics (Vishay, 2015)

8.3.5 RS PRO 100VA Panel Mount Transformer Datasheet

Datasheet

DIN Rail control Panel isolation Transformers IP21

RS Pro

The standard 1 phase EI panel transformers with IP21 degree of protection, DIN rail TS35 mount and screw mount sign according to the following specifications.

- High quality control, isolating and safety transformers designed for use in general applications
- Various options for primary winding
- Optional +/-15V adjustments windings
- Optional dual output to be connected for double current or double voltage
- Enclosed in box IP21
- Detailed product specification on permanent label
- High efficiency, low regulation design
- 100% electrical and flash tested



Specifications

Power:	40-400 VA
Frequency:	50/60 Hz
Primary:	Nominal +/-10%
Secondary:	See ordering details
Construction:	Class I
Protection:	IP21
Isolation:	4kV or 4.6 kV RMS
Temp. Class:	B (130°)
According to:	BS/EN 61558-1, AS/NZS 61558.1 and BS/EN 61558-2-6, AS/NZS 61558.2.6 or BS/EN 61558-2-4 AS/NZS 61558.2.4

Figure 35 - RS PRO 100VA Panel Mount Transformer Datasheet (Components, 2021)

Features and Benefits

- Panel mount transformer
- Primary voltage rating of 230 V AC
- Secondary voltage rating of 24 V AC
- Power rating of 100 VA
- Mounted by DIN rail
- Dimensions of 106 mm (L) x 90 mm (W) x 107 mm (D)
- Minimum operating frequency of 50 Hz
- Maximum operating frequency of 60 Hz
- Maximum temperature of +130°C
- Weight of 2.3 kg
- IP21 rated for protection against condensation, objects over 12 mm
- Meets standard EN 61558-1 for safe power transformers and power supplies

Figure 36 - RS PRO 100VA Panel Mount Transformer Features and Benefits (Components, 2021)

8.3.6 576403B00000G Heatsink Datasheet

Specifications		
Product Attribute	Attribute Value	Search Similar
Manufacturer:	Aavid	☐
Product Category:	Heat Sinks	☒
RoHS:	 Details	
Product:	Heat Sinks	☐
Designed for:	TO-3	☐
Heatsink Material:	Aluminum	☐
Fin Style:	Slanted Vane	☐
Thermal Resistance:	5.1 C/W	☐
Length:	45.97 mm	☐
Width:	45.97 mm	☐
Height:	31.75 mm	☐
Brand:	Aavid	
Color:	Black	
Product Type:	Heat Sinks	
Series:	5761/5762/5763/5764	
Factory Pack Quantity:	250	
Subcategory:	Heat Sinks	
Part # Aliases:	002432	
		Show Similar

Figure 37 - 576403B00000G Heatsink Datasheet (Mouser, 2021)

8.4 Load Regulation Calculation

Figure 38 shows that the no-load voltage of the power supply is 12.087Vdc.

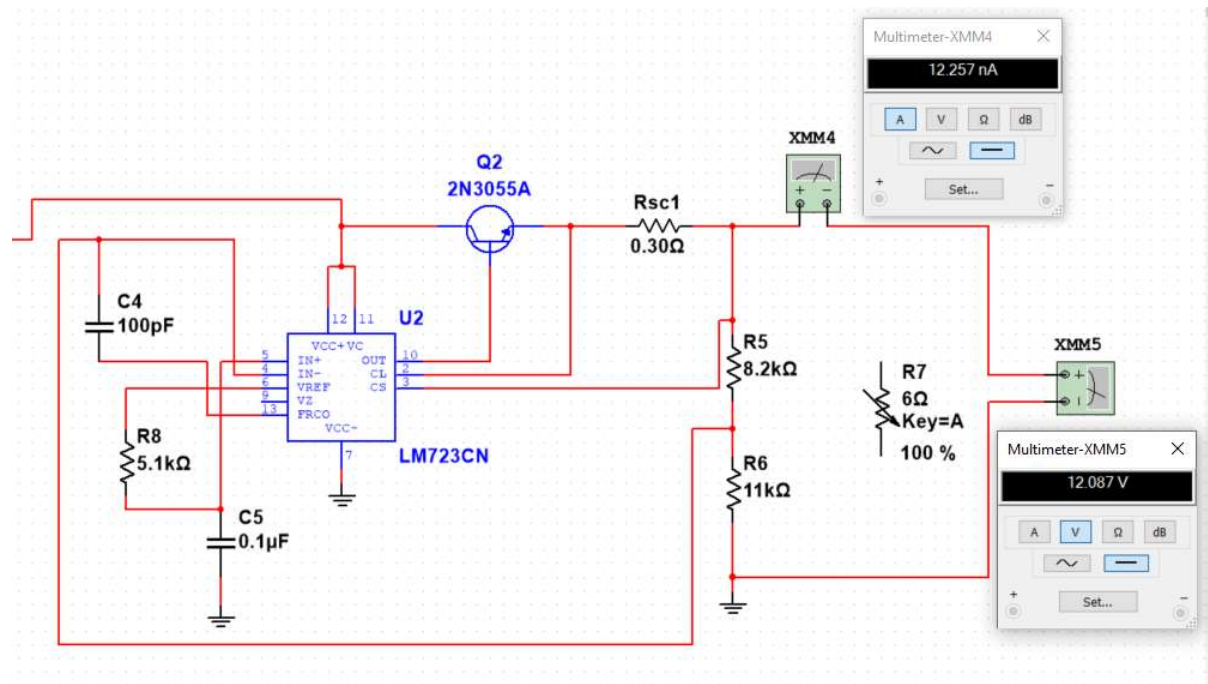


Figure 38 - Load Regulation Test, No-load Voltage

Figure 39 shows that the full-load voltage of the power supply is 12.00Vdc.

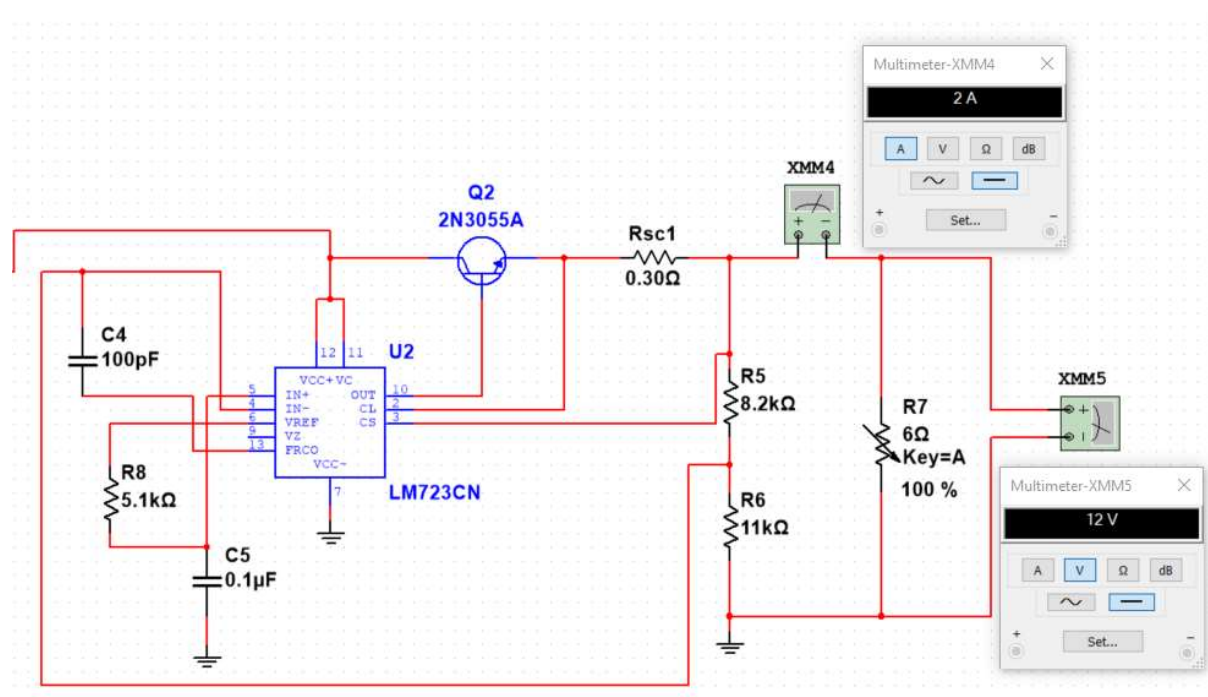


Figure 39 - Load Regulation Test, Full-load Voltage

8.5 Full Power Supply Circuit with 4 Channel Oscilloscope

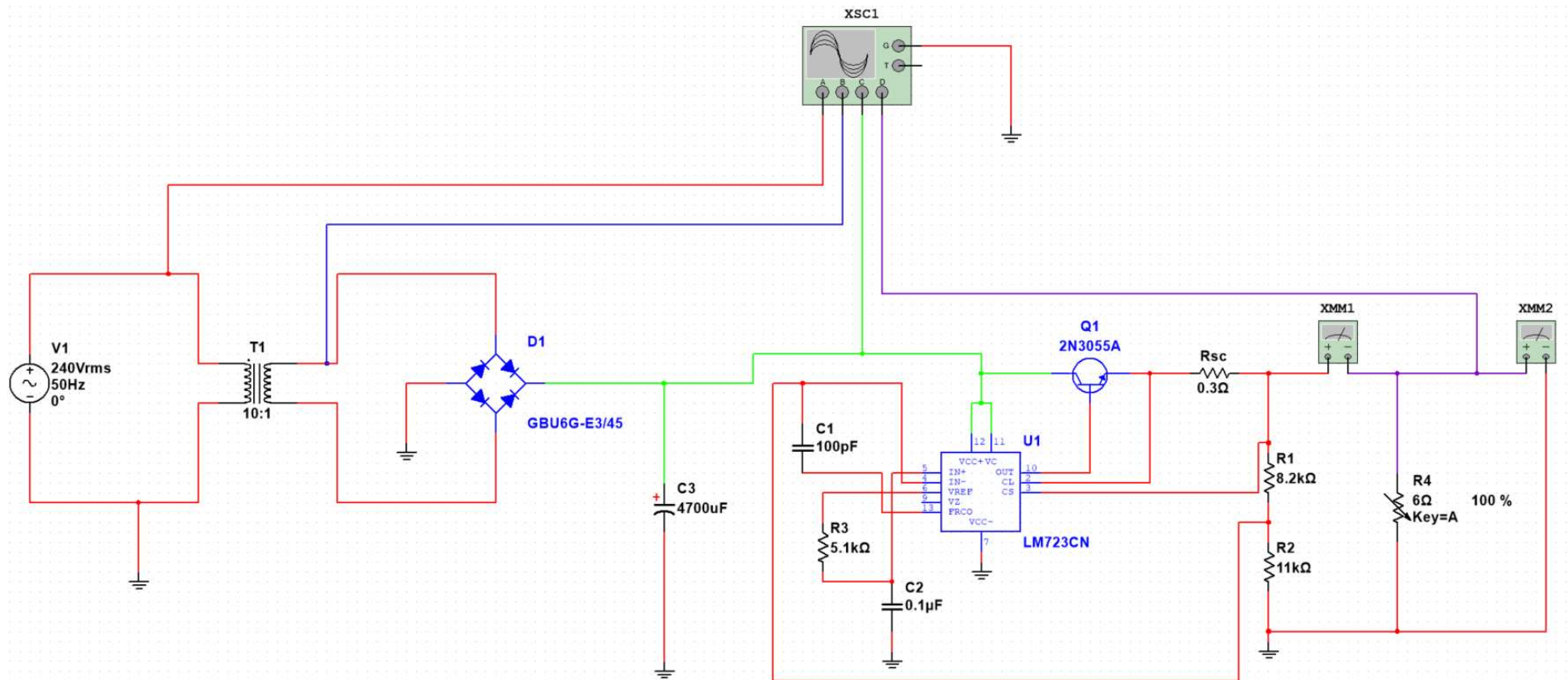


Figure 40 - Full Power Supply Circuit with 4 Channel Oscilloscope

FINAL GRADE

GENERAL COMMENTS

Instructor

85 / 100

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GRADING FORM: CSG-RUBIC

THOMAS GRENNAN

85

RESEARCH-INFORMED LITERATURE



There was evidence of considerable further reading and research from highly credible and reliable sources. Your interpretation and understanding of the additional research was

9

exceptional and demonstrated a deep underlying appreciation of the subject. Your references were consistently applied to a high level of competency and your reference list was extensive for this assignment.

KNOWLEDGE AND UNDERSTANDING



The knowledge and understanding of the subject demonstrated by this assignment was exceptional. There were no gaps in your knowledge of the basic principles and the higher level concepts were extremely well explained. Your explanation of the design process and calculations was also excellent and you have demonstrated an exceptionally detailed knowledge and critical understanding of the main concepts and expanded your knowledge beyond that contained in the course notes.

27

ANALYSIS



Your analysis of the task was outstanding, you have demonstrated highly competent analytical skills and your approach to the task was highly logical. You carried out a detailed evaluation of the results and included an excellent conclusion connecting ideas and providing logical and persuasive arguments. You have demonstrated a considerable capacity for independent thought and the ability to see beyond the question and your interpretation of the quantitative and qualitative data was exceptional with sound judgements based on wholly valid arguments.

27

PRACTICAL APPLICATION AND DEP.



Your application of practical skills for this task was generally exceptional. 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 attempted.

18

SKILLS FOR PROFESSIONAL PRAC.



In this assignment you have demonstrated skills in working individually and also collaboratively. Your written report was exceptionally well structured and written in a highly coherent and logical way. The report was presented in a professional manner using appropriate language and formatting, good diagrams in appropriate places, good sentence/paragraph structure and clear calculations. The word count was however exceeded.

4