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1. Executive Summary

This report covers the conception, design and testing of a customers specification, which included the power supply design and the overall project which successfully met the required values of 12V, 1A, and 12W. The conclusive Factory Acceptance Test (FAT) and the completed electrical schematic in the appendices serve as evidence of the achievement of the design of the new item. Oscilloscope tests provided a visual representation of the waveforms, validating the expected results outlined in the research. The conversion process from an AC sinewave to a ripple-like DC voltage through the bridge-rectifier and smoothing capacitor, followed by voltage regulation, showed the robust functionality of the power supply.

The critical role of resistor selection in the voltage regulator circuit was highlighted, showing consistent output voltages within specific resistor sets. Higher preferred E12 resistor values led to a slight reduction, while lower preferred values resulted in an increase. A trial-and-error approach was used, necessitated by the inability to meet the specifications with the E12 resistor values.

In the assessment of the front-end circuit, a small error in calculated versus simulated voltages validated the accuracy of the calculations. The oscilloscope trace visually confirmed the successful AC to DC rectification through the bridge-rectifier, affirming the reliability of the front-end circuit.

A systematic approach to modifying the voltage regulator circuit, involving the replacement of R1 with a variable resistor and fine-tuning, proved effective. Precision adjustments, from 5% to 1% increments, showcased the circuit's sensitivity. Notably, the final calibration with the variable resistor at 66%, corresponding to 19.8K Ω , successfully achieved the required 12V output.

Sustainability considerations were integral to the project, utilizing components from existing stock to minimize waste and promote resource efficiency. Environmental concerns were identified, such as the wet environment, and a solution involving the use of an IP67 rated control panel addressed the potential issues.

2. Planning and reflection

In this assignment, the task to build a regulated power supply will be split up into different sections and will be designed from right to left – with the last component designed first to ensure the correct output values are present from the electronic system.

A specification will be created that details the required output values of the power supply for DC current, voltage, power, and the input voltage and frequency. This will be followed by preliminary research on power supply design principles.

The next step will be dedicated to calculating all the component values that will be required for the design and simulation of the circuit using NI Multisim. The circuits will then be built on NI Multisim, with the voltage regulator first, then the front-end circuit comprising a transformer, bridge-rectifier, and a capacitor. The final design step is to find an efficient heatsink system, addressing thermal considerations.

The separate circuits can then be integrated into a comprehensive power supply system, conducting simulations, and refining the design as needed. This systematic plan ensures a step-by-step approach to meet the electrical, physical, and thermal requirements of the power supply project efficiently.

With the assignment complete, it can be seen that the work-plan was followed successfully, and each design step was followed – resulting in the testing of a functioning power supply circuit. This sort of pre-planning can be utilised in future projects as it is shown to be successful.

3. Research

Power supply units (PSUs) serve as critical components in electronic devices by converting electrical energy from an external source into a form compatible with the device's requirements.

The fundamental principle governing their operation is based on transforming alternating current (AC) to direct current (DC), which is commonly used to power electronic components. The first step is to transform the AC down to a lower, more manageable AC voltage.

The second stage involves an input rectification process where a bridge rectifier converts AC to DC. During the positive half-cycle of the AC input, two diodes conduct, allowing current to flow through the load in one direction. During the negative half-cycle, the other two diodes conduct, ensuring that current continues to flow in the same direction through the load. This process effectively converts the AC waveform into a pulsating DC waveform, where the negative portion is inverted to become positive. The resulting waveform, while still pulsating, has a unidirectional flow (Horowitz & Hill, 2015).

Subsequently, a smoothing capacitor is employed to reduce the pulsations, resulting in a more stable DC voltage. To obtain a smoother and more constant DC output, a filter capacitor is added after the rectifier. This capacitor charges during the peaks of the pulsating waveform and discharges as the waveform drops, effectively reducing the ripple and producing a more stable DC voltage (Storey, 2017).

The voltage is then regulated to the desired level using voltage regulation circuits. The primary function of the voltage regulator is to maintain a stable and constant output voltage despite variations in the input voltage or changes in the load. This ensures that the electronic components receive a reliable and consistent power supply (Ellis, 2015).

Figure 1 displays a block diagram of a PSU with the waveforms shown graphical at each step.

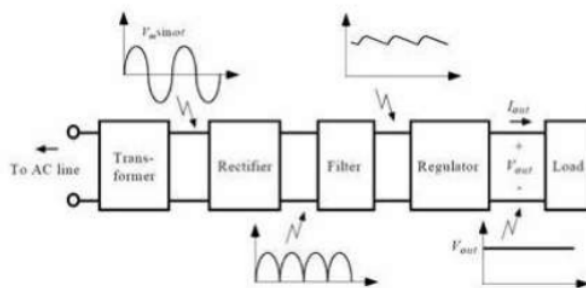


Figure 1 – (Armand, 2019)

4. Methodology

4.1. Customer Specification

A customer has requested a power supply unit to be designed for an application which requires a 12VDC output at 1A, with 12W of power.

The application is a piece of equipment that utilises vacuum lifting technology to lift sheet and slab metal. The task that has been assigned is to design the power supply unit for the control system for this equipment. Considerations will have to be made when designing the PSU, as the lifting equipment will be working in an environment that has liquids present and high temperatures due to induction furnaces being in close proximity.

The PSU will be supplying the power to the entire control system for the lifting equipment which include two vacuum pressure switches, three LED indicators and an alarm sounder. This equipment can be seen in table 1.

EQUIPMENT	FUNCTION
PRESSURE SWITCHES	If one pressure switch (PS) is made, then 'Low Vacuum LED' will be on. If both pressure switches are made, then 'Vacuum OK LED' will be made and 'Low Vacuum LED' will be off. The setpoint for PS1 is -0.01bar, and the setpoint for PS2 is -0.6bar.
ALARM SOUNDER	If the vacuum is on and both pressure switches are not made, then the sounder will alarm to notify operator that the load could fall.
SUPPLY PRESENT LED	This LED will be on if the 12V supply is present.
LOW VACUUM LED	This LED will be on if only one of the pressure switches is made to notify the operator that the load should not be lifted yet.
VACUUM OK LED	This LED will be on if both pressure switches are made to notify the operator that the load can now be safely lifted.

Table 1 – Equipment Function Table

The vacuum unit will be used to transfer sheet and slab metal to and from water-immersed ultrasonic testing tanks. A pneumatic vacuum pump will be used to create suction to pick up the products. The pneumatic pump was chosen instead of an electric pump, as it was seen as more cost-effective to use an already existing air supply line, rather than run a new electrical supply. The running costs for an electric pump were also taken into consideration when discussing sustainability and environmental factors. A IP67 control panel will be used to house the PSU and circuitry to ensure the equipment is protected from the wet work environment.

As can be seen from figure 2, an IP67 rated panel will ensure no ingress from dust and allow the panel to be immersed in up to 1m of water for 30 minutes. This level of water protection is greater than what is required but will be used to ensure the safe operation of the equipment.

Ingress Protection (IP) Ratings Guide

Example:

(Ingress Protection) **IP24**

Solids			Water		
1		Protection against solid object greater than 50mm.	1		Protection against vertically falling droplets.
2		Protection against solid object greater than 12.5mm.	2		Protection against vertically falling droplets when tilted up to 15°.
3		Protection against solid object greater than 2.5 mm.	3		Protection against spraying water up to an angle of 60°.
4		Protection against solid object greater than 1 mm.	4		Protection against splashes of water from all directions.
5		Limited ingress of dust. Will not interfere with equipment.	5		Protection against low pressure jets of water.
6		No ingress of dust permitted.	6		Protection against high pressure jets of water.
X	Protection level not formally tested.		7		Protection against immersion in water between 15cm - 1m deep for 30 minutes.
A digit of '0' for either solids or liquids indicates no protection.			8		Protection against immersion in water under pressure for long periods.
			9k		Protection from close-range, powerful, high temperature water jets.

Figure 2 – IP Ratings (Williams, 2017)

4.2. Voltage Regulator Design

The voltage regulator design consisted of choosing one with good regulation, short circuit protection, adjustable voltage out and configurable for large currents. The regulator chosen was the 14-pin integrated circuit (IC) LM723CN or MC1723 as it had all the requirements.

Some of the other regulators that were considered were the Zener regulator, the 78xx series regulator and the LM3157 regulator. Table 2 compares all 4 regulators.

REGULATOR	SPECIFICATION
ZENER	• Poor regulation meaning there is not accurate voltage regulation. • No protection. Therefore, the power supply will be damaged if there is a short circuit and maximum current is pulled.
78XX SERIES	• Choice of only 7805 or 7812 regulators, meaning 5V and 12V respectively. • Good voltage regulation. • No protection. Therefore, the power supply will be damaged if there is a short circuit and maximum current is pulled.
LM3157	• Adjustable voltage out. • Good voltage regulation. • No protection. Therefore, the power supply will be damaged if there is a short circuit and maximum current is pulled.
LM723CN/MC1723	• Short circuit protection. • Good voltage regulation. • Adjustable voltage out from 0 – 37V. • Configurable for large currents.

Table 2 – Regulator Comparison

As can be seen in table 2, the Zener would be a poor choice for this application due its poor voltage regulation and its lack of short circuit protection. The 78xx series shows an improvement on the voltage regulation when compared with the Zener but it also lacks short circuit protection and is also limited to two voltages – 5V and 12V. The LM3157 is almost the same as the 78xx series as it has good regulation and no protection, but it does have adjustable voltage out which would be beneficial for variable PSUs.

The LM723CN regulator stands out with its short circuit protection when compared with the other choices but also has the required good regulation, has a good range of 2 – 37V out, which can be seen in figure 3, and can be configured for large currents. As such, this makes it the obvious option for the regulator to be used in this project.

ELECTRICAL CHARACTERISTICS⁽¹⁾⁽²⁾⁽³⁾⁽⁴⁾ (continued)

Parameter	Conditions	LM723			LM723C			Units
		Min	Typ	Max	Min	Typ	Max	
Average Temperature Coefficient of Output Voltage ⁽⁵⁾	$-55^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$		0.002	0.015				%/ $^{\circ}\text{C}$
	$0^{\circ}\text{C} \leq T_A \leq +70^{\circ}\text{C}$					0.003	0.015	%/ $^{\circ}\text{C}$
Short Circuit Current Limit	$R_{SC} = 10\Omega$, $V_{OUT} = 0$		65			65		mA
Reference Voltage		6.95	7.15	7.35	6.80	7.15	7.50	V
Output Noise Voltage	BW = 100 Hz to 10 kHz, $C_{REF} = 0$		86			86		μVrms
	BW = 100 Hz to 10 kHz, $C_{REF} = 5 \mu\text{F}$		2.5			2.5		μVrms
Long Term Stability			0.05			0.05		%/1000 hrs
Standby Current Drain	$I_L = 0$, $V_{IN} = 30\text{V}$		1.7	3.5		1.7	4.0	mA
Input Voltage Range		9.5		40	9.5		40	V
Output Voltage Range		2.0		37	2.0		37	V
Input-Output Voltage Differential		3.0		38	3.0		38	V
θ_{JA}	PDIP					105		$^{\circ}\text{C/W}$
θ_{JA}	CDIP		150					$^{\circ}\text{C/W}$
θ_{JA}	H10C Board Mount in Still Air		165			165		$^{\circ}\text{C/W}$
θ_{JA}	H10C Board Mount in 400 LF/Min Air Flow		66			66		$^{\circ}\text{C/W}$
θ_{JC}			22			22		$^{\circ}\text{C/W}$

Figure 3 – Voltage Regulator Datasheet (Texas Instruments, 2013)

4.2.1. Voltage Regulator Calculations

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

$$R1 + R2 = 50k\Omega$$

$$R2 = \frac{V_{ref}}{V_{out}} \times (R1 + R2) = \frac{7.2V}{12V} \times (50k) = 30K\Omega$$

$$V_{ref} = 6.8V \text{ to } 7.5V$$

$$V_{ref} = 7.2V \text{ chosen}$$

$$R1 = 50k - R2$$

$$R1 = 50K - 30K = 20K\Omega$$

$$R_{sc} \approx \frac{V_{sense}}{I_{sc}} = \frac{0.6V}{1A} = 0.6\Omega \therefore 0.56\Omega$$

$$R3 = R1 || R2 \therefore \frac{R1 \times R2}{R1 + R2} = \frac{600K}{50K} = 12K\Omega$$

4.3. Input Circuit Design

4.3.1. Capacitor Calculations

$$V_c \text{ (voltage across capacitor)} = V_{in} \text{ (to regulator)}$$

$$\therefore V_c = 13.6V$$

$$V_{ripple} = 3V$$

$$V_m = V_c + \left(\frac{1}{2} \times V_c\right)$$

$$\therefore V_m = 20.4V$$

$$I_o = 1A$$

$$F = 50Hz$$

$$rf = \frac{V_{ripple}}{2\sqrt{2} \times V_c}$$

$$\therefore rf = 0.08 \text{ or } 8\%$$

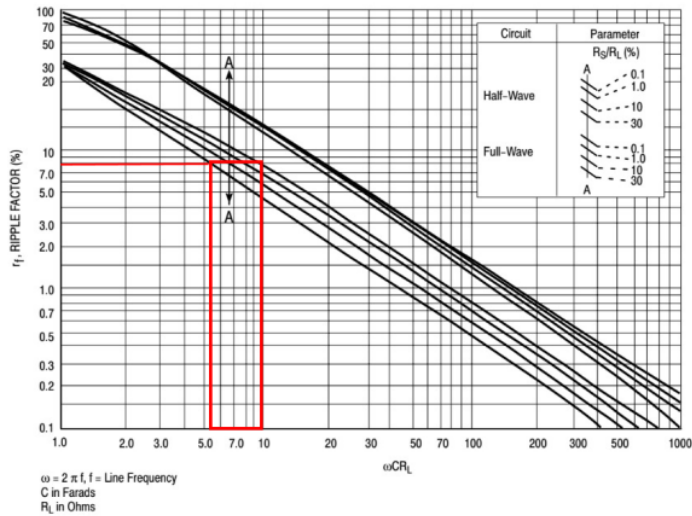


Figure 4 – Root-Mean-Square Ripple Voltage for Capacitor-Input Circuits (ON Semiconductor, 2002)

$$\omega C R_L = 5.2 \text{ to } 10 \text{ (from figure ...)}$$

$$\omega C R_L = 7.5 \text{ chosen}$$

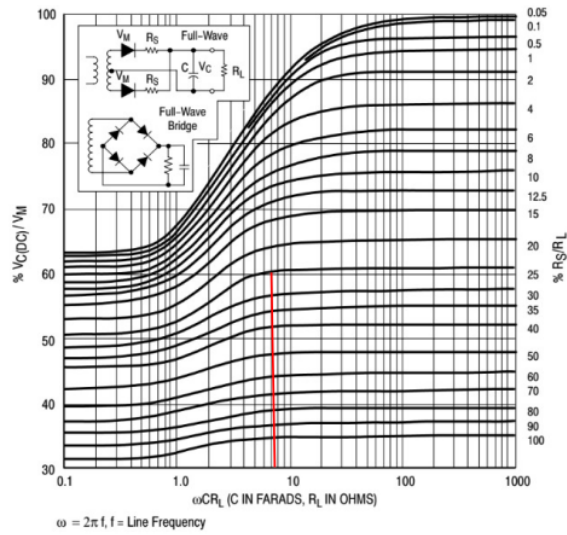


Figure 5 – Relation of Applied Alternating Peak Voltage to Direct Output Voltage in Full-Wave Capacitor-Input Circuits (ON Semiconductor, 2002)

$$Rl = 13.6\Omega$$

$$\frac{Rs}{Rl} = 0.25\Omega$$

$$Rs = 0.25 \times 13.6 = 3.4\Omega$$

$$C = \frac{\omega CRl}{2\pi F \left(\frac{Vc}{Io} \right)}$$

$$C = \frac{7.5}{2\pi \times 50 \times \frac{13.6}{1}} = 1.8mF$$

4.3.2. Rectifier Calculations

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

$$\therefore I_{F(AVG)} = \frac{1}{2} = 0.5A$$

$$I_{F(RMS)} = I_o$$

$$\therefore I_{F(RMS)} = 1$$

$$PIV = (V_m \times 2) + \frac{V_m}{2}$$

$$PIV = (20.4 \times 2) + \frac{20.4}{2} = 51V$$

$$I_{Surge} = \frac{V_m}{R_s}$$

$$I_{Surge} = \frac{20.4}{3.4} = 6A$$

$$\frac{R_s}{R_L} = \frac{3.4}{13.6} = 0.25$$

$$\% \frac{R_s}{nR_L} = \frac{3.4}{2 \times 13.6} = 0.125\%$$

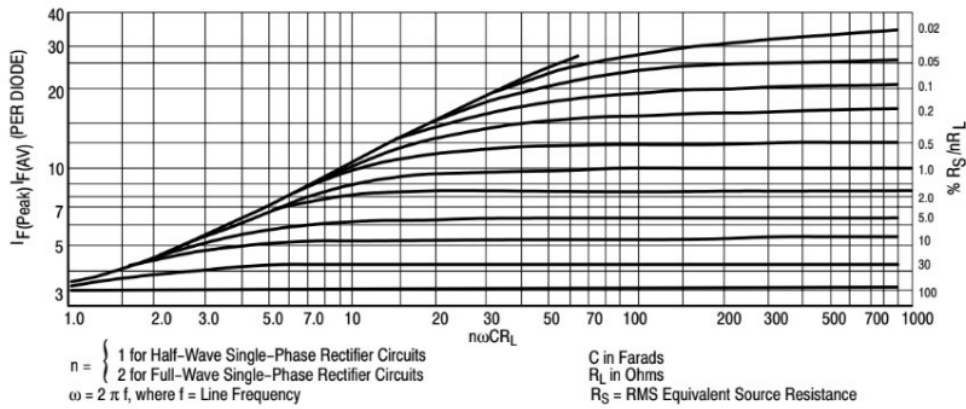


Figure 6 – Relation of RMS and Peak-to-Average Diode Current in Capacitor-Input Circuits (ON Semiconductor, 2002)

$$I_{F(Peak)} = 5.5A$$

4.3.3. Transformer Calculations

$$V_s = \frac{V_m + n}{\sqrt{2}}$$

$$V_s = \frac{20.4 + 2}{\sqrt{2}} = 15.8V$$

To ensure V_s is 15.8V, a step-down ratio of 15:1 will be required for a 240V incoming supply.

$$\text{Transformer Secondary Winding Resistance} = R_s \therefore 3.4\Omega$$

$$\text{Secondary Current } (I_{RMS}) = I_o \times \sqrt{2}$$

$$\text{Secondary Current } (I_{RMS}) = 1 \times \sqrt{2} = 1.41A$$

$$\text{Transformer VA} = V_s \times I_{RMS} \times \sqrt{2}$$

$$\text{Transformer VA} = 15.8 \times 1.41 \times \sqrt{2} = 25.47VA$$

4.4. Heatsink

The first design step of the heatsink was to choose the power transistor to be used in the PSU and find its maximum operating junction temperature and ensure that the junction temperature is kept below this to ensure safe operation of the device.

A 2N3055 (TO-3) transistor was used and its datasheet, seen in figure 7, utilised to find the required values needed to design an adequate heatsink. The two parameters taken from the datasheet were: T_J – Max. Operating Junction Temperature and $R_{thj-case}$ – Thermal Resistance Junction-Case Max.

The T_J value was 200°C, so 100°C was chosen, while the $R_{thj-case}$ value was 1.5°C/W.

1 Absolute maximum rating

Table 2. Absolute maximum rating

Symbol	Parameter	Value		Unit
		NPN	2N3055	
		PNP	MJ2955	
V_{CBO}	Collector-base voltage ($I_E = 0$)		100	V
V_{CER}	Collector-emitter voltage ($R_{BE} = 100 \Omega$)		70	V
V_{CEO}	Collector-emitter voltage ($I_B = 0$)		60	V
V_{EBO}	Emitter-base voltage ($I_C = 0$)		7	V
I_C	Collector current		15	A
I_B	Base current		7	A
P_{TOT}	Total dissipation at $T_c \leq 25^\circ\text{C}$		115	W
T_{stg}	Storage temperature		-65 to 200	°C
T_J	Max. operating junction temperature		200	°C

Table 3. Thermal data

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

Figure 7 – 2N3055 Datasheet (ST Life Augmented, 2023)

The equation used to find the required heatsink was:

$$\phi_{SA} = \frac{T_J - T_A}{PD} - \phi_{jc} - \phi_{cs}$$

The values used were:

- T_J , taken from figure 7, was 100°C.
- T_A , the ambient air temperature, was 30°C, due to the proximity of furnaces to the equipment.
- P_D , power dissipated, was 12W.
- θ_{CS} , case-to-heatsink, was found from figure 8, which was 0.36°C/W.
- $\theta_{JC} = R_{thj-case}$, therefore = 1.5°C/W.

$$\theta_{SA} = \frac{100 - 30}{12} - 1.5 - 0.36$$

$$\theta_{SA} = 4^\circ\text{C/W}$$

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

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

Figure 8 – θ_{CS} Table (ON Semiconductor, 2002)

From figure 9, as $\theta_{SA} = 4^\circ\text{C/W}$, there are only certain heatsinks that can be used, such as the Wakefield 621 and 623, and the IERC HP.

TO-204AA (TO-3)	
$\theta_{SA} (^{\circ}\text{C/W})$	Manufacturer/Series or Part Number
0.3–1.0	Thermalloy — 6441, 6443, 6450, 6470, 6560, 6590, 6660, 6690
1.0–3.0	Wakefield — 641 Thermalloy — 6123, 6135, 6169, 6306, 6401, 6403, 6421, 6423, 6427, 6442, 6463, 6500
3.0–5.0	Wakefield — 621, 623 Thermalloy — 6606, 6129, 6141, 6303 IERC — HP Staver — V3-3-2
5.0–7.0	Wakefield — 690 Thermalloy — 6002, 6003, 6004, 6005, 6052, 6053, 6054, 6176, 6301 IERC — LB Staver — V3-5-2
7.0–10	Wakefield — 672 Thermalloy — 6001, 6016, 6051, 6105, 6601 IERC — LA μP Staver — V1-3, V1-5, V3-3, V3-5, V3-7
10–25	Thermalloy — 6013, 6014, 6015, 6103, 6104, 6105, 6117

Figure 9 – Heatsink Selection Table (ON Semiconductor, 2002)

After comparing these heatsinks, the Wakefield 621 was chosen due to its small dimensions that were required as the power supply was being mounted in a small control panel. The datasheet used to choose the heatsink can be seen in figure 10.

Product Attribute	Attribute Value
Manufacturer:	Wakefield-Vette
Product Category:	Heat Sinks
RoHS:	 Details
Product:	Heat Sinks
Designed for:	TO-3
Mounting Style:	Screw
Heatsink Material:	Aluminum
Fin Style:	Rectangular Fin
Thermal Resistance:	2 C/W
Length:	120.6 mm
Width:	38.1 mm
Height:	11.7 mm
Series:	621
Brand:	Wakefield-Vette
Color:	Black

Figure 10 – Heatsink Datasheet (Wakefield, 2024)

5. Results

5.1. Voltage Regulator

Figure 11 shows the final regulator circuit with the required output of 12V.

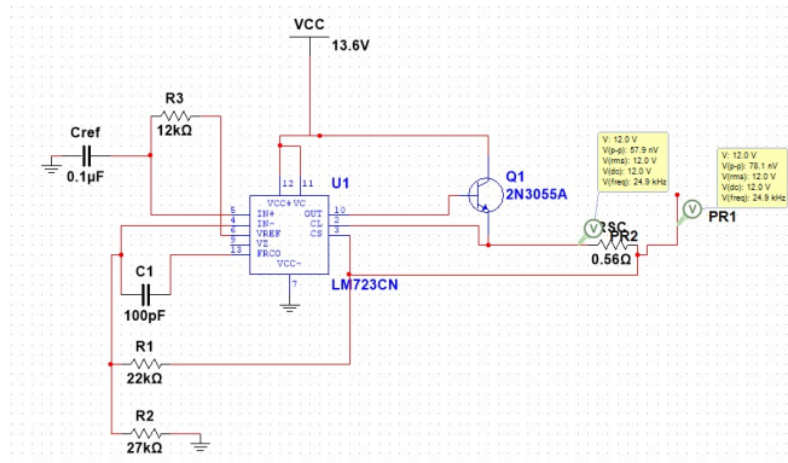


Figure 11 – Voltage Regulator Circuit

As can be seen in table 3, to get the correct output voltage of 12V, the preferred E12 resistor values used were lower than the calculated values and the ideal VCC was 13.6V.

R1 Value	R2 Value	Type	VCC (Vin)	Vout	Figure
20K	30K	Calculated	13.6V	11.5V	19
20K	30K	Calculated	100V	11.5V	20
18k	33k	Higher Preferred Resistor Values	13.6V	10.7V	21
18k	33k	Higher Preferred Resistor Values	100V	10.7V	22
22k	27k	Lower Preferred Resistor Values	100V	12.6V	18
22k	27k	Lower Preferred Resistor Values	13.6V	12V	11

Table 3 – Voltage Regulator Test Table

5.2. Front-End Circuit

Figure 12 shows the final front-end circuit with a V_{rms} of 13.6V output, which will be used to replace the VCC into the voltage regulator.

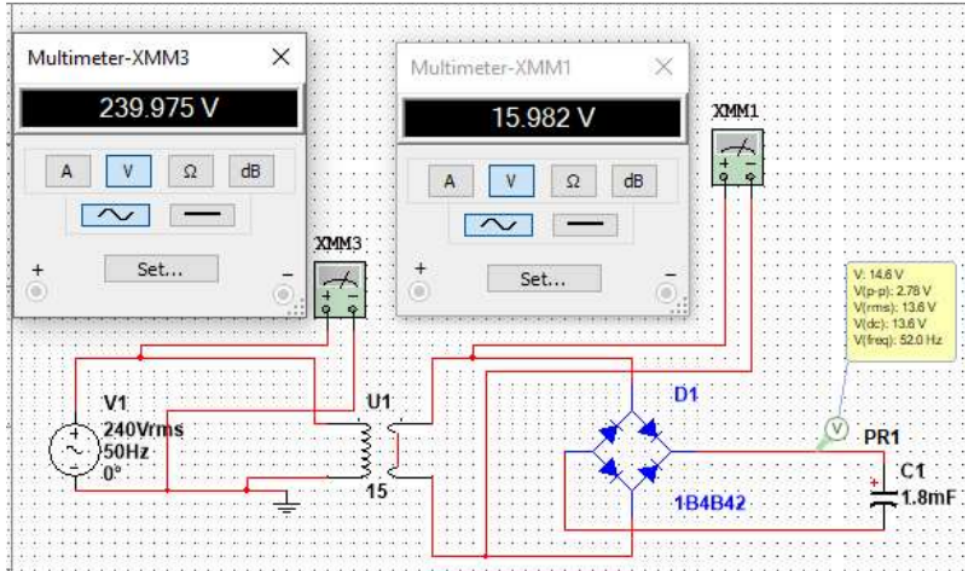


Figure 12 – Front-End Circuit

Table 4 shows the calculated and simulated voltage results for the front-end circuit, encompassing both the primary and secondary side voltages and the voltage across the capacitor.

	CALCULATED	SIMULATED	ERROR
PRIMARY VOLTAGE	240V	239.9V	-0.1V
SECONDARY VOLTAGE	15.8V	15.9V	0.1V
VOLTAGE ACROSS CAPACITOR	13.6V	13.6V	0V

Table 4 – Front-End Comparison Table

5.3. Final Power Supply Circuit

Figure 13 shows the complete circuit for the power supply with the front-end connected to the voltage regulator. The output voltage remained 12V after some modifications were carried out by changing the R1 resistor value.

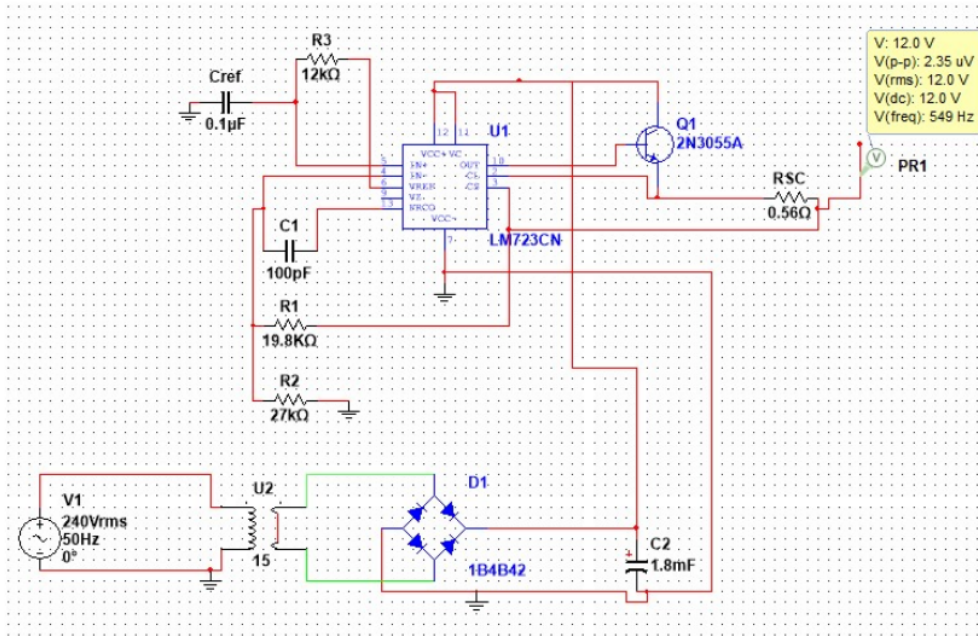


Figure 13 – Final Power Supply Circuit

Table 5 shows the different values of R1 and output voltage that were tested until the correct specification was met.

R1 Value	Vout	Figure (In Appendices)
22K	12.6V	28
22.5K	12.7V	29
21K	12.3V	27
19.5K	11.9V	25
19.8K	12V	26

Table 5 – Final Circuit Test Table

5.4. FAT

Table 6 details the Factory Acceptance Test (FAT) carried out to prove the functionality of the completed project.

Test	Result		Figure
	Pass/Fail	Description	
Check Supply Present LED	Pass	12V present at LED when supply to PSU turned on, illuminating the LED.	30
Check Vacuum Ok LED	Pass	12V present at LED when both pressure switches are on, illuminating the LED.	31
Check Vacuum Low LED	Pass	12V present at LED when only one pressure switch is on, illuminating the LED.	32
Pressure Switch 1 Functionality	Pass	Switches when -0.01bar of vacuum made. When only PS1 is on, Vac Low LED on.	33
Pressure Switch 2 Functionality	Pass	Switches when -0.6bar of vacuum made. When only PS2 is on, Vac Low LED on.	34
Vacuum Alarm	Pass	If vacuum on and both PS1 & PS2 are off, then alarm sounds.	32

Table 6 – Factory Acceptance Test Table

6. Analysis

6.1. Voltage Regulator

The provided data in table 3, in section 5.1, presents a comparative analysis of different resistor values (R_1 and R_2) and their impact on the output voltage (V_{out}) of a circuit. The first set of calculations with $20K\Omega$ and $30K\Omega$ resistors yielded an output voltage of 11.5V for both 13.6V and 100V input voltages. This indicates consistency in the output voltage despite variations in input voltage.

In the second set, higher preferred E12 resistor values of $18K\Omega$ (R_1) and $33K\Omega$ (R_2), which totalled $51K\Omega$, were chosen. The calculated output voltage for a 13.6V input was 10.7V, and similarly, for a 100V input, the output voltage remained at 10.7V. This suggests a consistent reduction in output voltage compared to the first set, emphasizing the impact of resistor selection on the circuit performance.

Contrastingly, the third set opted for lower preferred E12 resistor values of $22K\Omega$ (R_1) and $27K\Omega$ (R_2), as they totalled $49K\Omega$. The calculated output voltage increased to 12.6V for a 100V input and 12V for a 13.6V input. This demonstrates a positive correlation between the chosen resistor values and an increase in the output voltage.

The data implies that the choice of resistor values significantly influences the circuit's output voltage. Higher resistor values result in a lower output voltage, while lower resistor values lead to an increase.

The total resistance of R_1 and R_2 for the three sets used in the tests came to 50K for calculated values, 51K for the higher E12 values, and 49K for the lower E12 values that gave the required output voltage. This shows that the range of totals of R_1 and R_2 combinations were small, but the main factor in altering the output voltage was increasing R_1 's value and decreasing R_2 's.

6.2. Front-End Circuit

Table 4 in section 5.2., shows the calculated and simulated voltages for the front-end circuit, and the error between the two sets of values. There is a small error between the calculated primary and secondary side voltages of the transformer and their respective simulated values, but the voltage across the capacitor was the same. This proves the calculated component values were correct as the simulated voltage for all three tests match the calculated.

Figure 14 shows the front-end circuit with a multi-meter measuring the primary AC voltage, another multi-meter measuring the secondary AC voltage and a voltage probe measuring the rectified DC voltage.

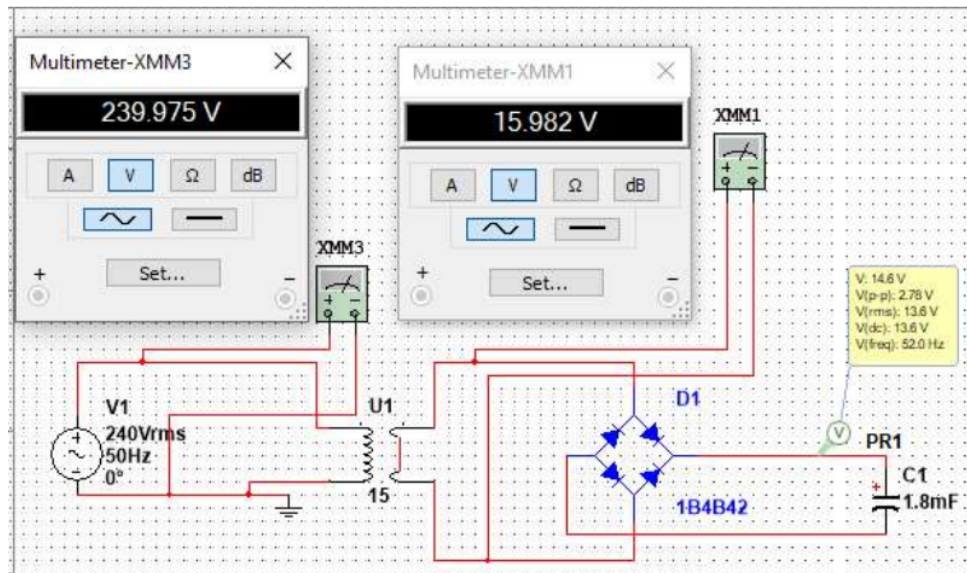


Figure 14 – Front-End Voltage Measurement

Figure 15 shows an oscilloscope trace of two voltages, before and after the bridge-rectifier – one of the transformer secondary side AC voltage and one of the rectified DC voltage. The transformer secondary voltage is the green trace, as a full sinewave can be seen, and the rectified voltage is the red trace as the negative half cycles have been inverted to become positive half cycles.

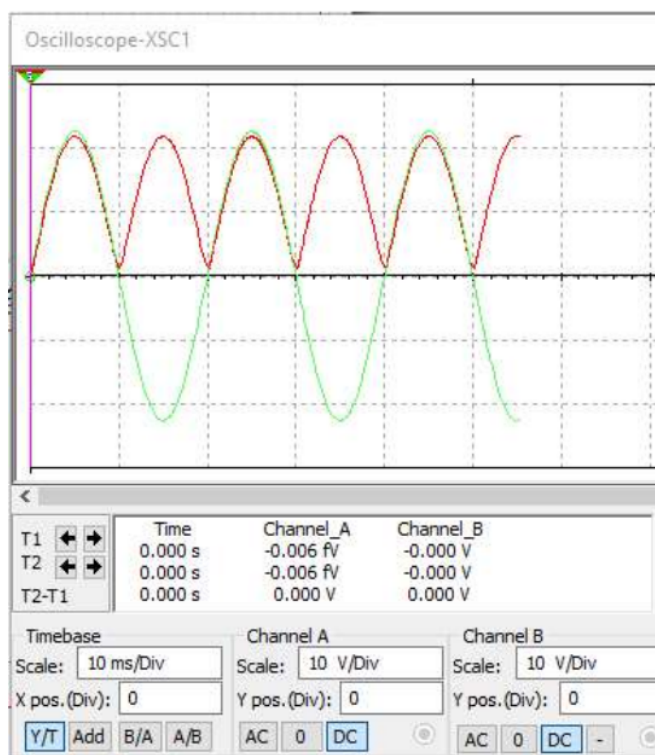


Figure 15 – Oscilloscope Trace of AC Voltage & Rectified Voltage

Figure 23, in section 10.2 of the appendices, shows an oscilloscope trace of the primary side voltage and the secondary side voltage. The difference in magnitude can be seen, with the peak value of the primary side at 339V, which can be explained by the following equation:

$$240V \times \sqrt{2} = 339V$$

6.3. Final Circuit

A 30K Ω variable resistor was used to replace R1, which had a value of 22K Ω , from the completed voltage regulator circuit. This can be seen in figure 16. This was used to quickly change the resistance of R1 and see how it affected the output voltage. The increments of the variable resistor were set at 5% first until the required 12V output could not be met.

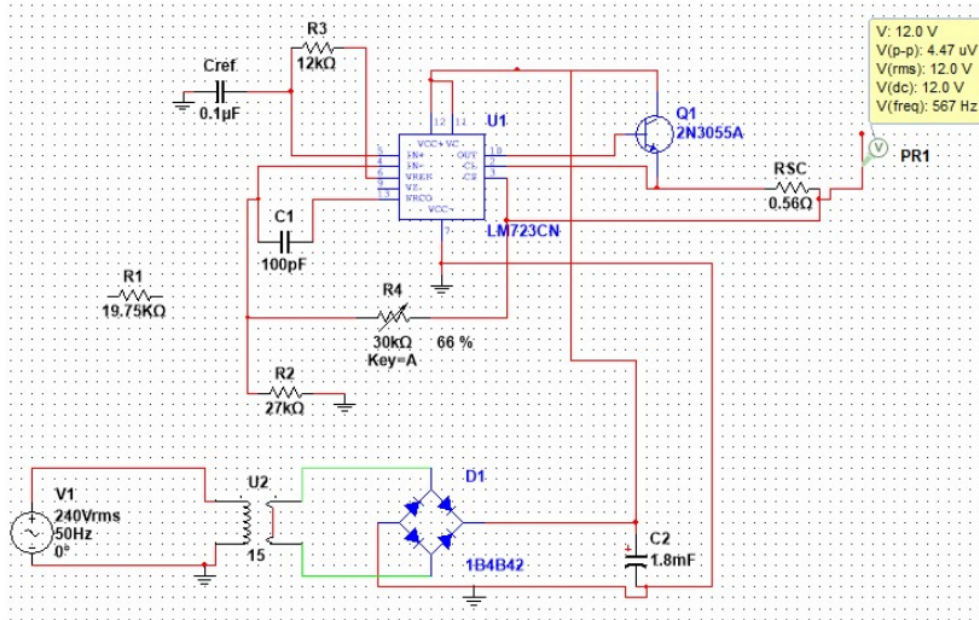


Figure 16 – Front-End Circuit with Variable Resistor

With R4 at 65%, the output voltage was 11.9V and when R4 was at 70%, the output voltage was 12.3V, which can be seen in table 5 in section 5.3. Therefore, the increments were changed to 1%, and R4 was set at 66% and this gave an output voltage of 12V, which can be seen in figure 16. 66% of 30K Ω equated to 19.8K Ω , therefore R1 was altered to 19.8K Ω and replaced R4 for the final circuit test.

Figure 17 shows an oscilloscope set up to measure the regulated voltage in green, and the rectified voltage with a smoothing capacitor in red. The green trace is the final regulated voltage out, with 12V out constant which can be seen with both markers on the graph showing Channel B, the green trace, to be at 12V. The red trace is the rectified voltage but with the smoothing capacitor charging up, which can be seen with the step in the red trace which flat lines when the rectified voltage begins to drop. A comparison of the rectified voltage and the voltage across the capacitor can be seen in figure 24 in the appendices.

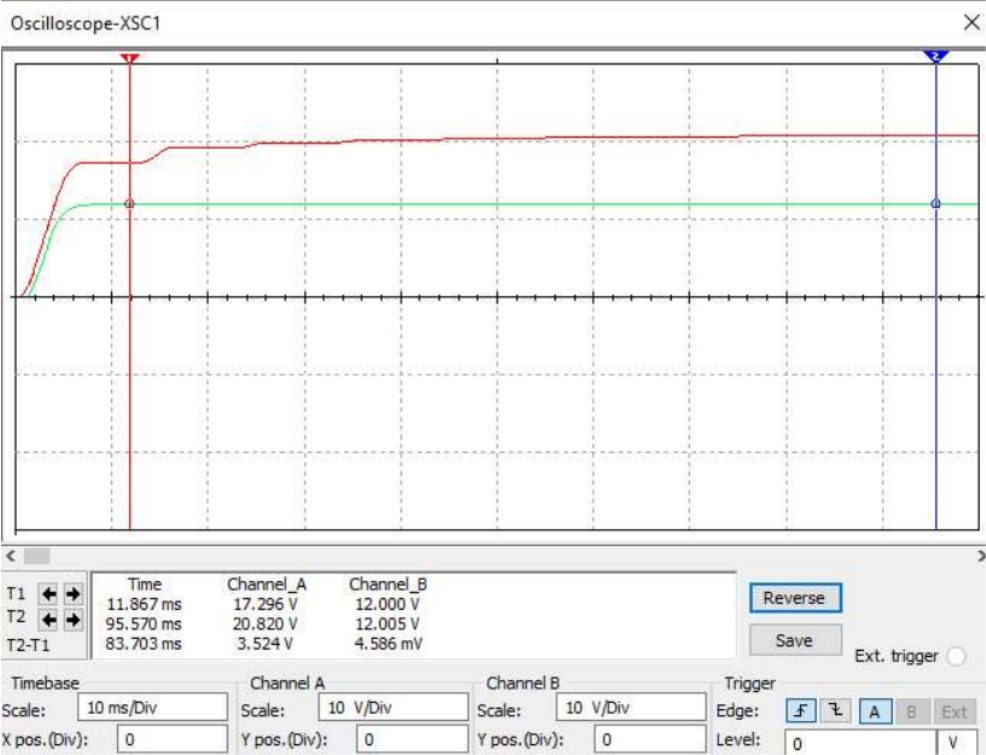


Figure 17 – Oscilloscope Trace of Smoothed DC Voltage & Voltage Charging the Capacitor

7. Evaluation

7.1. Voltage Regulator

The analysis in section 6.1 offers a comprehensive evaluation of the relationship between resistor values (R_1 and R_2) and the resulting output voltage (V_{out}) within a circuit subjected to varying input conditions.

Notably, the consistency in output voltage observed within each resistor set, particularly the first and second sets, suggests a degree of stability in the circuit's response. The utilization of higher preferred resistor values in the second set resulted in a slightly reduced output voltage, underlining the impact of resistor selection on the circuit's performance.

Conversely, the third set, employing lower preferred resistor values, demonstrated an increase in output voltage. This sensitivity to resistor changes emphasizes the need for precision in resistor selection to align with desired output specifications.

As the resistor values have such an effect on the output voltage, an improvement could be made to first add variable resistors in place of R_1 and R_2 to easily change the resistance and instantly see the voltage change.

7.2. Front-End

The small error observed between the calculated primary and secondary side voltages of the transformer, along with the matching voltage across the capacitor, is a positive indicator. This alignment suggests that the calculated component values were accurate, as evidenced by their close correlation with the simulated values across all three tests.

The oscilloscope trace presented in Figure 15 further supports the evaluation by visually depicting the transformer secondary side AC voltage and the rectified DC voltage before and after the bridge-rectifier, respectively. The green trace representing the transformer secondary voltage exhibits a full sine wave, indicating the successful transformation of AC power. Simultaneously, the red trace representing the rectified DC voltage demonstrates that the negative half cycles have been inverted through the bridge-rectifier, aligning with the expected behaviour.

The overall evaluation suggests a successful correlation between calculated and simulated values, validating the accuracy of the front-end circuit's component values. The oscilloscope trace visually reinforces the expected behaviour of the circuit in transforming AC to DC, further confirming the integrity and functionality of the front-end circuit.

7.3. Final Circuit

The evaluation of the voltage regulator circuit modification involving the replacement of R1 with a 30K Ω variable resistor and subsequent adjustments provides insights into the impact on the output voltage. The methodical approach of varying resistance increments and observing output voltage changes demonstrates a systematic exploration of the circuit's behaviour.

The initial use of a 30K Ω variable resistor to replace R1 at 22K Ω allowed for a broad adjustment range. The step increments of 5% provided a coarse analysis, revealing that the required 12V output could not be achieved within these steps. The decision to refine the increments to 1% and adjust R4 accordingly demonstrates a meticulous approach to fine-tune the circuit.

The detailed observations, such as the output voltage at R4 values of 65% and 70%, highlight the sensitivity of the circuit to resistance changes. The shift from 11.9V to 12.3V with a 5% change in R4 emphasizes the need for precision in resistor adjustments. The subsequent adjustment to 66% and the attainment of the desired 12V output voltage indicate a successful calibration. With R4 at 66% corresponding to 19.8K Ω , the R1 value could be adjusted to the same and inserted back into the circuit in place of R4.

8. Conclusion

In conclusion, the required specification set out by the customer was met, regarding the power supply design and the overall project. The required power supply values of 12V, 1A and 12W were met as seen in the results of this report, and the final testing of the project can be seen in the Factory Acceptance Test (FAT) and a completed electrical schematic in figure 35 of section 10.5 of the appendices.

The oscilloscope tests successfully displayed the waveforms, seen in figures 15 and 17, which can be compared with the expected results of the research in figure 1. The negative AC sinewave was inverted into a positive half wave by the bridge-rectifier, this voltage was then converted to a ripple-like DC voltage by the smoothing capacitor as it discharged voltage when the wave began to drop, and the voltage regulator converted the voltage to constant DC.

With the voltage regulator, the resistor values and their impact on the output voltage underscored the critical role of precise resistor selection in this circuit design. The data revealed consistent output voltages within specific resistor sets, highlighting the stability of the circuit's response. While higher preferred E12 resistor values led to a slight reduction in output voltage, lower preferred E12 values resulted in an increase. When the final circuit was connected, it became apparent that the required output specifications couldn't be achieved with E12 resistor values. Consequently, a trial-and-error approach was employed to select alternative resistor values.

Regarding the front-end circuit, there was a small error observed in the comparison between calculated and simulated voltages for the transformer's primary and secondary sides, along with the matching capacitor voltage, which proved the accuracy of the calculations in the method. The oscilloscope trace visually supports the expected behaviour of the circuit, confirming successful AC to DC rectification through the bridge-rectifier. This alignment between calculated and simulated values, along with the visual confirmation from the oscilloscope trace, collectively indicates the reliability and functionality of the front-end circuit.

There was a systematic approach to modifying the final power supply circuit by replacing the R1 resistor with a variable resistor and fine-tuning the values. The coarse analysis with 5% increments showed the sensitivity of the circuit, prompting a shift to 1% increments for precision. The adjustment of the variable resistor from 65% to 70% resulted in a voltage shift from 11.9V to 12.3V, emphasizing the importance of accurate adjustments. The final calibration with the variable resistor at 66%, corresponding to 19.8K Ω , successfully achieved the required 12V output.

The components used for this project were used from existing stock to aid with sustainability concerns. These are standardised parts used across site on various other machines and systems, therefore only a small number of spares need to be held rather than adding additional parts to the stores that will only be used for this project, promoting resource efficiency. This reduces the need for excessive manufacturing of unique components, minimises waste and leads to a more sustainable approach to resource management.

There were some environmental issues that were identified in the design process, such as allowing for an IP67 rated control panel to be used to house the PSU as it was in a wet environment, and this rating allowed for greater protection against liquid ingress.

9. References

Armand, K., 2019. *Linear Power Supply*. [Online]

Available at: <https://www.slideserve.com/armand/linear-power-supply-powerpoint-ppt-presentation>

[Accessed 11 01 2024].

Ellis, M., 2015. *Understanding electronic power supplies in circuit designs*. Fresno: CreateSpace Independent Publishing Platform.

Horowitz, P. & Hill, W., 2015. *The Art of Electronics*. 3rd ed. Cambridge: Cambridge University Press.

ON Semiconductor, 2002. *Linear & Switching Voltage Regulator Handbook*. 4th ed. Denver: Literature Fulfillment .

ST Life Augmented, 2023. *2N3055 Complementary Power Transistors*. [Online]

Available at: <https://www.st.com/en/datasheet/2n3055.pdf>

[Accessed 26 01 2024].

Storey, N., 2017. *Electronics : a systems approach*. 6th ed. Harlow: Pearson.

Texas Instruments, 2013. *LM723 Datasheet*. [Online]

Available at: <https://www.ti.com/lit/ds/symlink/lm723.pdf?ts=1708917407225>

[Accessed 20 01 2024].

Wakefield, 2024. *Wakefield 621*. [Online]

Available at: <https://www.mouser.co.uk/ProductDetail/Wakefield-Vette/621A?qs=8GtUBYxqNFDEpJUOKBCleA%3D%3D>

[Accessed 20 01 2024].

Williams, D., 2017. *All You Need To Know About IP Ratings*. [Online]

Available at: <https://heatingpoint.com/advice-centre/wp-content/uploads/2017/02/IP-Rating-Chart.jpg>

[Accessed 10 01 2024].

10. Appendices

10.1. Voltage Regulator

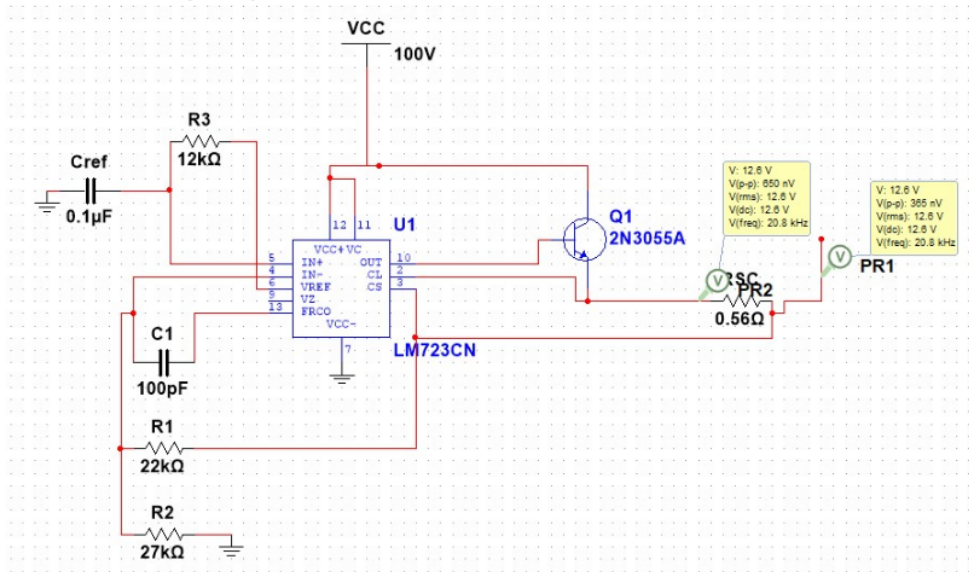


Figure 18 – Lower Preferred E12 Values & 100V VCC with 12.6V out

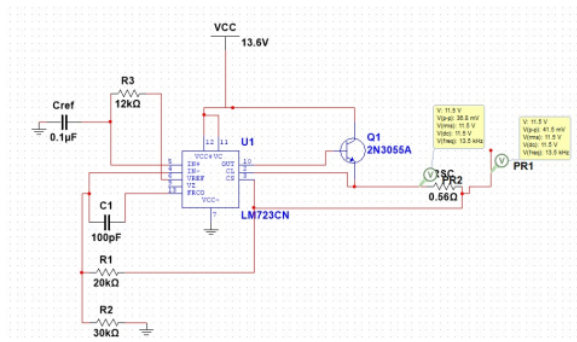


Figure 19 – Calculated Resistor Values with 13.6V VCC & 11.5V out

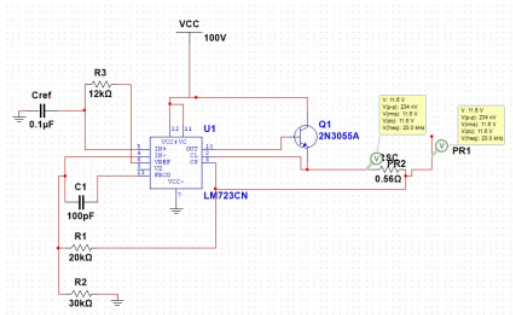


Figure 20 – Calculated Resistor Values with 100V VCC & 11.5V out

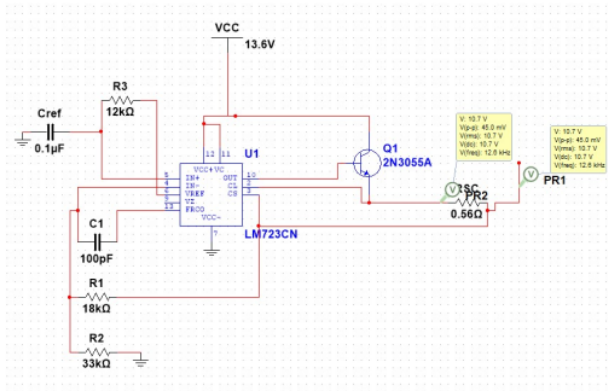


Figure 21 – Higher Preferred E12 Values with 13.6V VCC & 10.7V out

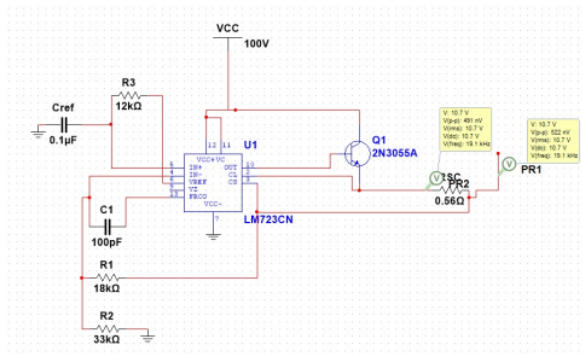


Figure 22 – Higher Preferred E12 Values with 100V VCC & 10.7V out

10.2. Front-End Circuit

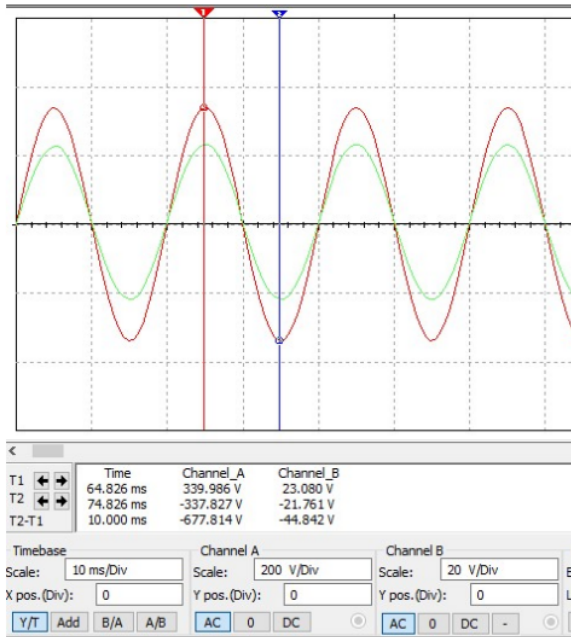


Figure 23 - Front-End Circuit Primary & Secondary Voltages



Figure 24 – Rectified Voltage compared with Voltage Across Capacitor

10.3. Final Circuit

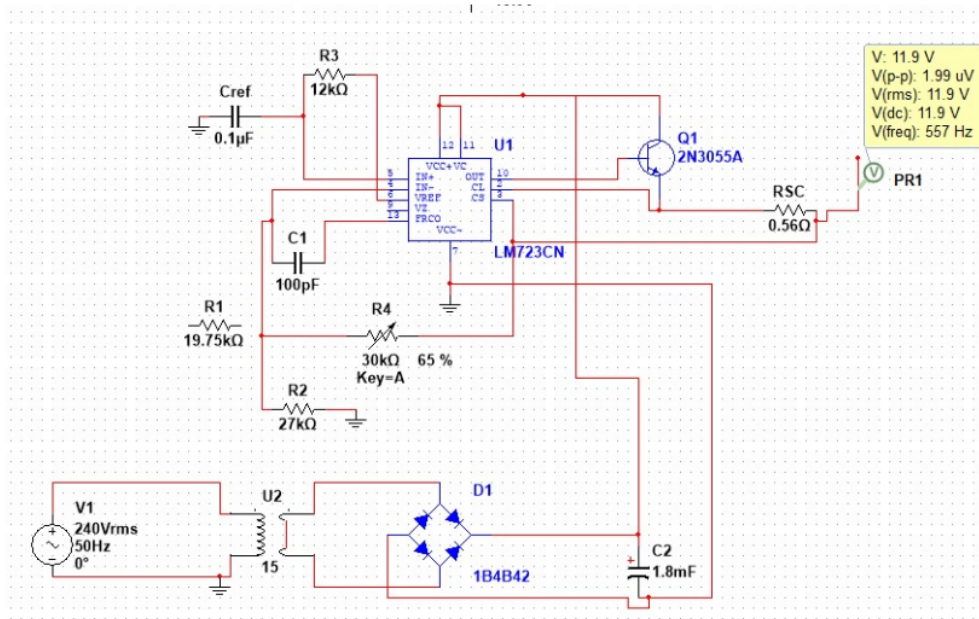


Figure 25 – Variable Resistor set at 65%

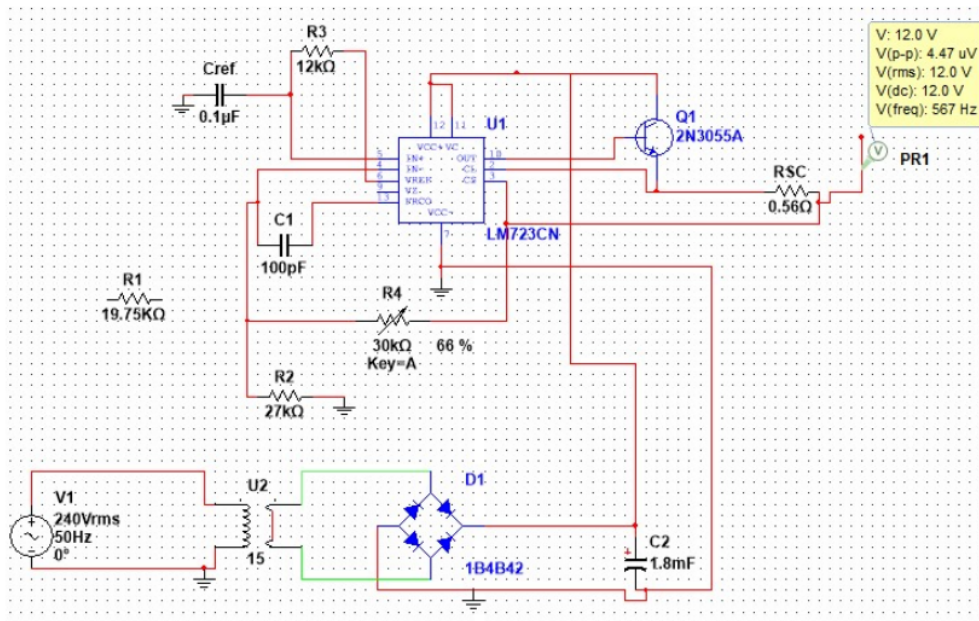


Figure 26 - Variable Resistor set at 66%

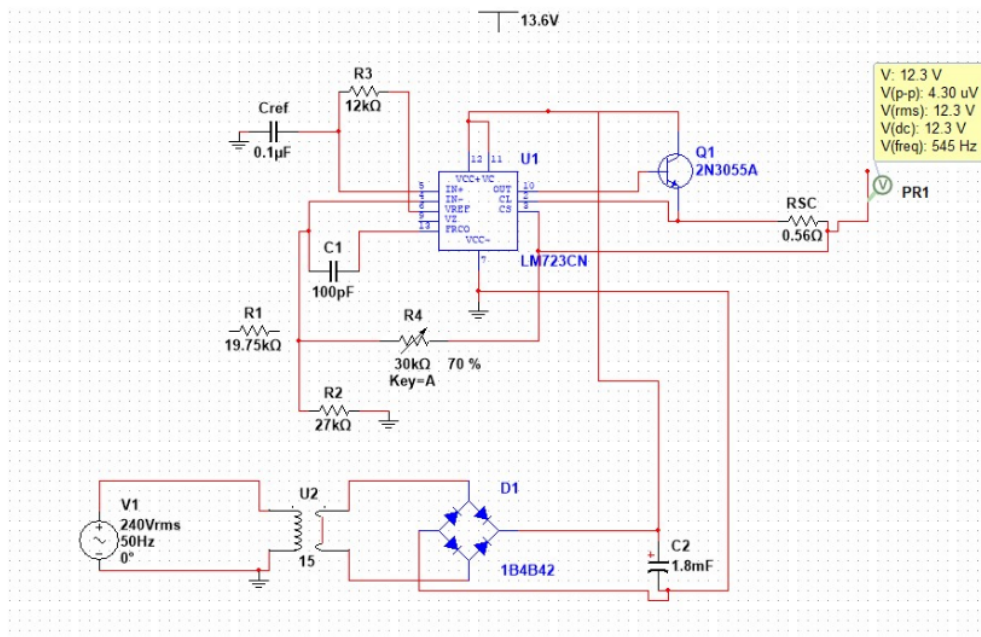


Figure 27 - Variable Resistor set at 70%

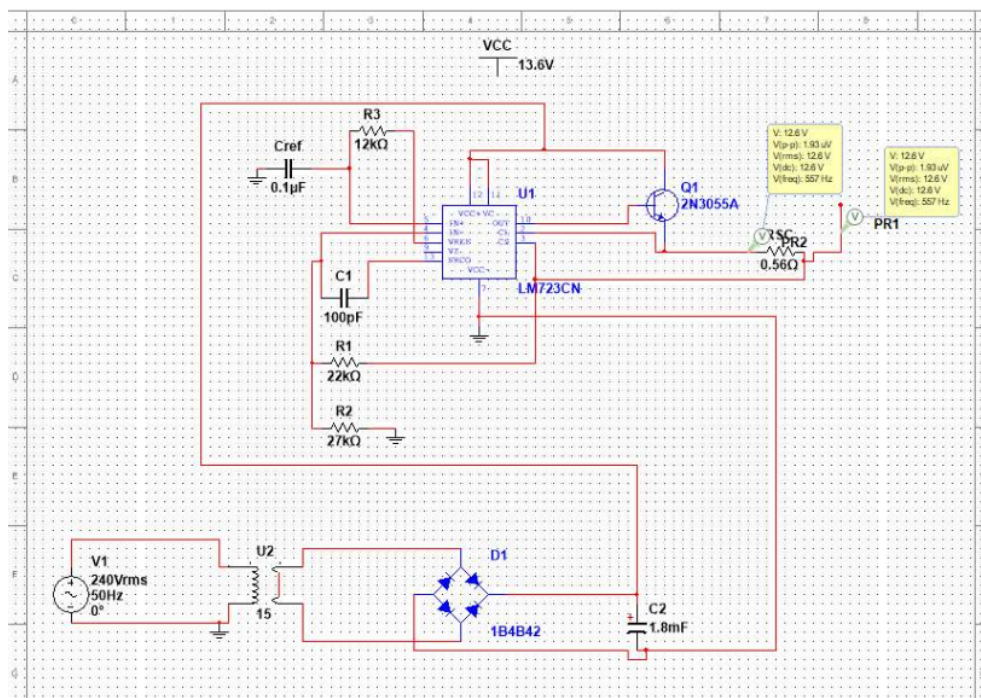


Figure 28 – Final Circuit with Resistor Values from Voltage Regulator Design

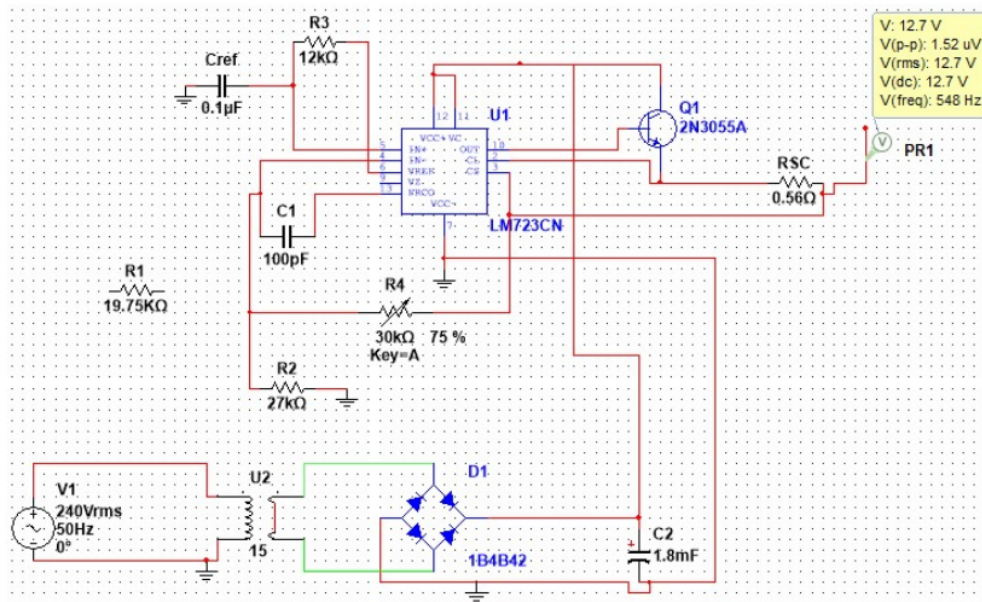


Figure 29 – Variable Resistor set at 75%

10.4. FAT



Figure 30 – Power On LED



Figure 31 – Vacuum Ok LED ON



Figure 32 – Low Vacuum LED & Alarming



Figure 33 – 12V when PS1 Switched



Figure 34 – 9V when PS2 Switched

10.5. AutoCAD Drawing of Complete Vacuum Lift Equipment Project

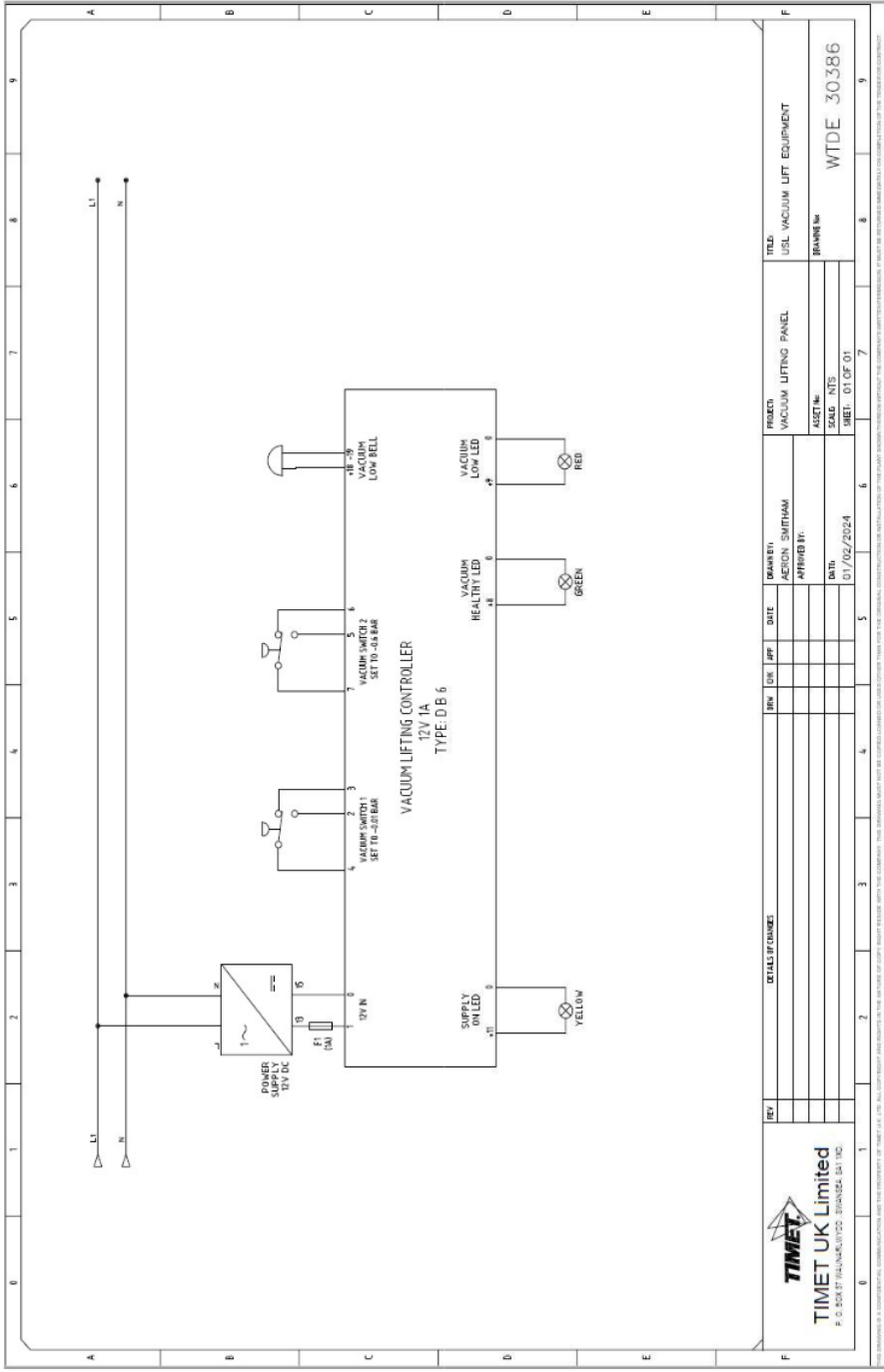


Figure 35 – AutoCAD Drawing of Completed Project

FINAL GRADE

GENERAL COMMENTS

85/100

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GRADING FORM: CSG-RUBIC

AERON SMITHAM**85****RESEARCH-INFORMED LITERATURE**

There was evidence of further reading and research with the inclusion of a reference list and appropriate in text referencing. Your interpretation and understanding of the additional research was good. Your references were appropriate to the task and your reference list was of an appropriate length for this assignment. Some of the material was not needed for the assignment however.

6**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.

26

ANALYSIS



Your analysis of the task was excellent, both in class and as shown in this assignment. 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 relating your practical results to accepted theory. You have demonstrated a capacity for independent thought and your interpretation of the quantitative and qualitative data was excellent with sound judgements based on wholly valid arguments.

17

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.

27

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.

9