COVERSHEET

THE UNIVERSITY OF WESTERN AUSTRALIA
Achieve International Excellence

Faculty of Engineering, Computing and Mathematics

Assignment, Report & Laboratory Coversheet for Individual & Group Assignment

SUBMITTING STUDENT		
SURNAME Page	**GIVEN NAMES** Hannah	**STUDENT NUMBER** 22498279
UNIT NAME Electrical and Electronic Design Project 2		**UNIT CODE** ELEC5552
TITLE/TOPIC OF ASSIGNMENT Requirements Analysis		**NAME OF LECTURER/TUTOR**
DATE/TIME DUE Friday 18/08/23 at 5pm	**DATE/TIME SUBMITTED** Friday 18/08/23	

HONOURS STUDENTS ONLY	**OFFICE USE ONLY**
By signing this document, I further assert that the length (word count) of my dissertation is within the maximum allowed length governed by the project unit I am enrolled in. Penalties, as outlined on this website, will be applied for over length dissertations.	

FOR GROUP ASSIGNMENTS ONLY — **NAME**	**STUDENT NUMBER**
1. Serena Joppich	22721338
2. Vani Srivastava	22501707
3. Julia Taule	22388829
4. Hannah Page	22498729
5. Myles Kelly	22722165
6. Sebastian Hasleby	22510801
7.	
8.	

Unless other arrangements have been made it will be assumed that all group members have contributed equally to group assignments/laboratory reports

DECLARATION

I/We are aware of the University's policy on academic conduct (see over) and I/We declare that this assignment/project is my own/my group's work entirely and that suitable acknowledgement has been made for any sources of information used in preparing it. I/We have retained a hard copy for my/our own records.

SIGN: Serena Joppich	**SIGN:** Se
SIGN:	**SIGN:** M Kelly
SIGN:	**SIGN:**
SIGN:	**SIGN:**

NOTE: No assignment will be accepted without the declaration above being signed and dated

SEE OVER FOR INFORMATION ON REFERENCING & PLAGIARISM

REFERENCING

Information on appropriate referencing (citation) styles can be found under "Manage Your References" at: www.is.uwa.edu.au/information-resources/guides

Note that:
Each drawing, picture, photograph, quotation or block of text copied from a source must be acknowledged individually. This can be done using a referencing style (see above) or by including the full reference in the text or in a footnote. It is not sufficient to simply list sources in a bibliography at the end without including the individual references to the sources in the main text.

The same rules apply to materials taken from the web. The authorship and source must be traceable.
The boundaries between your original work and copied work must be clear. Use quotes, indentation and/or font style to make the distinction clear.

PLAGIARISM

"The appropriation or imitation of another's ideas and manner of expressing them to be passed off as one's own".

(The Macquarie Dictionary, 1981)

Synonyms:

Piracy, copying, forgery, lifting, expropriation, appropriation

"Plagiarism is the unattributed use of someone else's words, creations, ideas and arguments as one's own. Within university policies it is usually further extended to include the use of 'too close' or extensive paraphrasing. For example, cutting and pasting text from the Web without attributing it to the author is plagiarism and therefore dealt with as cheating. Similarly, substituting a few words of copied text without changing the structure of the piece also constitutes plagiarism. There is a range of penalties for academic misconduct, depending on the seriousness of the cheating, from loss of credit to expulsion from the University." (UWA Handbooks 2013)

The University of Western Australia treats plagiarism as serious academic misconduct. The University can impose severe penalties, including expulsion. Refer to Statue 17 Student Discipline and the associated Regulations for Student Conduct and Discipline at www.uwa.edu.au/current/information/discipline

See also

Faculty Policy on Plagiarism:

www.ecm.uwa.edu.au/students/exams/dishonesty

UWA's policy statement on Ethical Scholarship, Academic Literacy and Academic Misconduct: www.handbooks.uwa.edu.au/postgraduate/policies

UWA ELEC5552

Project 2: MEMS Testing Power Supply (ANFF)
Team 14

Author(s)
Hannah Page (22498729)
Vani Srivastava (22501707)
Myes Kelly (22722165)
Sebastian Hasleby (22510801)
Serena Joppich (22721338)
Julia Taule (22388829)

Requirement Analysis
Volume 1

Project Partners: Michal Zawierta, ANFF

UWA Supervisor: Jega Gurusamy

Team Number: 14

Group Meeting Day and Time: Thursday 3pm

Word Count: 9,189

Word Limit: 10,000

Version 1.0

Revision History

Date	Version	Description	Author
07/August/23	0	Document structure	Julia Taule
15/August/23	0.1	Draft Compiled	All
18/August/23	1.0	Good Copy Finalised	All

Team Contribution

Team Member	Student Number	Report Section
Vani Srivastava	22501707	Previous Design Waveform Generator Stakeholders
Myles Kelly	22722165	Requirements
Hannah Page	22498729	Executive Summary Block Diagram Stakeholders Device Interface Other Considerations
Sebastian Hasleby	22510801	DC/AC Frequency Adjustment Device Control Requirements
Serena Joppich	22721338	Protection Requirements Selection and Prioritisation Methodology Constraints
Julia Taule	22388829	Introduction Voltage regulation Relevant Standards and Regulations Conclusion

0. Executive Summary

The ELEC5552 project partner, the Australian National Fabrication Facility WA, has requested teams to design and construct a digitally controlled, variable voltage power supply for the testing of microelectromechanical systems. The provided project brief included many technical requirements, and identifying, defining, and addressing all requirements and constraints early in the project lifecycle is essential for a successful design.

This report is the cornerstone of requirement management within the ELEC5552 design project and will introduce the project goals, evaluate the project stakeholders, and review the key literature. This information is used to produce a list of specific, prioritised requirements, each with corresponding plans for development and verification.

The stakeholder analysis identified the design team and project partner representatives as those with both high interest and power in the project. It was determined that these parties must be managed closely with frequent detailed communications. Other UWA staff including UWA Safety and Purchasing were identified as having high power due to their potential impact on the project's completion. They will require early and traceable communications to ensure their requirements for safety or procurement are met.

Initial literature review identified few commercially available power supplies that could meet all the project partner's requirements. Further research focused on individual components and the architecture that may be utilised in the design. The literature review concludes with a summary of the essential standards that must be used in the design.

The requirements originated from several sources, including the project brief, technical queries, standards, and best practices. They are split into five categories: Safety Critical, Critical, High, Medium, and Low. These classifications are used to help prioritise the requirements that have been selected.

The requirements have been listed in order of descending priority. The top identified requirements include compliance with Australian standards, fast output protection in cases of exceeding current limits, providing a hardware voltage interlock and ensuring the enclosure may be safely handled by users. All requirements are numbered for traceability and feature a specific description, priority, source and proposed delivery and verification methodology.

As a part of the other requirements, key constraints have been identified. These include technical constraints such as the expected connectors and input voltage, as well as project constraints such as time and budget limits.

Identifying and clearly defining these stakeholders, requirements and constraints produces an explicit project scope, reducing future scope creep or miscommunication. It also ensures the design features and requirements may be validated prior to construction, reducing risk of project partner dissatisfaction.

Table of Contents

1. Introduction

The Australian National Fabrication Facility WA (ANFF-WA) is a semiconductor fabrication facility supporting research and proof of concept development for industry. The WA node provides services for micro- and nanofabrication of electro-mechanical systems (MEMS) and infra-red sensor technology [1]. For this, they require high accuracy, specialised equipment for both fabrication and testing. Testing of MEMS devices requires high voltage and extremely low currents to cause a build-up of electrostatic discharge, whilst not causing residual polarity to build up within the devices. Commercially available power supplies often either lack the desired characteristics, such as a variable output functions, or are prohibitively expensive.

1.1 Project Goal

ANFF-WA has requested a variable power supply for use in charging the capacitor-like MEMS devices. The power supply should be able to generate AC and DC from an external 12V DC supply, ensure safe operation and have adjustable voltage and frequency capabilities [2]. The projects goals are thus twofold:

i) Deliver a functioning design informed by our developing requirements analysis.

ii) Conduct the project in line with UWA’s safety requirements.

1.2 Purpose of this Document

This requirements analysis aims to define the project context and scope. Through a comprehensive analysis of design requirements, design decisions can be made with sufficient knowledge of client and stakeholders’ requirements, ensuring delivery of a high-quality end product that meets the intended objectives. This document also allows for future change management as the documented requirements serve as a basis for managing future changes or updates throughout the lifecycle of the project.

1.3 Report Structure

This report starts by identifying the roles and responsibilities of all relevant stakeholders and defining the required stakeholder management before presenting a summary of the current state of the art and relevant information used to determine the design requirements. Following this, the top 20 requirements are presented, including a short description of proposed delivery and verification methodology. Additional requirements and constraints will also be covered.

2. Stakeholders

Stakeholders are defined as parties that can materially affect the project’s outcome and may or may not benefit from the project. These include both stakeholders who contribute and who are impacted by the project output [3].

Initial stakeholder identification was performed through the PPIR process, brainstorming, and investigating the project documentation. They have been outlined in Table 1, with their roles and responsibilities with respect to the project outlined, providing rationale for their recognition as stakeholders.

Table 1: Stakeholder identification, including justification and management plan.

Stakeholder	Role and Responsibility	Engagement Plan
Design team	The design team will be responsible for all design and development decisions and is highly engaged due to the assessment of the project. The team aims to gain practical engineering experience and contribute to a successful project outcome.	Weekly meetings and shared drive for files. Teams channel and messaging for urgent matters. Clear task delegation. Skill development opportunities.
Dilusha Silva	As unit coordinator, Dilusha will provide guidance, access to testing and construction equipment and feedback. Additionally, he is acting as a project partner representative and as such is highly invested in the project outcome.	Weekly TQ's and information sessions. Meetings as required. Assessments submitted through LMS.
Michal Zawierta	As a project partner representative, Michal will be providing TQ information, and has high interest in the final design and functionality.	Weekly TQ's and information sessions. Meetings as required.
ANFF-WA	Project partner – has set the initial design brief and is the lab that will use the final design. Their end goal is successful development of a digitally controlled power supply for MEMS testing.	Engagement through project partners – Dilusha Silva and Michal Zawierta
Jega Gurusamy	As group facilitator, Jega will be present at weekly meetings and provide feedback on design processes. Additionally, he will approve components prior to purchasing, giving him higher stakeholder power.	Weekly meetings, contribution reports and design reviews.
UWA Safety	Must approve Team Safety agreement prior to any construction or testing. May drastically impact project timeline if approval is not gained.	One-off safety agreement and additional paperwork as required.
End users-Researchers	Will use the final design, however, they have little power at this stage and will instead be represented through the project partner representatives.	Engagement through project partners and discussion with Jega.
Suppliers	Suppliers are crucial for meeting the team’s time and cost constraints. Additionally, purchasing parts in small quantities may require additional supplier engagement.	Emails and queries through web portals.
UWA Purchasing Department	Will either purchase or reimburse component costs within budget. Require engagement to ensure components are purchased in time and design team is not purchasing with own money.	Submission of purchasing-orders or receipts. Team has been informed that a one-off submission is preferred.
Regulatory bodies	Regulatory bodies such as ERAC are not necessarily high power or interest at this point in the design, as the team’s design is research-based and will not be going to market. However, organisations and associated standards contribute helpful information about commercial or safety requirements that are required for future iterations.	Read provided material surrounding standards and safety – no need to engage at this point.

Following their identification, stakeholders were assessed with respect to their interest and power, as seen in Figure 1. This assessment was based on the roles and responsibilities outlined in Table 1. As highlighted, each quadrant relates to different levels of importance and required management.

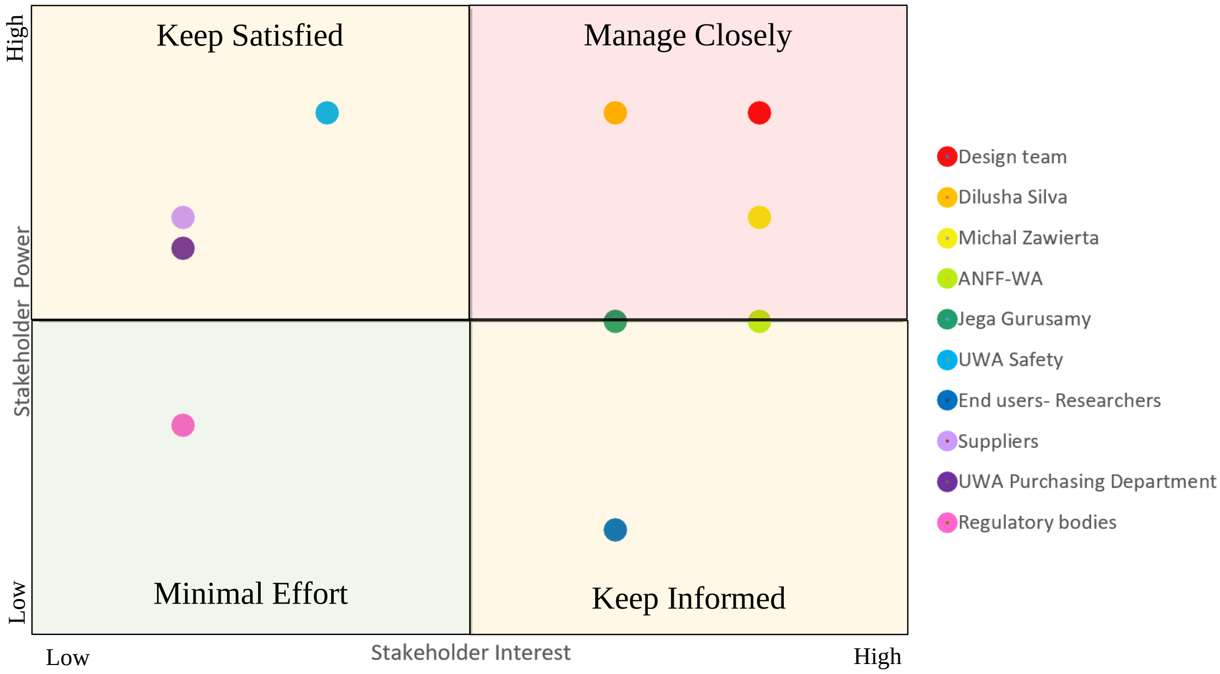


Figure 1: Stakeholder analysis matrix.

Lastly, the required stakeholder management and engagement was defined for each stakeholder, based on the interest-power matrix produced. This information has been included in Table 1 above for conciseness, and includes the planned content, format, and frequency of stakeholder engagement.

3. Relevant Literature

3.1 Architecture and Previous Designs

3.1.1 Previous Designs and Architecture

Martin-Ramos et., al proposes a structure for a power supply in which the key component is the step-up transformer in the DC-DC converter. The transformer has a large turns ratio to obtain a high voltage and high isolation distances, however this increases the leakage inductance [4]. Alternatively, Siravo et., al proposes “MAGY”, an innovative high voltage low current power supply, where a series of independent, regulated, bi-directional DC sources are used, without any switching at the module output. Dedicated modules produce a high voltage, and then other modules produce smaller voltages to increase the resolution in the output voltage. This is known as the asymmetric multilevel converter [5]. Due to the complexity and cost constraints of the transformer power supply method, the non-transformer method will be investigated in the team’s design. There are three different topologies for this type of power supply: buck (step-down), boost (step-up) and the buck boost (inverting) [6]. A buck-boost regulator is the preferred method, which will be justified in later sections.

The preliminary design architecture can be seen in the block diagram shown in Figure 2. Although rudimentary, it identifies some key modules and interfaces that will be integral to the design. The red arrows indicate the flow of power through the system, the black lines indicate the flow of information, either control or data, and the surrounding box defines the scope.

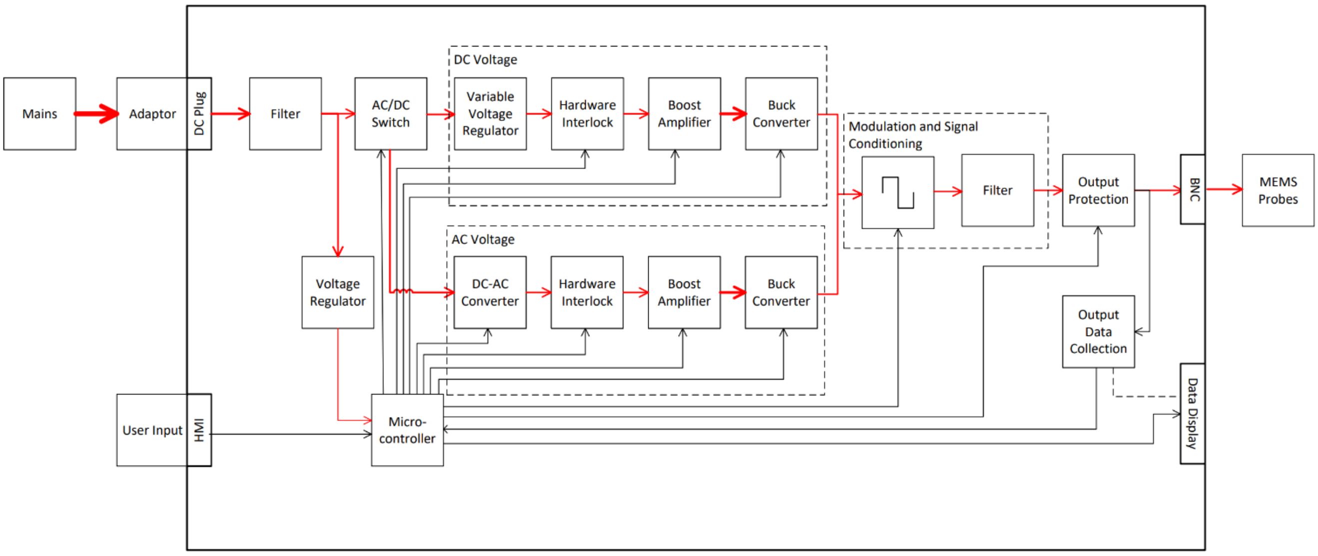


Figure 2: System block diagram.

After the DC input is supplied, initial filtering may be applied depending on the quality of the signal. It is expected that when using the lab power supplies for testing, this will be unnecessary but may need to be added when being powered by a commercial power adaptor. A preliminary voltage regulator will step down to the necessary voltage for the microcontroller and logic circuits, either 3.3V or 5V.

The circuit switch near the input will allow for either the AC or DC circuit to be used. This switch may potentially be controlled directly by the user input, or through the microcontroller as an intermediate. The circuit then deviates to the AC and DC systems, however both utilise similar concepts of increasing the voltage and then regulating it down to the specific necessary output voltage, as specified by the user input.

Finally, the power (which is now at the correct voltage) will undergo filtering and potentially modulation via a square wave, depending on the user input. These output values will be monitored and displayed to the end user. As many design decisions have not yet been made, this is a basic overview that allows for the research into different components and concepts necessary for the design and requirements.

3.1.2 DC/DC

A DC-DC stage converter is implemented when it is required to step up or down the voltage in a DC system. It usually consists of two stages: the first regulation stage and the output regulator and filtering stage. The first stage generates a stable DC output, and the second stage sets the final output voltage and filters out any noise [7]. Isolated converters are usually utilised for high-voltage systems as it reduces the user exposure to high voltage when servicing the output side system.

3.1.3 DC/AC

Low power DC/AC inversion presents a unique challenge in this design due to common industrial methods such as pulse width-modulated (PWM) and multi-level-modulated (MLM) inversion mainly catering to low frequency, high power contexts [8]. Their unsuitability stems from their creation of a high dV/dt during operation which leads to harmonics which adversely impact other devices [9]. Leveraging these devices requires a careful implementation of signal filtering. Figure 3 showcases how active filtering utilises a capacitive storage to reduce distortion at the load. An additional shunt filter can be introduced to allow for low frequency filtering and ensure that the active filter does not saturate [9].

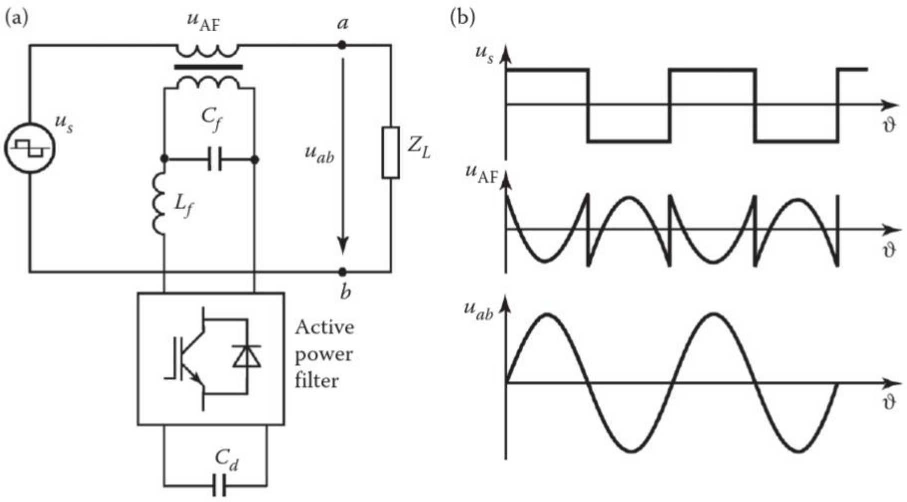


Figure 3: Active filtering (left) and resultant waveforms (right) [9].

It is noted that this method has not been tested in this context, so we focus on novel methods which utilise analogue components. The push pull amplifier (and other amplifier architectures) is of key interest as it allows the team to utilise the developed DC/DC voltage supply to deliver the DC/AC signal. This has the added benefit of current being limited by the DC/DC converter. Figure 4 shows an *LT Spice* simulation that demonstrates the working principle of a Class B Amplifier. State of the art amplifiers excel well beyond the desired frequency range [10], giving this method a stronger justification.

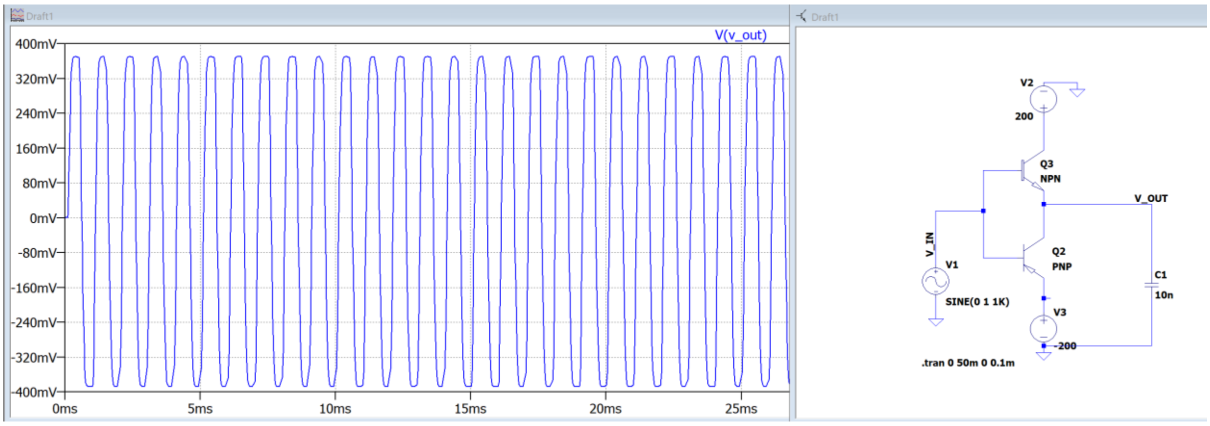
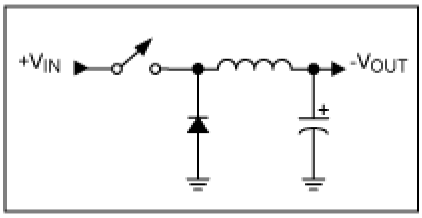


Figure 4: LT Spice simulation of Class B amplifier working principle.

3.2 Design Components

3.2.1 DC Voltage Regulation

The power supply requires the functionality of regulating the output voltage from 0 to 200V. Hence, a step-down or buck converter is necessary to regulate the 12V input voltage to a value between 0 and 12V and a boost converter to deliver voltages from 0 to 200V. Figure 5 shows a typical buck (left) and boost (right) converter circuit diagrams.



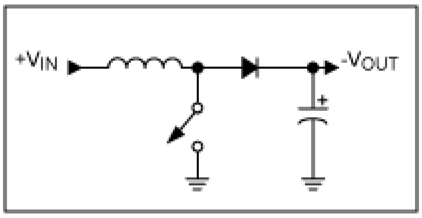


Figure 5: Buck (left) and boost (right) converter circuit diagram [11].

The switch is usually a MOSFET and is turned on and off by applying a PWM signal to the gate. This can be supplied from a microcontroller and is usually time-based for simplicity of construction and use. The inductor and capacitor form an LC filter to minimise high frequency noise. By adjusting the switch on time, the output voltage can be adjusted by the following relation, where D is the duty cycle, T is the control period and t_{on} is the switch on time.

$$D = \frac{V_{out}}{V_s} = \frac{t_{on}}{T}$$

The largest losses in this circuit arise from the voltage drop across the diode. This can be mitigated by using Schottky diodes due to their low forward voltage drop, or a MOSFET instead [11]. These components present the main limitation on possible output voltage range for the devices and must be considered when selecting components for the design [12]. Constructions using the additional MOSFET is often referred to as a synchronous rectifier and can achieve efficiency above 90% as the voltage drop across the switch is in the order of millivolts [11].

The most used control method for converters is voltage- or current-mode PWM. These methods sample the output signal and compares it to an oscillator ramp signal. The output of this comparator is then sent to the gate of the switch, where changes in the error signal results in changes to the signal sent to the switch. Hence, both the duty cycle and the output are adjusted [13]. Voltage-mode compares the voltage and current-mode compares the current. Current-mode is often preferred due to its capability of current control and metering ensuring fast corrections of inconsistencies [14].

The selection of inductor size depends on the desired switching frequency and output current, where a high inductance reduces the ripple in the output current. The recommended current ripple ratio ($r = \frac{\Delta I}{I_{OUT}}$) is 0.25-0.5 for buck- and 0.2-0.4 for low-power boost converters at maximum rated load [15, 16]. Meanwhile, the output capacitors impact the voltage ripple and transient response at the output, where increased capacitance leads to a reduction in voltage ripple and a faster transient response [17]. Additional capacitors are often incorporated at the input and output to achieve the desired system specifications [18].

Few buck and boost converters that can deliver the required voltage range for this application are available in the market. Hence, one can deploy multiple stages of converters to achieve the required step size and range. More specifically, buck converters may be connected in parallel to improve transient performance and voltage ripple [19]. Finally, multiple boost converters may be connected in series, forming a multistage converter to achieve the required maximum output voltage [20].

3.2.2 Wave generator

To design a sine wave generator circuit, a Wien bridge oscillator can be implemented [21]. ***Error! Reference source not found.*** Figure *6* shows a circuit where resistors R_1 and R_2 and capacitors C_1 and C_2 are components used to adjust the frequency, whereas resistors R_3 and R_4 are components used for the feedback loop. For the circuit to oscillate at the required frequency, the ratio of R_3 to R_4 needs to be greater than 2, to provide sufficient loop gain [21].

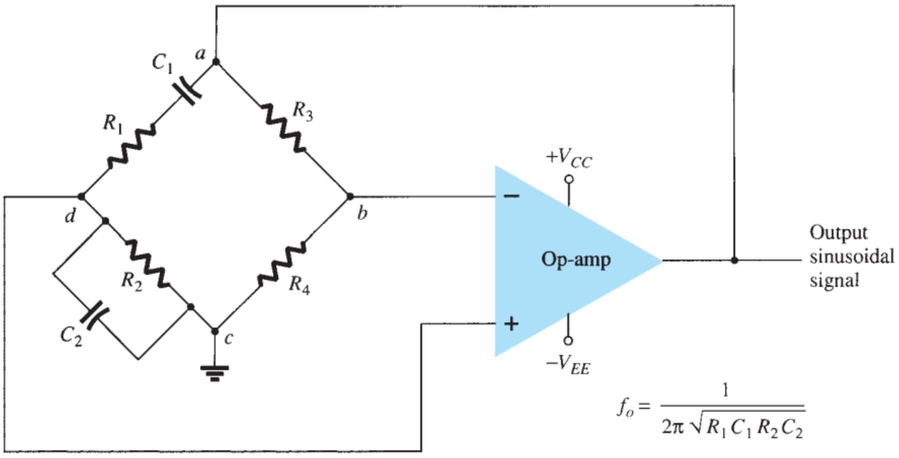


Figure 6: Wien bridge oscillator circuit *[21].*

To design a square wave generator, a high voltage, low output impedance and a fast rise time is required. High voltage MOSFETs can be used, as they are simple and reliable with a rise time of approximately 50ns [22]. The circuit topology is shown in Figure 7.

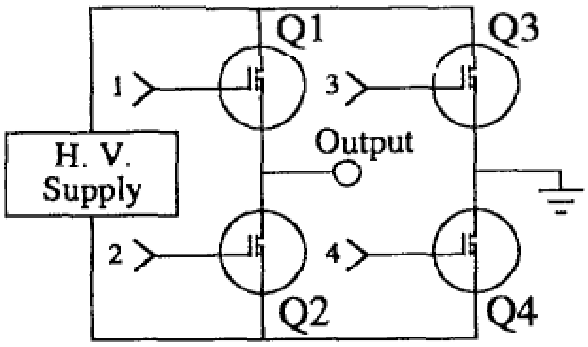


Figure 7: MOSFET topology for square wave generator [22].

The different MOSFETs can be turned on at different times by the microcontroller to produce specific desired voltage outputs, such as a “high” or “low”, thus producing a square wave output. An example timing sequence is shown in Figure 8.

Time	$Q1$	$Q2$	$Q3$	$Q4$	Output
t_1	on	on	off	off	ground
t_2	off	on	off	off	intermediate
t_3	off	on	on	off	neg. high voltage
t_4	off	off	on	off	intermediate
t_5	off	off	on	on	ground
t_6	off	off	off	on	intermediate
t_7	on	off	off	on	pos. high voltage
t_8	on	off	off	off	intermediate

Figure 8: Timing sequence of MOSFETs [22].

3.2.3 Frequency Adjustment

The approach to frequency adjustment is contingent on the DC/AC method selected. For PWM and other MOSFET based architectures, the signal is produced by varying pulse widths through rapid gate activation. This switching is determined by communication with the microcontroller, with PWM inverters generally quoted as being able to deliver up to 650Hz. The analogue approach allows for the purchase of dedicated function generator blocks. The *XR-2206 Function Generator* is an example of a 0.01Hz – 1MHz sine wave generator which can easily conform to the frequency adjustment criteria.

3.2.4 Protection

The power supply design requires fast tuneable output protection, in which the output voltage is switched off if the output current exceeds 1 – 10 mA.

A typical overcurrent protection circuit consists of a current sensing resistor, operational amplifier and a MOSFET or relay [23, 24], as seen in Figure 9.

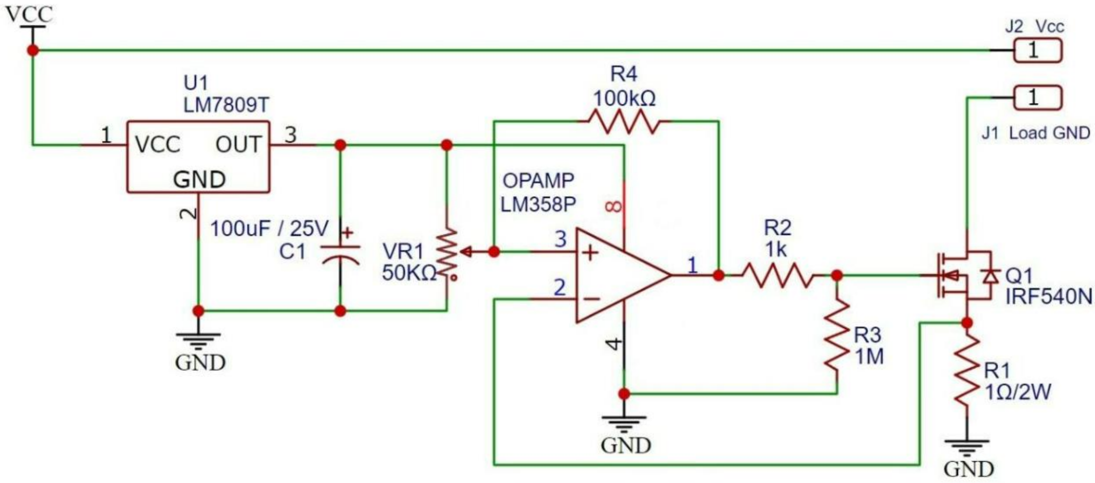


Figure 9: Overcurrent protection circuit [23].

The load current flows from the load to the drain terminal of the MOSFET (shown as IRF540N in Figure 9) and through a shunt resistor (shown as R1) to ground [23, 24]. The load current produces a voltage drop across this resistor in accordance with Ohm’s Law. This voltage is applied to the inverting terminal of the op-amp (shown as LM358P in Figure 9) and compared with the voltage reference set at its non-inverting terminal [23, 24].

If the voltage across the shunt resistor is greater than the voltage reference, the op-amp produces a negative supply voltage [23, 24]. This drives the MOSFET into its OFF state, thus disconnecting the load. The voltage reference can be adjusted using a potentiometer (shown as VR1 in Figure 9), allowing adjustment of the circuit's tripping point and thus enabling its tuneability [24].

The resistor R4 acts a feedback resistor between the op-amp's output and input [23, 24]. The resistor R2 functions as the MOSFET's gate driving resistor used to regulate its switching speed [24]. The resistor R3 acts as a pull-down resistor for the MOSFET, ensuring effective discharge of the MOSFET to ground when in its OFF state [24].

A voltage regulator (shown as LM7809T in Figure 9) is used to provide a stable power supply to the op-amp, such that it is not affected by transient changes (for example, a sudden change in load current or input voltage) and thus allowing optimal performance [24]. The capacitor C1 is used to filter out fluctuations in the voltage regulator's output voltage, ensuring a smooth and consistent output [24].

3.2.5 Device Interface

As specified by the project partner, the system requires a method for the end user to adjust parameters including voltage, power waveform, frequency, current protection limit and a hardware interlock. The user must be able to access these values and understand which parameters have been set. Additionally, it is best practice to have a visual indication for power and overcurrent states to increase safety.

LED and 8-segment displays with built-in voltage and current meters are available, however supplies are often only rated for low voltage or precision, expensive, or from unreliable suppliers. As a result, the design will likely need a custom measurement and display system.

The method of tuning each parameter will depend on the circuit implementation and variable being adjusted. Standard lab power supplies feature rotary control knobs. As the design brief specifies a 0.05V division and up to 200V, it is expected that a multi-stage tuning system will be required. This may feature multiple knobs which can adjust the values at different magnitudes to ensure both the voltage division and maximum voltage can be obtained.

The system will need to switch between different output waveforms. These include DC, square wave, AC and a square-wave AC power supply. Additionally, the hardware interlock needs to be available for both AC and DC voltages. As these are discrete modes, unlike the continuous-valued parameters like voltage and current, a button or switch would be more suitable for these inputs.

Considering all these features, an initial preliminary interface has been designed, seen in Figure 10. It also features additional LEDs next to the 8-segment displays so end users can see which parameter is being read and altered. Further research into the simplest method to display and adjust these parameters is still necessary, as the additional circuitry and programming could add unnecessary complexity.

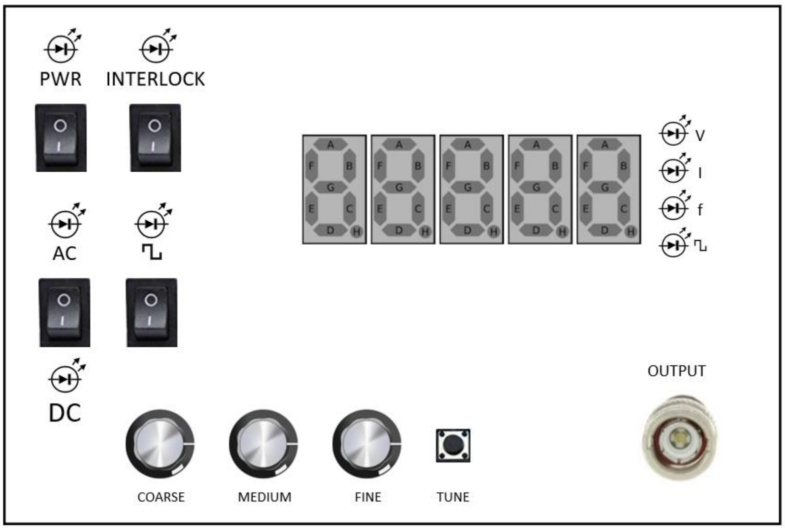


Figure 10: Preliminary interface concept.

3.2.6 Device Control

As the user requires digital control of the power supply and most safety features will be implemented through the supply's digital interface, it is important to choose a microcontroller which has adequate peripheral features, I/Os and computing capacity for the desired project. Table 2 contrasts three renowned microcontroller suites.

Table 2: Comparison of ESP32, STM32 and Arduino MCUs.

	Advantages	Disadvantages
ESP32	• Rich wireless connectivity features • Dual processor cores	• Only programmable in C/C++
STM32	• Better price to performance ratio • Strong peripherals • Some devices can use Python • Good documentation	• Expensive • Low availability
Arduino	• Rich peripheral offerings • Open-source libraries • Beginner friendly	• Lowest performance

As mentioned prior, key safety features such as interlocking will be implemented via communication between the MCU and ancillary components. This will be done through either I2C or SPI. I2C requires two lines, the Serial Data (SDA) and Serial Clock (SCL), leading to lower board complexity and less wiring. It has simple addressing and can accommodate any permutation of master and slave controllers [25]. SPI, on the other hand requires four lines, a master out slave in (MOSI), master in slave out (MISO), slave select/chip select (SS/CS) and clock (SCLK) [25]. What the protocol enjoys in simplicity it loses in hardware complexity and signal integrity due to the lack of acknowledgment and difficulties in adding devices.

3.3 Other Considerations

3.3.1 Output stability and noise

The project partner has explicitly specified maximum output voltage ripple and noise values. Voltage ripples are the residual periodic voltage fluctuations from AC-DC conversion, whilst noise includes aperiodic fluctuations, introduced from a multitude of sources. Switching voltage regulators will be utilised to increase the voltage to the required output values. These regulators inherently introduce voltage ripples as the main noise source, as well as potentially wideband noise and high frequency spikes [26]. Additionally, the power adaptor supply from mains may also introduce voltage ripples.

There are many methods of attenuating and removing noise from power sources. Selecting a method relies on an understanding of both the power supply circuitry, load impedance, and noise characteristics. Although the noise frequency and characteristics may not be known until the design is constructed, initial designs will contain multiple levels and types of filtering to reduce the impact of any noise. Filters on the output power line will be used to reduce the noise to within the limit specified by the project partner.

High frequency switching in the power supply circuitry may produce additional noise within the digital control circuits unless adequately accounted for. To reduce the noise coupled between the switching power and other circuitry, parasitic capacitance and inductance must be reduced. The simplest method will be to space out traces for digital and power circuits, reducing the coupling and mitigating any potential signal issues for the digital control. Additionally, decoupling and bulk capacitors will be utilised at the microcontroller power supply to protect the device from any potential spikes. As the system does not feature high speed signalling and decreasing the system size is not a high priority, increasing the space between traces and routing them to decrease any coupling effect should be a satisfactory method of managing noise within the circuit.

3.3.2 Isolation and Grounding

Power supplies may be designed as isolated or non-isolated. In an isolated system, there is galvanic isolation between the input and output using transformer components and each side has different grounds levels. Isolated systems are often utilised in high-risk use cases where the consequences of equipment failure are considered highly unacceptable, such as medical devices. These however increase the cost and complexity of the system and also introduce potential ground plane issues. Due to the design’s low current and its required fast output protection, the risk of electrocution during operation is already considered acceptably low so isolation is not defined as a requirement.

To ensure safe handling of the case, it is important to provide an earth connection to the chassis ground. This provides a low impedance return path for any current that may be caused by faults, which would otherwise produce an electrocution risk. Earthing is commonly provided by connecting the mains earth wire to the chassis, however the available mains power adaptors do not provide access to this wire, so additional earthing precautions and delivery methods must be investigated. Additionally, grounding the chassis will produce shielding effects.

3.4 Relevant Standards and Regulations

It is essential that the design and process follows the relevant standards and regulations to ensure the quality and safety of the final product. The following standards and guidelines are relevant to this project.

AS/NZS-3820: Essential Safety Requirements for Electrical Equipment
All purchased components and the final design must comply with this standard. It outlines safety criteria for electrical equipment supplying voltage prior to entering the market [27].

AN/NZS-3008: Cables for alternating voltages up to and including 0.6/1 kV—Typical Australian installation conditions
This standard provides a guideline for selecting cables used in electrical installations, including their properties and relevant derating in typical Australian conditions [28].

AS/NZS-3000: Electrical installations
This standard provides general guidelines for Low Voltage electrical design, construction and verification to be conducted to ensure all electrical installations are fit for purpose and safe [29].

AS/NZS-61010.1: Safety requirements for electrical equipment for measurement, control and laboratory use – Part 1 – General requirements
This standard covers the general safety requirements and verification methods applicable to electrical control equipment used in a laboratory setting. It covers aspects such as electric shock, high temperatures, fires and burns [30].

UWA Electrical Safety and Work Procedure
This procedure is relevant to individuals undertaking electrical activities on behalf of the university [31], with the objective of ensuring a safe work environment. The following electrical legislations are to be consulted in conjunction with this procedure:

- Occupational Safety and Health Act 2022, as the 1984 version is superseded [32];
- Occupational Safety and Health Regulations 2020, as the 1996 version is superseded [33];
- Electricity Act 1945 [34];
- Electricity (Licensing) Regulations 1991 [35]; and
- Electricity Regulations 1947 [36].

4. Requirements

This section details the design requirements as formulated by the team. This includes their priority category and manner in which they were stated by the client, ranking, source, delivery method and testing/verification method. Any changes in these requirements that may occur during the design process will be discussed with the client and justified by the design team.

4.1 Selection and Prioritisation Methodology

Table 3 outlines the requirement priority system as devised by the team. The requirement priority categories are as follows, from highest to lowest: Safety Critical, Critical, High, Medium and Low.

Table 3: Requirement priority categories.

Priority category	Description
Safety Critical	Any requirement which presents a safety hazard to individual/s if not incorporated into the design.
Critical	Any requirement which is necessary to fulfil the design's functional requirements and must be implemented for successful design delivery. Without meeting these requirements, the system will not operate.
High	Any requirement which is necessary to fulfil the design's functional requirements and must be implemented to achieve client satisfaction.
Medium	Any requirement which is not necessary to fulfil the design's functional requirements and is considered of high importance for client satisfaction.
Low	Any requirement which is not necessary to fulfil the design's functional requirements and is considered of low importance for client satisfaction.

The requirements are also classified by the nature by which the client stated them. The classifications are as follows:

- Spoken (S) – explicitly stated by the client.
- Unspoken (U) – not explicitly stated by the client but still expected to be delivered.
- Exciter (E) – may not be expected by the client but would be beneficial.

4.2 Standard Testing Conditions

For the testing and verification sections for hardware requirements, the type of testing that should be performed is largely the same and hence the 'standard testing conditions' will be defined and referenced throughout.

The standard testing conditions and procedure for the developed system are as follows:

- Testing is performed under typical lab environmental conditions, (temp, pressure, humidity).
- The measurements that fulfill each requirement will be taken for two system states:
    1. With a capacitive load analogous to a typical MEMS device connected to the output.
    2. With no load connected to the output.

4.3 Top 20 Requirements

4.3.1 Req-01 – Compliance with Australian Standards

Requirement Description:
Design and testing carried out must comply with AS/NZS-61010.1 (Safety Requirements for Electrical Equipment) as well as other relevant standards highlighted in Section 3.4 of this report.

Delivery Method:		**Testing & Verification:**	
Ensuring that the chosen design components meet the relevant safety standard outlined in AS/NZS-61010.1 for legal compliance. The design is to be constructed in accordance with AS/NZS-3000 and AS/NZS-3820.		Performing and documenting safety tests (such as overcurrent protection, leakage current, grounding, etc.) to ensure compliance with the relevant safety requirements.	
Priority Category:	Safety Critical	**Rank:**	1
Source:	Design Team	**S/U/E**	Unspoken

4.3.2 Req-02 – Overcurrent Output Voltage Cut-off

Requirement Description:
The device must incorporate output protection that switches off output voltage if the output current exceeds the set current limit (as per Req-17). Protection must be resettable to allow for repeat testing and give visual indication when cut-off is engaged.

Delivery Method:		**Testing & Verification:**	
Protection circuit with current sensing resistor to detect load current, an op-amp to compare voltage across the current sensing resistor with the set voltage reference and a MOSFET/relay to switch off the output if the current limit is exceeded. LED turns on when engaged.		Using an oscilloscope to measure the output current under various load conditions and ensuring that the output voltage is switched off when the set current limit is exceeded.	
Priority Category:	Safety Critical	**Rank:**	2
Source:	Project Brief	**S/U/E**	Spoken

4.3.3 Req-03 – Maximum Response Time of Overcurrent Protection

Requirement Description:
The device must incorporate output protection capable of response times in the tens (10’s) of milliseconds after current limit detection.

Delivery Method:		**Testing & Verification:**	
Designing a protection circuit using high-quality components with fast response times. This is important for both user and MEMS device preservation and safety.		Under standard test conditions, an oscilloscope can measure and verify that the 1%, 5% and average response times of output protection for various loads are compliant.	
Priority Category:	Safety Critical	**Rank:**	3
Source:	Project Brief, TQ 31	**S/U/E**	Spoken

4.3.4 Req-04 – DC Hardware Interlock

Requirement Description:
The device must incorporate a hardware interlock that limits the DC voltage to 100V.

Delivery Method:	
When the safety interlock is <u>open</u> the output voltage is limited to 100V, and output protection is triggered if the measured terminal is higher than 105V ± 1V. This is important to prevent users coming into contact with hazardous voltages.	
Priority Category:	Safety Critical
Source:	Project Brief

Testing & Verification:	
Under standard testing conditions, the output terminal voltage should be measured with the interlock open to validate the 100V limit. Closing the interlock allows voltages up to 200V; testing the output protection by opening the interlock when above 105V.	
Rank:	4
S/U/E	Spoken

4.3.5 Req-05 – AC Hardware Interlock

Requirement Description:
The device must incorporate a hardware interlock that limits the AC voltage to 50V RMS.

Delivery Method:	
When the safety interlock is <u>open</u> the output voltage is limited to 50V RMS, and output protection is triggered if the measured terminal voltage is higher than 52.5V RMS ± 0.5V.	
Priority Category:	Safety Critical
Source:	Project Brief

Testing & Verification:	
Under standard testing conditions, the output terminal voltage should be measured using an oscilloscope with interlock open to validate 50V RMS limit. Closing the interlock allows voltage up to 200V RMS; testing the output protection by opening the interlock when above 50V RMS.	
Rank:	5
S/U/E	Spoken

4.3.6 Req-06 – Enclosure Construction Properties

Requirement Description:
Enclosure must be constructed to have sufficient rigidity, protection from electric shock and fire/elevated temperature.

Delivery Method:	
Choosing case materials with suitable thermal, insulation and mechanical properties (i.e., not bare sheet metal). Internal insulation for high voltage circuit elements will be incorporated.	
Priority Category:	Safety Critical
Source:	TQ 11

Testing & Verification:	
Performing thermal, electrical insulation, and mechanical testing to ensure the case can withstand typical lab treatment and accidental mishandling. Further verification using the AS/NZS-3820 and AS/NZS-61010.1 Clause 8 guidelines can be performed upon client request.	
Rank:	6
S/U/E	Spoken

4.3.7 Req-07 – Internal Failure Detection and Output Protection

Requirement Description:
The device will be designed such that, in the event of any internal failure, the output is disabled (no voltage) and a clear visual indication is given.

Delivery Method:		**Testing & Verification:**	
Should an internal failure occur (by component electrical overstress or unintended paths to ground) it will quickly be recognised as the closed loop control systems that produce the desired voltages provides continuous feedback to the controller. Upon detection, all high voltage circuits are isolated from the DC input and indicator LED is lit.		Prior to circuit integration into the case, an internal failure can be simulated by grounding a high voltage component during operation to ensure detection, output cut-off and isolation occurs.	
Priority Category:	Safety Critical	**Rank:**	7
Source:	TQ 51	**S/U/E**	Spoken

4.3.8 Req-08 – DC Output Voltage Range

Requirement Description:
The device must be capable of providing a DC output voltage over the range of 0-200V, adjustable as per Req-09.

Delivery Method:		**Testing & Verification:**	
Using a combination of tuneable and set gain DC-DC amplifiers in various configurations (series, parallel) to reach the desired voltages on a high voltage DC rail connected to output.		Under standard testing conditions, output voltage can be measured and verified throughout the desired range, checking for consistency, accuracy and settling time.	
Priority Category:	Critical	**Rank:**	8
Source:	Project Brief	**S/U/E**	Spoken

4.3.9 Req-09 – Output Voltage Adjustment Fidelity

Requirement Description:
The device must be capable of output voltage adjustments of as little as 0.05V.

Delivery Method:		**Testing & Verification:**	
Precise control achieved by using closed loop control systems and by combining multiple amplification step voltages with different gains and tuning accuracies. Alternatively (and/or concurrently), using highly sensitive potentiometer/tuning knobs for a high degree of manual control.		Under standard testing conditions, measuring the AC and DC outputs as the desired voltage is changed to confirm minimum adjustment.	
Priority Category:	Critical	**Rank:**	9
Source:	Project Brief	**S/U/E**	Spoken

4.3.10 Req-10 – Maximum Current Output

Requirement Description:
The device must be capable of supplying up to 10 mA of current over the full range of AC and DC outputs.

Delivery Method:		**Testing & Verification:**	
Choosing components that can continuously and stably sustain 10mA currents at the desired voltages. As the maximum output power is 2W, most components of this voltage rating should suitable.		Under standard testing conditions, an oscilloscope can be used to measure the output currents and validate the maximum current.	
Priority Category:	Critical	**Rank:**	10
Source:	Project Brief	**S/U/E**	Spoken

4.3.11 Req-11 – Switchable Output Signal Amplitude Modulation for DC Outputs

Requirement Description:
The device must incorporate a switchable output signal amplitude modulator (100% level) using a square wave signal over the range of 10–100Hz for all DC outputs, tuneable as per Req-15.

Delivery Method:		**Testing & Verification:**	
Using a digitally generated square wave signal to switch a high speed MOSFET that modulates the output signal. The selected MOSFET must be rated to the output power at 100% duty cycle (i.e. no modulation).		Under standard testing conditions, an oscilloscope can be used to verify the frequency of the modulating wave (square wave) and ensure that the switching speed is sufficient for negligible rise/fall times.	
Priority Category:	Critical	**Rank:**	11
Source:	Project Brief, TQ 2	**S/U/E**	Spoken

4.3.12 Req-12 – Tuneable AC Voltage Output Capability

Requirement Description:
The device must be capable of providing an AC output over the range of 0-200V RMS, adjustable as per Req-9, with a frequency range of 50-300kHz, tuneable as per Req-16.

Delivery Method:		**Testing & Verification:**	
A high voltage DC rail will be used to amplify a low amplitude control/switching signal through some semiconductor switching scheme (IGBT or MOSFET). The produced signal will then require filtering and clean-up using methods such as grounded capacitors and low-pass filters.		Under the standard testing conditions, waveform analysis (using an oscilloscope) will ensure output waveform accuracy and smoothness over the full voltage range for all frequency steps. ‘Smoothness’ meaning minimal skew and consistent rise, fall and peak-peak times.	
Priority Category:	Critical	**Rank:**	12
Source:	Project Brief, TQ 1	**S/U/E**	Spoken

4.3.13 Req-13 – Switchable Output Signal Amplitude Modulation for AC Outputs

Requirement Description:
The device must incorporate a switchable output signal amplitude modulator (100% level) using a square wave signal over the range of 10–100Hz for all AC outputs, tuneable as per Req-15.

Delivery Method:		**Testing & Verification:**	
Using a digitally generated square wave signal to switch a high speed MOSFET that directly modulates the output signal. The selected MOSFET must be rated to the output power at 100% duty cycle (i.e., no modulation).		Under standard testing conditions, an oscilloscope can be used to verify the frequency of the modulating wave (square wave) and ensure that the switching speed is sufficient for negligible rise/fall times.	
Priority Category:	Critical	**Rank:**	13
Source:	Project Brief, TQ 2	**S/U/E**	Spoken

4.3.14 Req-14 – Operation using a Specific Voltage from an External Power Supply Adapter

Requirement Description:
The device must be designed to operate using an external power supply adapter that provides a <u>specified</u> DC voltage in the range of 5 to 30 V. If possible, the design will utilise a 12 V input.

Delivery Method:		**Testing & Verification:**	
The design will be developed for use with a 12V DC input. If the need to change the input voltage arises during the development of the device, the 5-30V range provides a suitable buffer to deliver client requirements. A recommendation of a preferred, market available adapter and tested alternatives will be provided with the final design.		Final design capability can be verified demonstrably to the client under standard test conditions, showing that the device is capable of the required range of output functionality using the specified external power adapter.	
Priority Category:	Critical	**Rank:**	14
Source:	Project Brief	**S/U/E**	Spoken

4.3.15 Req-15 – Square Wave Frequency Adjustment Step Size

Requirement Description:
The device must be capable of adjusting the output square wave modulation frequency in steps of 10Hz.

Delivery Method:		**Testing & Verification:**	
Given that the digital controller can generate a square wave of 100Hz, it should have no issue adjusting the switching period such that the frequency is stepped by 10Hz.		Under standard testing conditions, the step frequency change can be verified using an oscilloscope.	
Priority Category:	Critical	**Rank:**	15
Source:	TQ 2	**S/U/E**	Spoken

4.3.16 Req-16 – AC Frequency Adjustment Step Size

Requirement Description:
The device must be capable of AC frequency adjustments steps of ~10 kHz.

Delivery Method:		**Testing & Verification:**	
A voltage-controlled oscillator (VCO) circuit connected to the sine wave generator circuit will be used to generate the VCO frequency which will change the oscillation frequency of the output.		Under standard testing conditions, the step frequency change can be verified using an oscilloscope.	
Priority Category:	Critical	**Rank:**	16
Source:	TQ 1	**S/U/E**	Spoken

4.3.17 Req-17 – Current Limit Tuning Fidelity

Requirement Description:
The current limit is tuneable between 1 and 10 mA, using steps of ~2 mA.

Delivery Method:		**Testing & Verification:**	
Using an adjustable current-limiting circuit. This consists of a current-sensing resistor placed in series with a load. The voltage across this resistor is fed to a comparator, which compares it to the reference voltage that represents the desirable current limit. This reference voltage can be set using a potentiometer or a digital-to-analogue converter. If the current limit has been exceeded, the comparator adjusts a MOSFET or transistor to increase its resistance, limiting the current flow. This feedback loop continues until the output current reaches the desired limit.		Under standard testing conditions, the step current protection cut-off changes can be verified using an oscilloscope.	
Priority Category:	Critical	**Rank:**	17
Source:	TQ 22	**S/U/E**	Spoken

4.3.18 Req-18 – Effect of Noise on Output Signal

Requirement Description:
The device output voltage must not deviate more than 0.05V from the expected voltage under steady state conditions. This includes noise and the impact of voltage ripples.

Delivery Method:		**Testing & Verification:**	
Several methods of maintaining signal integrity and reducing noise: 1. High-quality, low-noise components. 2. Proper grounding strategy and layout using ground planes and minimising ground loops. 3. Decoupling capacitors near active component power pins. 4. EMI Filtering on in/output to attenuate high frequency noise. 5. Ensure amplifier circuit stability using proper feedback and compensation to limit over/undershoot. 6. Temperature management as high heat contributes to increased component noise.		Under standard testing conditions, the level of noise present in the system should be evaluated and verified using an oscilloscope for the full range of AC and DC voltages and current outputs. Testing under non-ideal conditions (increased heat, electromagnetically noisy lab settings etc) should be considered at this stage to increase device versatility.	
Priority Category:	Critical	**Rank:**	18
Source:	TQ 61	**S/U/E**	S

4.3.19 Req-19 – Use of CERN-OHL-P Licensed Hardware

Requirement Description:
The project hardware must be prepared using the open-source CERN-OHL-P License.

Delivery Method:		**Testing & Verification:**	
The final design will be shared with the client under the CERN-OHL-P license.		Provide documentation for relevant hardware license.	
Priority Category:	Critical	**Rank:**	19
Source:	Project Brief	**S/U/E**	Spoken

4.3.20 Req-20 – Project Handover Deadline

Requirement Description:
Project handover must occur on Friday Week 12 (20/10/2023). This is a project constraint.

Delivery Method:		**Testing & Verification:**	
Carefully allocating tasks and roles to team members and regularly tracking project progress to ensure compliance with the project deadline.		Submission is complete and on-time.	
Priority Category:	Critical	**Rank:**	20
Source:	Project Brief	**S/U/E**	Spoken

4.4 Other Requirements

4.4.1 Req-21 – Overtemperature Shutdown

Requirement Description:
The device will shut down if internal temperature exceeds 80˚C.

Delivery Method:	
Placement of temperature sensors close to higher heat components. Should the controller detect that the temperature limit has been exceeded, the device will cut off the output and isolate the input from amplification components until the internal temperature has dropped to ~60˚C.	
Priority Category:	High
Source:	Design Team

Testing & Verification:	
Ideally this should not occur given proper heatsink and (if necessary) active cooling solutions. The total output power is only 2W, hence the system is unlikely to trigger the overtemperature under normal conditions (which is only triggered during a component fault or excessive external heat). Thus, to test the system, using a heat gun directly on the sensor may be required to verify its activation.	
Rank:	21
S/U/E	U

4.4.2 Req-22 – BNC Output Ports

Requirement Description:
The device will use high-voltage BNC ports for the output signals. This is a project constraint.

Delivery Method:	
Use the appropriate BNC connections for the output signal in the design.	
Priority Category:	High
Source:	TQ 24

Testing & Verification:	
Using an oscilloscope to verify that the output signal is as desired and expected from the ports.	
Rank:	22
S/U/E	S

4.4.3 Req-23 – Sharing of Project Outcomes

Requirement Description:
Project outcomes will be shared with the project partner using GitHub. This is inclusive of: reports; designs; prototype documents; CAD Models; PCB Files; component registers; testing results; a design modification registry and may develop as the project progresses.

Delivery Method:	
Creating a GitHub project repository containing all relevant project files and providing the project partner access to this repository.	
Priority Category:	High
Source:	Project Brief

Testing & Verification:	
GitHub is well structured, complete and on-schedule.	
Rank:	23
S/U/E	Spoken

4.4.4 Req-24 – Component Selection

Requirement Description:
The process of selecting components shall be conducted with careful consideration of component availability, lead times, and the current manufacturing state. This approach aims to ensure timely procurement and seamless integration of components into the final product.

Delivery Method:		**Testing & Verification:**	
Carefully selecting components with high availability and low lead times and identifying alternative options in case of unexpected delays or shortages.		As part of the final design, identifying and providing recommendations for component alternatives should stock be unavailable.	
Priority Category:	High	**Rank:**	24
Source:	Design Team	**S/U/E**	Exciter

4.4.5 Req-25 – Human-Machine Interface

Requirement Description:
The human-machine interface must allow users to set device parameters including the output signal type, frequency and voltage, as well as the output protection current limit.

Delivery Method:		**Testing & Verification:**	
Have multiple knobs for the tuning of continuous parameters such as voltage and frequency, and either buttons or switches to choose discrete settings, such as AC/DC or modulation.		Connect the output to a multimeter and check that the outputs correctly correspond to the user input. Ensure each type of output is accessible by user.	
Priority Category:	Medium	**Rank:**	25
Source:	Project Brief, TQ 59	**S/U/E**	S

4.4.6 Req-26 – Repairability, Maintainability and Operational Lifespan

Requirement Description:
The design shall prioritise repairability, maintainability, and an operational lifespan of a minimum of 10 years. Some measures shall be considered to address potential component unavailability in the future by providing recommendations for suitable replacements.

Delivery Method:		**Testing & Verification:**	
Carefully selecting components based on factors such as their lifespan, availability and reliability. Using a modular architecture which enables easy access to individual components for repair or replacement. Use of standardised connectors and interfaces, such as the BNC ports and chosen input power adapter.		As part of the final design, provide recommendations to the client on replacement/alternative components should specific parts get discontinued. Should a necessary part look likely to be unavailable within the lifespan, advocate for a last-time buy strategy to stockpile that part.	
Priority Category:	Medium	**Rank:**	26
Source:	TQ 51	**S/U/E**	Exciter

4.4.7 Req-27 – Use of Restriction of Hazardous Substances Directive compliant components

Requirement Description:
Design shall use Restriction of Hazardous Substances Directive (RoHS) compliant components wherever feasible.

Delivery Method:	
Prioritising the use of components that are RoHS compliant, where possible. Component websites (such as Mouser) can filter components based on their RoHS certification.	
Priority Category:	Medium
Source:	Design Team

Testing & Verification:	
Inspecting the documentation of components to verify their RoHS certification.	
Rank:	27
S/U/E	Exciter

4.4.8 Req-28 – Project Budget

Requirement Description:
The project budget will be less than $350 inclusive of all prototyping, testing and final design. This is a project constraint.

Delivery Method:	
Carefully monitoring all project expenses throughout the prototyping, testing and final design phases and recording all expenses in the project budget. Regularly review and modify the budget when necessary to stay within the allocated amount.	
Priority Category:	Low
Source:	Project Brief

Testing & Verification:	
Inspecting the project budget to ensure adherence to the allocated amount.	
Rank:	28
S/U/E	Spoken

4.4.9 Req-29 – Programmability

Requirement Description:
The device should incorporate a programmable output feature that allows users to define precise voltage and frequency parameters for designated durations. Once defined, output can be run using one button press. This feature will work for either AC or DC output for a given run.

Delivery Method:	
Development of programmable sequencing on the device processor, or running the program through a connected computer.	
Priority Category:	Low
Source:	End User

Testing & Verification:	
Testing the programmable output feature under various voltage and frequency settings to ensure that the user can define these parameters and run the output with a single button press.	
Rank:	29
S/U/E	E

4.5 Constraints

Project constraints are specifications and/or restrictions which affect the execution of the project [3].

Req-14 – Operation using a Specific Voltage from an External Power Supply Adapter
The device will require a specific input voltage (i.e., 12V) and will not support a range of voltages. The input DC voltage is assumed to be stable under load and have negligible ripple and noise such that minimal input clean-up and regulation is required.

Req-19 – Use of CERN-OHL-P Licensed Hardware
This is a project constraint, as it imposes a limit on the type of hardware used in the design.

Req-20 - Project Handover Deadline
This is a project constraint, as it imposes a limit on the time available for the team to complete the project.

Req-22 – BNC Output Ports

This is a project constraint, as the requirement to accommodate this port type will affect the design of the circuity and the selection of components used in the design.

Req-28 – Project Budget
This is a project constraint, as it imposes limitations on the components and resources that can be used to deliver the project.

5. Conclusion

This report outlines the project goals, stakeholders and the relevant requirements to meet the project goal of delivering a fit for purpose variable power supply. These requirements have been identified through consultation with the client and investigations into the current state of the art. The requirements have been ranked and delivery and verification methodology have been proposed. The top three critical requirements for the success of this project are:

1. Compliance with Australian Standards
2. Overcurrent Output Voltage Cut-off
3. Maximum Response Time of Overcurrent Protection

These are all crucial as they ensure safe operation of the power supply. Satisfying these requirements as well as the remaining outlined critical requirements will ensure a safe and functional final design. The team will also aim to satisfy all additional requirements to ensure satisfaction for all stakeholders.

6. References

[1] Australian National Fabrication Facility (ANFF), "Australian National Fabrication Facility ACT Node & WA node," 30 March 2023. [Online]. Available: https://anff-act.anu.edu.au/HTML/About_us.html. [Accessed 11 Aug 2023].

[2] D. Silva and M. Zawierta, "ELEC5552 Design Project 2 – 2023: Project 2 MEMS testing power supply," University of Western Australia , Perth, 2023.

[3] S. Hartley, "Project management : a practical guide to planning and managing projects," Crows Nest, NSW, Allen & Unwin, 2018.

[4] J. A. Martin-Ramos, A. M. Pernia, J. Diaz, F. Nuno and J. A. Martinez, "Power Supply for a High-Voltage Application," *IEEE Transactions on Power Electronics,* vol. 23, no. 4, 2008.

[5] U. Siravo, J. Alex, M. Bader, M. Carpita, D. Fasel, S. Gavin and A. Perez, "MAGY: An innovative high voltage–low current power supply for gyrotron," *Fusion Engineering and Design,* pp. 880-883, 2011.

[6] M. C. Brown, Practical Switching Power Supply Design, Elsevier Science, 2012.

[7] Z. Peterson, "DC-DC Converter Topologies: Which is Best for Your System?," North West Engineering Solutions, 2023. [Online]. Available: https://www.nwengineeringllc.com/article/dc-dc-converter-topologies-which-is-best-for-your-system.php. [Accessed 12 Aug 2023].

[8] F. L. L. a. H. Ye, Advanced DC/AC inverters: applications in renewable energy, 1st edition., Boca Raton: CRC Press, 2012.

[9] E. C. S. E. R. P. V. Y. Rozanov, Power electronics basics: operating principles, design, formulas and applications, Boca Raton: CRC Press, 2015.

[10] M. M. D. S. N. Poluri, "High-Efficiency Modes Contiguous With Class B/J and Continuous Class F ^ Amplifiers," *IEEE microwave and wireless components letters,* vol. 29, no. 2, pp. 137-139, 2019.

[11] Analog Devices, "DC to DC Buck Converter Tutorial & Diagram," Analog Devices , 2023. [Online]. Available: https://www.analog.com/en/technical-articles/dc-to-dc-buck-converter-tutorial.html. [Accessed 12 Aug 2023].

[12] F. D. Stasi, "Working with Boost Converters," Texas Instruments , Dallas, 2015.

[13] Electronics Coach, "Buck Converter," 2023. [Online]. Available: https://electronicscoach.com/buck-converter.html#google_vignette. [Accessed 12 Aug 2023].

[14] C. Glaser, "Methods of output-voltage adjustment for," *Analog Design Journal,* no. 3Q, 2019.

[15] Texas Instruments , "AN-1197 Selecting Inductors for Buck Converters," Texas Instruments , Dallas, 2012.

[16] J. Li, "How to Select a Proper Inductor for Low Power Boost," Texas Instruments, Dallas, 2016.

[17] Tech Web, "Selection of Output Capacitors," Technical Information Site to Learn the ABCs of Design, 27 April 2017. [Online]. Available: https://techweb.rohm.com/product/power-ic/dcdc/dcdc-design/2366/. [Accessed 15 Aug 2023].

[18] J. Arrigo, “Input and Output Capacitor Selection,” Texas Instruments , Dallas, 2006.

[19] D. Baba, “Benefits of a multiphase buck converter,” Texas Instruments , Dallas, 2012.

[20] M. S. Bhaskar, S. Pdamanaban, F. Blaabjerg and P. W. Wheeler, “Benefits of a multiphase buck converter,” IEEE, 2018.

[21] R. L. Boylestad and L. Nashelsky, Electronic Devices and Circuit Theory, Pearson Prentice Hall, 2013.

[22] T. Usher and G. A. McAuley, “High-voltage MOSFET bipolar square-wave generator,” *Physics Faculty Publications,* vol. 3, 1993.

[23] A. Singh, “Over Current/Short Circuit Protection Using LM358 OPAMP,” Hackatronic, 9 December 2021. [Online]. Available: https://www.hackatronic.com/over-current-short-circuit-protection-using-lm358-op-amp/. [Accessed 14 August 2023].

[24] S. Gupta, “Overcurrent Protection using Op-Amp,” Circuit Digest, 18 November 2019. [Online]. Available: https://circuitdigest.com/electronic-circuits/overcurrent-protection-circuit-using-op-amp. [Accessed 14 August 2023].

[25] Y. Misra, Programming and interfacing with Arduino, Boca Raton: CRC Press, 2021.

[26] L. Liu, “Comprehensively Understand and Analyze Switching Regulator Noise,” *Analog Devices*, 2019.

[27] Standards Australia , “AS/NZS 3820:2020 Essential safety requirements for electrical equipment,” 2020.

[28] Standards Australia , “AS/NZS 3008.1.1:2017 Cables for alternating voltages up to and including 0.6/1 kV—Typical Australian installation conditions,” 2017.

[29] Standards Australia , “AS/NZS 3000:2018, Electrical installations,” 2018.

[30] Standards Australia, “Safety requirements for electrical equipment for measurement, control and laboratory use - General requirements (IEC 61010-1:2001, MOD),” Standards Australia, 2003.

[31] University of Western Australia, “Electrical Safety and Electrical Work Procedure,” University Safety Committee, Perth, 2020.

[32] Government of Westen Australia , “Occupational Safety and Health Act 2022,” 2022.

[33] Government of Western Australia, “Occupational Safety and Health Regulations 2020,” 2020.

[34] Government of Western Australia, “Electricity Act 1945,” 1945.

[35] Government of Western Australia, “Electricity (Licensing) Regulations 1991,” 1991.

[36] Government of Westen Australia , “Electricity Regulations 1947,” 1947.